CONTROL OF EMISSIONS FROM CHROME ELECTROPLATING AND ANODIZING OPERATIONS

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Abstract

This paper presents a profile of the chrome plating and chromic acid anodizing industry in California and the emissions of hexavalent chromium associated with it. A process description for chrome plating is given and control techniques commonly used by the plating industry are reviewed and evaluated. An assessment is made of best available control technology (BACT) for hexavalent chromium emissions and of particular technologies which may be able to exceed control levels achievable with BACT. Process parameters which influence emissions, and a systems engineering approach for the reduction of emissions are also discussed.

This report has been reviewed by the staff of the California Air Resources Board and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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I. INTRODUCTION

Chromium is a hard, lustrous metal. It is used as an alloying element for many types of steel, in refractories (fire brick), and to produce various chromium chemicals. In addition, chromium can also be used as a protective or decorative coating for other materials. Chromium coatings are usually deposited on the surface of other materials (which are themselves metal or metal coated) by an electrochemical process known as chrome plating. By varying certain process parameters, most notably the length of the plating time, a chrome plater can produce either a thick, hard, wear resistant layer of chrome metal on the surface of the object plated, or a thin, decorative (bright and shiny) layer.

Hard chrome plating is done on parts such as crank-shafts, hydraulic rams and cylinders, valves, pumps, and other components which are subject to excessive wear, corrosion, or high friction. A significant amount of hard chrome plating is done to restore worn parts such as engine crank-shafts prior to their reuse. Decorative chrome surface coatings are generally applied to items such as car bumpers, appliances, furniture, and plumbing fixtures.[1]

Both hard and decorative chrome plating typically are done in aqueous solutions of chromic acid (CrO_3, a hexavalent chromium compound) and sulfuric acid. For decorative plating, there are commercially available plating baths which are trivalent chromium-based.

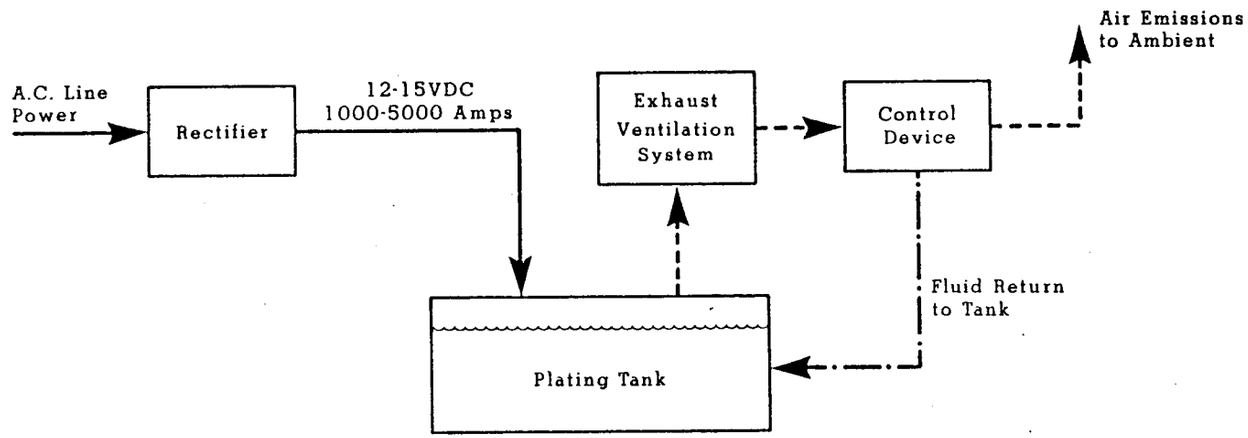
In chromic acid-based plating, the item to be plated is suspended in the chromic acid bath and connected as the cathode (negative electrode) of an electrolytic cell. A typical hard chrome plating process schematic is shown on Figure 1. A low DC voltage is applied across the cell, causing hexavalent chromium in solution to deposit as metallic chromium on the item. In a side reaction which occurs at the cathode, hydrogen ions in solution are reduced, producing hydrogen gas. This side reaction consumes 80 to 90 percent of the current applied to the plating tank.

Chromic acid anodizing is an electrochemical process used to create a decorative and protective surface coating. In this process, the metal part is connected as the anode (positive electrode) in a bath containing chromic acid. As Cr(VI) is reduced in the bath, the metal surface of the part oxidizes to provide a protective finish. The same phenomenon of hydrogen gas evolution occurs[1].

The hydrogen gas bubbles rise to the surface of the plating bath, and as they break the surface they create a chromic acid mist. To protect employees, the mist may be collected by a local ventilation system, passed

Figure 1

Typical Hard Chrome Plating Process - Schematic



through a control device, and conveyed to the outside atmosphere. Mists may also be controlled at the bath surface with physical barriers (floating bead or ball layers, or foam blankets) or by altering the surface tension of the bath to suppress mist formation. In some cases, a combination of these techniques is used.

In the past, actions taken to reduce emissions from chrome plating operations to the outside air were based, in most cases, on the nuisance aspect of the corrosive chromic acid mist. In February 1988, the Air Resources Board adopted a regulation which requires plating and anodizing shops to achieve specific levels of control of hexavalent chromium emissions. This regulation, and subsequent regulations adopted by the South Coast Air Quality Management District (SCAQMD) and the Bay Area Air Quality Management District (BAAQMD), are based on the health effects of hexavalent chromium, which has been shown to be a potent human carcinogen. These rules can be found in the Appendix. Details on the identification of hexavalent chromium as a toxic air contaminant and the ARB's supporting data for control measure development can be found in References 1, 4 and 5.

In this paper we will cover the following topics regarding hexavalent chromium emissions from plating operations:

1. A profile of the industry in California, including process descriptions and geographical distribution of plating shops;
2. The nature and magnitude of hexavalent chromium emissions in California;
3. Parameters which may influence emission characteristics;
4. Typical control devices in use today;
5. An assesment of the best available control technology (BACT) for chrome plating and anodizing; and
6. Technology transfer to achieve a higher degree of control than BACT.

The authors are hopeful that the information presented here will be useful to district permit engineers and others who are evaluating permit applications for electroplating facilities.

II. Profile of the Chrome Plating Industry in California

This section presents a geographical distribution, based on survey results, of chrome plating and anodizing facilities in California. Facilities are categorized also by type of plating done.

A. The Number and Distribution of Plating Shops

Table 1 shows the numbers of platers of various kinds estimated to operate in California. These data are derived from surveys performed in 1987 by the ARB and by local air pollution control districts. Of the total of 416 platers, 65 percent are in the South Coast Air Basin.

The amount of plating and anodizing done in California is expected to parallel the increase in general manufacturing activity. Limiting factors to the growth or expansion of the industry include foreign competition (for decorative chrome plating), and difficulty in meeting new source standards in urban areas (for hard plating and anodizing operations).

Table 1

Estimated Number of Chrome Platers in California

Air Basin	Number of Platers	
	decorative	hard/anodizing
South Coast	154	119
Bay Area	26	19
San Diego	18	20
San Joaquin Valley	21	6
Sacramento Valley	15	4
So. Central Coast	6	6
Others	2	0
Total	242	174

III. PROCESS DESCRIPTIONS AND HEXAVALENT CHROMIUM EMISSIONS

This section describes hard chrome plating, decorative chrome plating, and chromic acid anodizing processes, and gives quantitative estimates of emissions from the chrome plating industry. The general mechanism of mist generation, and the amount of emissions generated by hard and by decorative plating, are examined. Average emission factors for both controlled and uncontrolled sources are presented. Available source test data are reviewed, with particular focus on the characteristics of chrome plating emissions which make them difficult to control.

A. Process Description

Both hard and decorative chrome plating are conducted in steel-lined tanks containing chromic acid, sulfuric acid, and water. Some plating baths also contain fluoride compounds. A low DC voltage at high current is applied and flows from the anode (positive electrode) to the part being plated (cathode or negative electrode). Along with this current flow,

positively charged Cr (VI) ions in solution draw electrons from the cathode while negative anions release electrons to the anode (which is typically made of an insoluble lead-tin or lead-antimony alloy). Chrome plate, or metallic chromium, is deposited on the surface of the object being plated.[30] Figure 2 shows a typical hard chrome plating tank schematic.

The major chemical reactions which are responsible for chromic acid mist formation are shown below:

<u>Anode reaction[30]</u>

1. $2Cr^{+3}+3O_2-6(e)--2CrO_3$

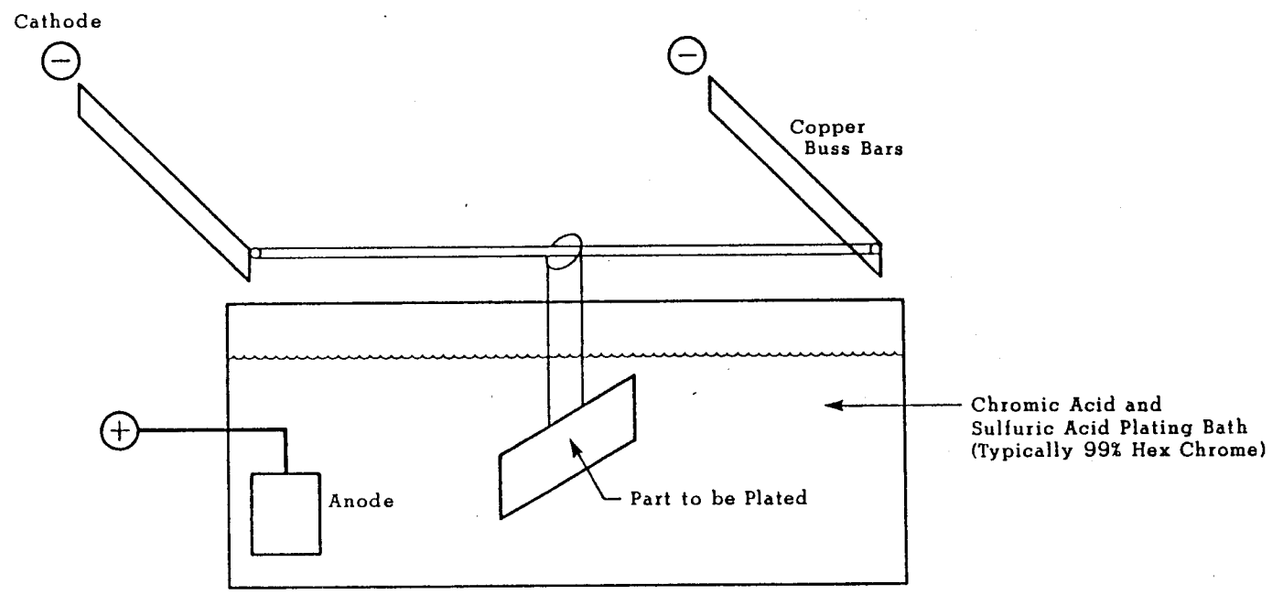
<u>Cathode reactions[30]</u>

1. $Cr_2O_7^{=}+14H^{+}+12(e)--2Cr^{o}+7H_2O$
2. $2H^{+}+2(e)--H_2$

The anodic reaction above purifies the plating bath by reoxidizing the trivalent chromium present in the bath to chromic acid. Trivalent chromium is considered a contaminant in hard chrome plating baths. Chromic acid mist generation is primarily due to the cathodic reactions. Reaction 1 at the

Figure 2

Typical Hard Chrome Plating Tank - Schematic



cathode causes the deposition of chromium upon the surface of the object being plated. This reaction consumes only 10-20 percent of the current. Reaction 2 consumes a majority of the current used in the cathodic reactions--the evolution of hydrogen gas. It is the hydrogen gas bubbles bursting at the bath surface that entrains chromic acid from the bath, creating emissions of chromic acid mist.

Although the electrochemistry is the same in hard and in decorative plating, there are notable differences in application, process, and emission control techniques between the two.

Hard chrome is generally applied to parts in high friction or wear applications and is usually deposited directly on steel. Hard chrome plate (a layer of over 1 micron thick) accounts for a majority of all chrome plated. Work pieces are typically lowered into the tank by chain hoist from above and suspended from a rack which rests on the top of the tank. In hard plating, bath composition, temperature (130-150°F), applied current (typically thousands of amps), and plating time (typically hours) are monitored and controlled. Tanks deeper than 4 or 5 feet are sometimes agitated with compressed air to maintain bath circulation and prevent thermal stratification of the bath.

Some hard chrome platers use either a bath additive (which either lowers surface tension or creates a layer of foam, or both) or floating plastic balls or beads to aid in chromic acid mist control at the surface of

the bath.[30] In other cases, the chromic acid mist is collected by a ventilation system and conveyed to the outside air directly or after passing through a mist eliminator, a packed bed scrubber, or other control device.

There are currently no widely used alternatives to hard chrome plating (with the exception of some new nickel-Teflon-Flouride matrix surface coatings).[2]

Decorative chrome plating, defined as a coating of less than 1 micron thick, and is generally applied to items such as auto parts, appliances, furniture, and plumbing fixtures.[1] The chrome layer is usually deposited on top of a nickel or copper base coat. Decorative chrome plating is typically carried out using shorter plating times (minutes) and lower currents (hundreds of amp-hours) than hard chrome plating. Decorative chrome plating baths are usually no deeper than 4 or 5 feet. Parts to be plated are moved in and out of the plating baths and rinse tanks either manually or, in high production facilities, on automated racks. In such a facility with automated plating lines, a conveyor belt moves the parts on racks from tank to tank, lowering the racks of parts into each tank in turn. Plating bath composition for decorative plating may include fluoride catalysts (fluorosilicates or fluoborates) to increase efficiency.[30]

Emissions from decorative platers are typically controlled by additives that decrease bath surface tension or create a dense blanket of

foam on the bath surface. A tank ventilation system (similar to that used in hard plating) is sometimes used to collect mists.

Alternatives to the use of hexavalent chrome-based decorative chrome plating have been developed. These processes, which use proprietary baths, are based on trivalent chromium. In trivalent decorative chrome plating, hexavalent chrome is considered a bath contaminant. Consequently, no appreciable amounts of hexavalent chrome are present in the plating bath.[30] Due to the difference in bath composition and chemical reactions that occur during trivalent chromium plating, chromic acid mists are not generated. Plating efficiencies for this process range from 20-25 percent, slightly higher than for chromic-acid-based plating processes.[30]

Chromic acid anodizing is typically done on aluminum or magnesium parts. Anodizing is very different from plating in that no layer of chromium metal is deposited on the part. This process creates an oxide layer on the object's surface for corrosion resistance, electrical insulation, coloring, or improved dielectric strength. In chromic acid anodizing, the tank itself acts as the cathode (negative) and the aluminum or magnesium part as the anode (positive). The reaction is carried out in a bath which is initially a chromic acid solution. As anodizing proceeds, hexavalent chromium in the bath is reduced to trivalent chromium. Chromic acid anodizing is generally not as sensitive to process parameters to attain an acceptable surface finish as decorative or hard chrome plating. This

process can be used over a wide range of voltages, bath temperatures and anodizing times.

B. Hexavalent Chromium Emissions and Industry Emission Factors

This section describes the derivation of average emission factors, and the calculation of statewide emission estimates for the chromium electroplating industry.

Emissions of Cr(VI) from electroplating facilities can be estimated as follows:

Emissions (mg) = Emission Factor(mg/Amp-hr) x Current (Amp)
x tank operation (hrs)

Average emission factors were derived for hard and decorative chrome platers based on source test results of existing facilities. Table 2 lists the source test data used to develop these emission factors. Emission factors for anodizing are assumed to be equal to those for hard plating. The limited data available for anodizing, shown on Table 2, supports this conclusion.

Table 2

Results of Source Tests at Plating Tanks

Plant	Location	Ref.	Annual Cr. Emissions (lbs.)	Emissions, mg/amp-hr uncontrolled[a]	Emissions, mg/amp-hr controlled	Control Efficiency
Hard Plating						
Able Machining	So. Carol.	7	9.0	9.1(9.1)[b]	.15 (.14)	98%
Steel Heddle	So. Carol.	13	9.9[d]	13.1 (13.9)	.50 (.450	96%
Greensboro Indust.	No. Carol.	8	25[d]	4.9 (4.3)	.61 (.59)	88%
Carolina Plating	No. Carol.	15	11[d]	2.3 (1.1)	.15 (0.44)	93%
U.S. Navy	Long Beach	12	5.4[d]	1.9 (1.9)	.15 (.15)	89%
U.S. Navy	Virginia	11	3.0[d]	3.7 (3.7)	.14 (.14)	95%
Tarby	Hunt. Bch.	14	11[d]	9.5 (1.5)	.23 (.06)	98%
Standard	Los Angeles	18	62	.082 (.057)	.040(.039)	51%
Ni-Cr	"	31	170	.17 (.1)[c]	.11 (-)	35%
Plato Products	Glendora	16	.54[d]	--	.04 (.02)	43%
Chrome Crankshaft	Southgate	17	9.0[d]	--	--	98%
Pamarco	Orange	32	10	1.8 (1.8)	.99 (.99)	44%
"	"		.2	.73 (.54)	.02 (.01)	97%
Embee Plating	Santa Ana	19	3.8[d]	--	--	79%
Piedmont Indus.	No. Carol.	20	3.9[d]	23 (24)[c]	.14 (.14)	99.4%
Dec. Plating						
C.S. Ohm	Missouri	21	.29	.049 (.011)	--	
"		21		.007 (.002)	.010 (.002)	0%
Price-Pfister	Pacoima	22	.73	.019 (.021)	.015 (.007)	21%
"	Pacoima	23	1.4	.14 (.14)	.029 (.029	79%
Anodizing						
McDonnell Douglas	Torrance		.018	1.9 (1.1)	.16 (.091)	94%

a before control device
b values in ( ) are Cr(VI); values without ( ) are total chromium
c data not used for emission factor
d assuming 3,000 hours of operation per year

Most source tests shown on Table 2 report emissions of both total chromium and Cr(VI). In some cases, Cr(VI) was measured at lower concentrations or amounts than total chrome. Because the chromium in a chromic acid-based plating bath should be at least 99 percent Cr(VI) for proper plating, data for total chromium have been used to calculate emission factors. However, for the anodizing source test, measured emissions of Cr(VI) were used, because anodizing baths are known to contain Cr(III) as well as Cr(VI).[1]

Source test results and the emission factors are expressed in terms of mass of Cr(VI) emitted per amp-hour of plating, activity. Amp-hours are chosen as the process rate because in plating the amount of mist created is proportional to the amount of hydrogen evolved. The amount of hydrogen evolved is proportional to the current (amps) and to the length (hours) of a plating job. Other variables like the configuration of the tank (especially depth), tank freeboard (height between the surface of the plating bath and the top of the plating tank), surface area and shape of the plated item, and the electrical efficiency (chromium plated per amp-hour) most likely affect emissions also. Additionally, parameters such as length and layout of exhaust ducting, inlet sampling point location, exhaust gas velocity, and flow conditions can reasonably be expected to affect the measurements used to calculate emission factors. Therefore, the sizeable range of emissions from hard platers evident in Table 2 is not surprising.

Emissions on a mass/amp-hour basis from decorative platers, as seen in Table 2, are on the order of one percent of the uncontrolled emissions from hard platers. This is attributed to the effect of an anti-mist additive maintained in the plating solution at the test facility to control the concentration of Cr(VI) in the workplace. Because additives are used by most decorative platers in lieu of ventilation systems to meet OSHA requirements, limited data on emission rates are available from decorative plating operations where anti-mist additives are not used. Preliminary results of decorative plating emissions with and without anti-mist additives show that control efficiencies of 99 percent and greater are achievable in practice through the use of commercially available anti-mist additives.

The data for uncontrolled emissions per amp-hour at Standard Nickel/Chromium and Piedmont Industrial Platers (shown in Table 2), were not included in the development of an average emission factor for hard plating. These were the highest and lowest data by considerable margins. Neither of these two facilities was a "typical" hard plating facility: Standard Nickel/Chromium had a very deep tank (38 feet), and very low uncontrolled emissions, while Piedmont Industries had three tanks which were exhausted in parallel, and very high uncontrolled emissions. The mean of all other data for uncontrolled emissions from hard plating is 5.3 mg/amp-hour. This value

was used as an average emission factor for calculating emissions at hard chrome facilities that did not have controls.

Controlled emission factors for hard chrome plating were also calculated on the basis of source test results as shown in Table 2. Emission control at the facilities noted on Table 2 typically consisted of a low-energy wet scrubber and/or a demister. The average control efficiency among tests done in California is 75 percent. For plating shops that use control devices, 25 percent of the average uncontrolled emission factor, or 1.3 mg/amp-hour, was used to estimate emissions. For tanks in which anti-mist additives are used, 95 percent control of the average uncontrolled emission factor was used. This corresponds to 0.26 mg/amp-hour.[1] The authors have employed this value to estimate average emissions from controlled hard plating operations.

The mean emission rate for decorative chrome shops in which an anti-mist additive was used was 0.025 mg/amp-hour. Because there are few data for removal efficiency at decorative shops where control devices are used, the removal efficiency value (75 percent) employed for hard chrome plating was used.

Table 3 summarizes the average emission factors.

Table 3

Cr(VI) Emission Factors[a] by Plating Type
(mg/amp-hour)

	Uncontrolled	Controlled	
		scrubber	foam[b]
Hard plating/ anodizing	5.3	1.3	.26
Decorative plating	0.50	.13	.025

a based on data for total chromium
b foam or foam plus scrubber

To calculate statewide emissions from plating facilities, average or site-specific emission factors, and site-specific data on current and hours of operation, were used. This data was acquired by surveys of platers in the Bay Area, South Coast, San Diego Air Basin San Joaquin Valley and Sacramento Valley Air Basins. About 63 percent of all survey recipients responded. It is assumed that the data from the non-respondents had the same statistical distributions as the data from the respondents in each air basin.

Table 4 shows emissions of Cr(VI) for the shops with the highest, lowest, and median emissions. The large differences between the hard and decorative shops examples reflect the emission factors in Table 3 and the fewer hours of operation typical of decorative plating. The large range within each category, three to four orders of magnitude, reflects the range of shop sizes (i.e, process rate) and the variability of other factors such as exhaust system configuration or process parameters.

These estimates are useful indicators of the potential range of emissions and of aggregated emissions, and are not intended to replace facility-specific determination of emissions through source testing and process rate measurements. The reliability of these estimates is best in the most aggregated form, for instance, statewide. The limitations of applying the average emission factors given here to a specific facility must be recognized in interpretation of the resulting emission estimates.

Table 4
Distribution of Emissions of Cr(VI) by Plating Shop Type
(pounds per year per shop)

	Decorative	Hard	Anodizing
Shops that do not control emissions[a]			
lowest	.001	.077	.60
median	.092	11	6.7
highest	31	510	170
all[b]	122	1,900	320
Shops that control emissions			
lowest	.006	.002	.006
median	.10	20	.44
highest	.72	1,200	22
all[b]	11	9,800	98

[a] "Control" refers to a scrubber or de-mister.
[b] in state

Table 5 shows the total emissions of Cr(VI) from chrome plating operations in selected air basins in California and depicts total emissions in each category. Despite the presence of controls, the number and size of hard plating shops cause the amount of their emissions to far exceed any other category. Ninety-four percent of plating emissions are due to hard plating. Sixty-four percent of all hard plating emissions occur in the South Coast Air Basin.[1]

C. EMISSION CONTROL AND VENTILATION SYSTEMS

Because of both acute and chronic health effects, it is necessary to prevent chromic acid mists from entering workplace air. The amount of chromic acid mist leaving the bath surface and entering workplace air may be reduced by two methods: a blanket of floating plastic beads (or balls) on the plating bath surface, or a mist suppressing bath additive to reduce surface tension or create a layer or blanket of foam on the bath surface. After the mist has left the bath surface, it may be collected by a ventilation system to reduce the amount entering workplace air.

Decorative chrome platers typically use bath additives for mist control. Preliminary EPA data has shown that mist suppressants for decorative chrome platers can be greater than 99 percent effective when used properly. Floating beads or balls are not commonly used by decorative

Table 5
Plating Emissions of Cr(VI) by Air Basin[a]
(lbs/year)

Air Basin	Plating Type			Total
	Hard	Decorative	Anodizing	
Bay Area	1,910	8	7	1,925
Sacramento	427	0	0	427
San Diego	1,340	8	536	1,884
San Joaquin	72	1	0	73
South Central Coast	14	0	2	16
South Coast	7,730	117	77	7,924
Total	11,493	134	622	12,249

a based on survey responses; adjusted for response rate

platers because they are suseptible to drag out in automated production lines, and may be trapped by the part as it's lowered into the bath, interfering with plating.

Hard chrome platers and chromic acid anodizers do not widely use either floating beads or balls or mist suppressant additives. However, survey results do show that approximately 16 percent of hard plating shops do use mist suppressants, in spite of the fact that this has reportedly caused pitting of the chrome plate.

The effectiveness of bead/ball blankets for decorative or hard plating, and of mist suppressing bath additives for hard plating, are not well documented at this time.

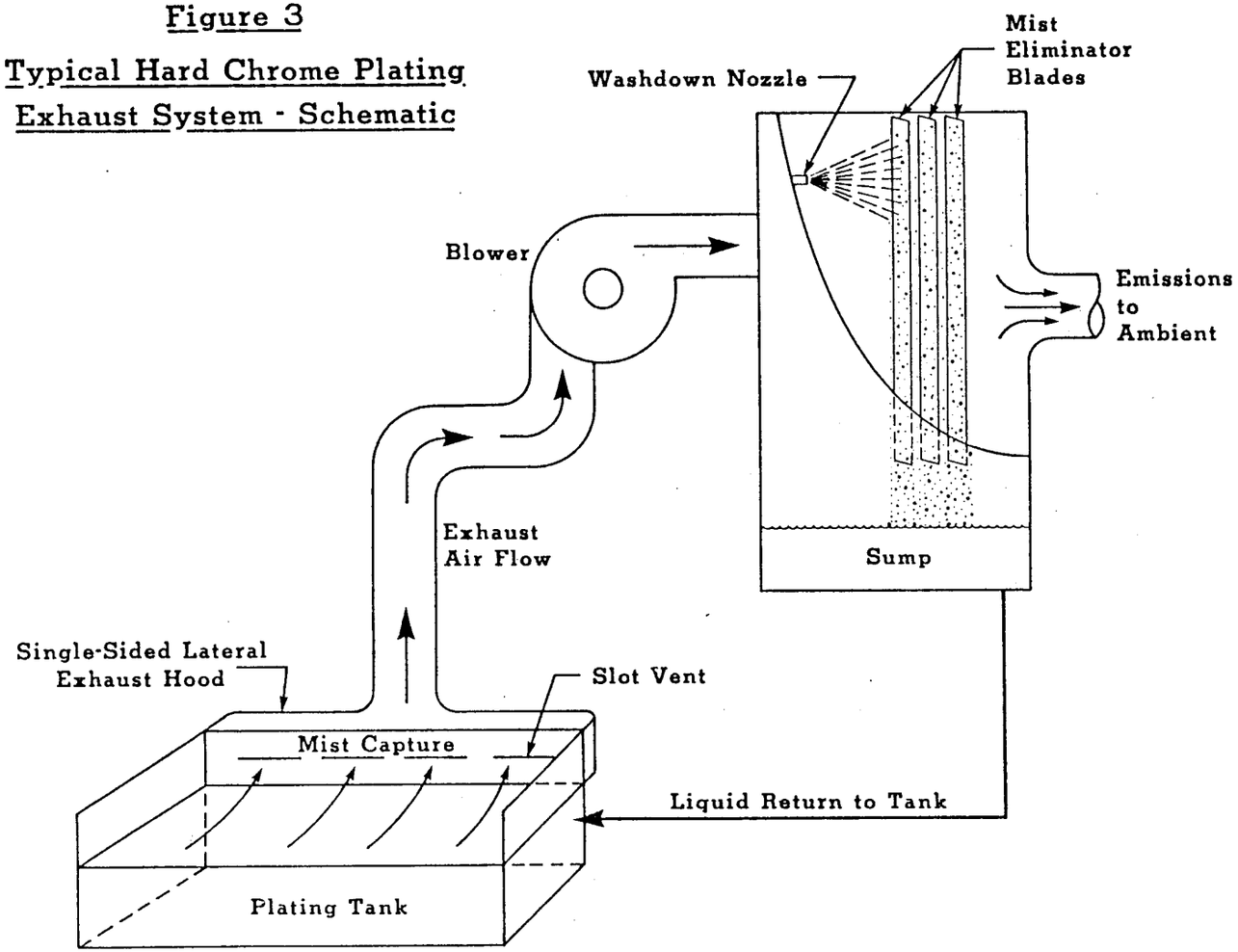
Although there are methods available as described above to control emissions at the point of generation (at the bath surface), an estimated 70 percent of hard chrome plating shops use ventilation systems to collect mist at the bath surface and remove it before it enters the workplace air. There are several reasons for this. First, it is generally accepted that a properly installed, maintained, and operated ventilation system can by itself achieve compliance with workplace air standards, without changes to the plating bath or process. Secondly, some platers have experienced difficulty in using mist suppressant bath additives, which may interfere with plating quality, or in using balls or beads. Beads or balls have been reported to become trapped under or in the part as it is lowered into the

tank, either interfering with plating or causing problems when the part is put into service. Also, the proper use of mist suppressant additives, requires more operator attention than it appears is devoted to regular, inspection, and maintenance of ventilation systems. The final reason that hard chrome platers do not typically use mist suppressant bath additives is that in the South Coast Air Basin there is a permit requirement for tank ventilation systems (and for emission control devices). There has been little regulatory pressure to encourage emissions reductions through mitigation of emissions at their origin. Such an approach is preferrable, if it is technically feasible, because it is usually the most cost-effective solution in terms of both capital and operating costs (e.g., reduced or no disposal costs associated with wastes from air pollution control equipment). Given the widespread use today of only conventional ventilation systems, and the fact that these systems will likely play a role in worker protection in combination with source reduction techniques, it is reasonable to examine current practices in ventilation system design.

In the conventional ventilation systems currently used in the plating industry, chromic acid mists are collected by slot vents which usually run along the long side (or sides) of the tank. Figure 3 shows a typical hard chrome plating exhaust system schematic. Overhead exhaust hoods are not used in the plating industry, because overhead hoods would draw mists from the tank surface into the breathing zone of anyone who was working at the tank.

Figure 3

Typical Hard Chrome Plating Exhaust System - Schematic



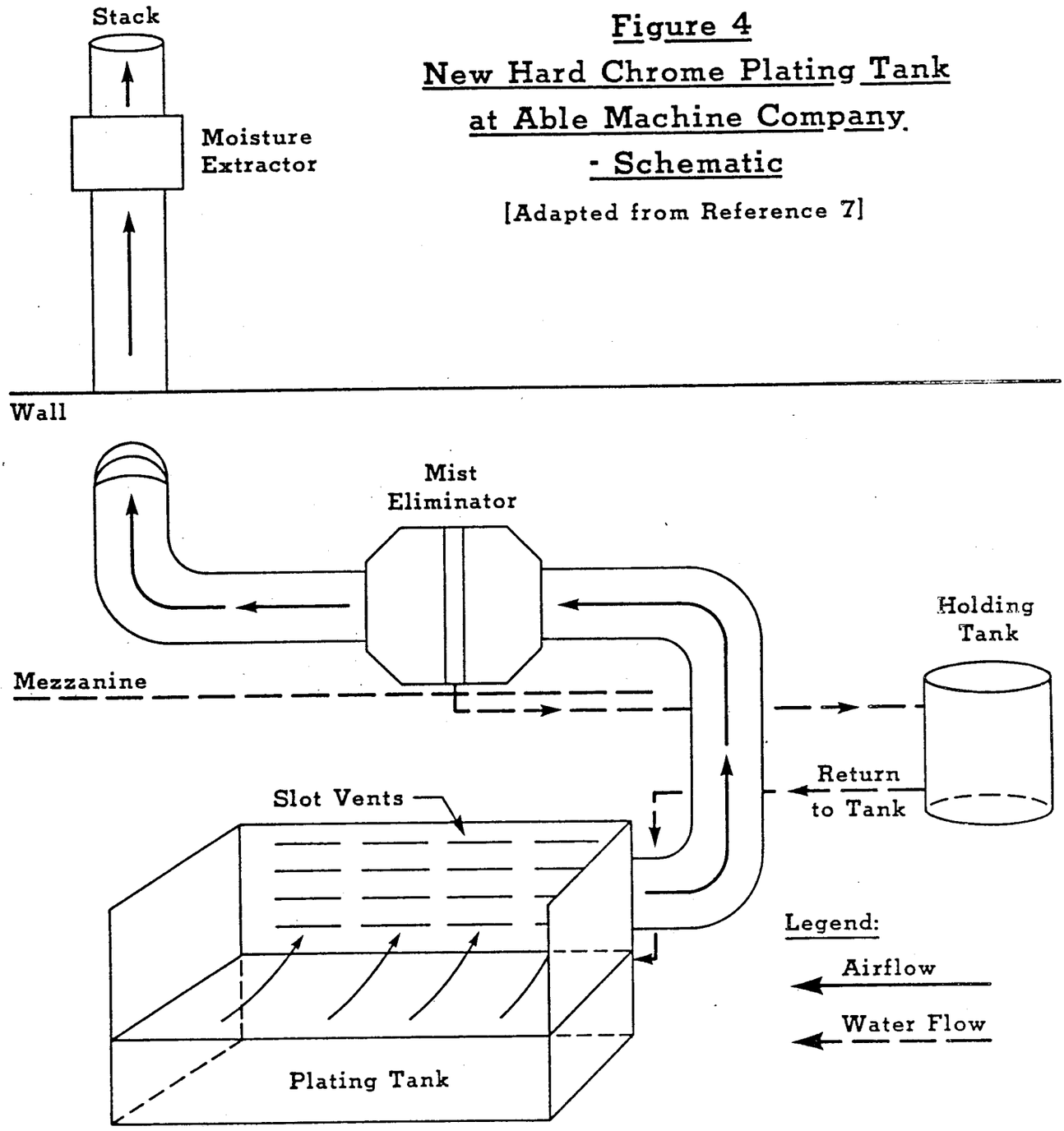
Slot vents and accompanying fans are sized in terms of proper inlet design velocities. Two factors, tank length-to-width ratio and tank surface area, are used to determine the required design velocity necessary to assure adequate capture of mists.[6] Single hoods have a maximum reach of about 2 feet; wide tanks typically have slot vents along both long sides of the tank. For wide tanks, there are two approaches to slot vent operation. In a push-pull system, one slot vent is an intake ("pull") while the other supplies air under pressure ("push") . This design "sweeps" the tank surface, directing chromic acid mist across the plating bath surface and into the "pull" vent. Push air flow is typically about 5 ft^3/minute per square foot of plating tank surface area.[30] A sketch of a new hard chrome plating tank is shown on Figure 4. In contrast, a "pull-pull" system has intake (suction) vents along both long sides of the tank. Makeup air is drawn from the workroom carrying chromic acid mist with it into both "pull" vents.

In some cases, the ends of tanks are closed off. Such baffling of plating tanks, like the one shown in Figure 4, is typically done when the tanks are free standing in areas that are susceptible to cross drafts. Baffling eliminates cross drafts which could disturb the flow across the tank surface and interfere with mist capture.

The Occupationaly Safety and Health Administration workplace air standard of 0.05 mg/m^3 (8-hours average) is the maximum indoor air concentration limit not to be exceeded for plating and anodizing facilities.

Figure 4
New Hard Chrome Plating Tank at Able Machine Company - Schematic

[Adapted from Reference 7]



The American Conference of Governmental Industrial Hygenists recommends exhaust air flows of approximately 225-250 cfm/ft^2 of tank area for hard and decorative chrome plating and anodizing done in open tanks.[6] Air flow rates are high due to the acute and chronic toxicity of hexavalent chromium, and the fact that slot vents along the tank edge(s) are used; consequently, emissions from plating operations consist of a relatively dilute mixture of chromic acid mist in air.

D. EMISSION CHARACTERISTICS

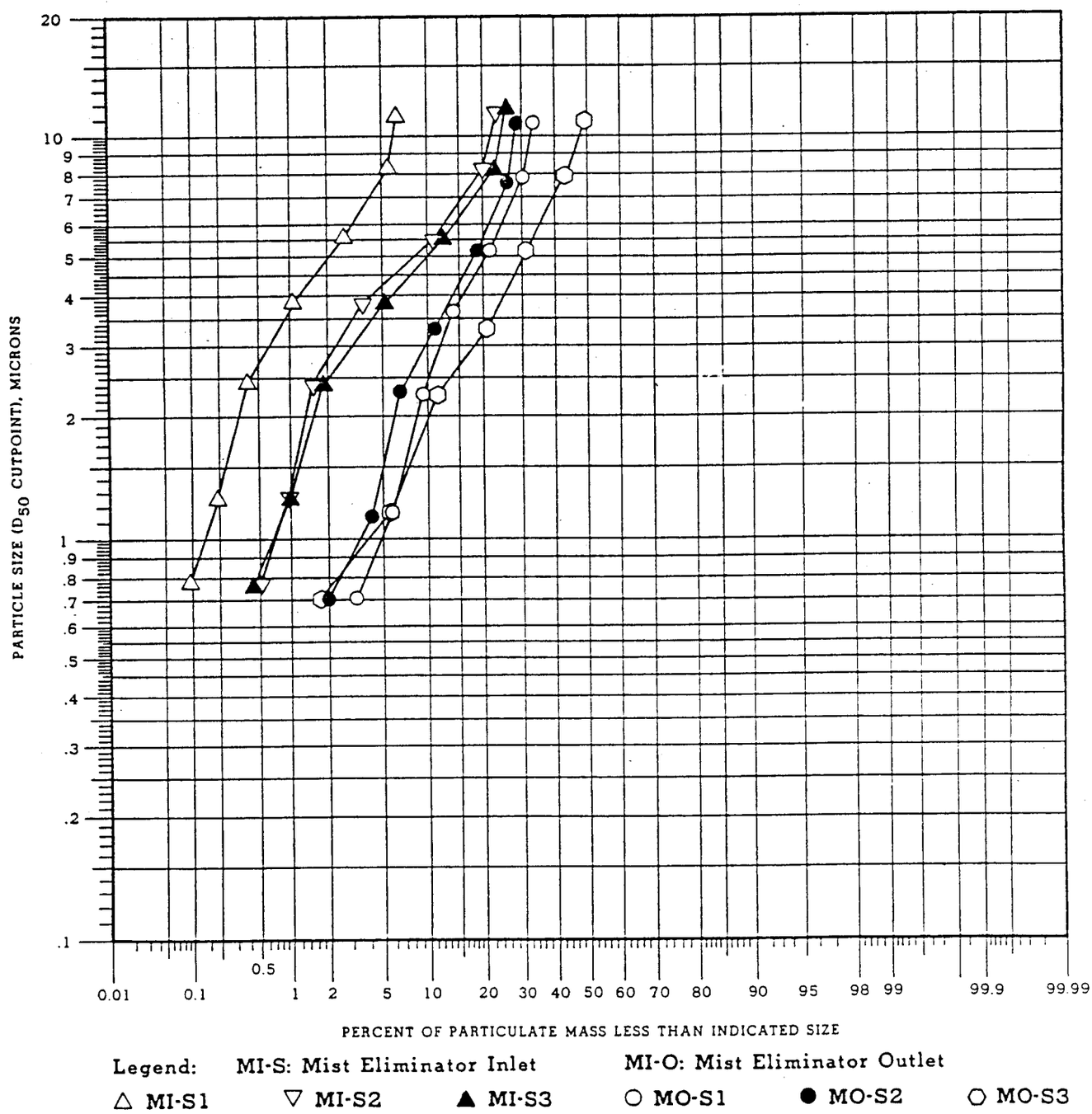
Both the mass and other characteristics of emissions from electroplating facilities vary depending upon specific process parameters and the physical configuration of the plating tank and ventilation system. This section will focus on a major characteristic of emissions critical to emission control--notably particle size distribution.

Particle size distributions of emitted chromic acid mists are difficult to measure, and have been shown to be highly variable. Figure 5 shows an example of several inlet and outlet particle sizing runs at a hard chrome facility, while Figure 6 shows an example of a single inlet and outlet particle sizing run done at a different facility.[7,8] Table 6 is a summary of these data, and shows that after eliminating curves for runs MO-S3 (mist eliminator outlet-sizing run 3) and MI-SI (mist eliminator inlet-

Figure 5

Graphical Summary of Particle Sizing Data - Greensboro Industrial Platers

[Source: Chromium Electroplaters Test Report, Greensboro Industrial Platers - Reference B]

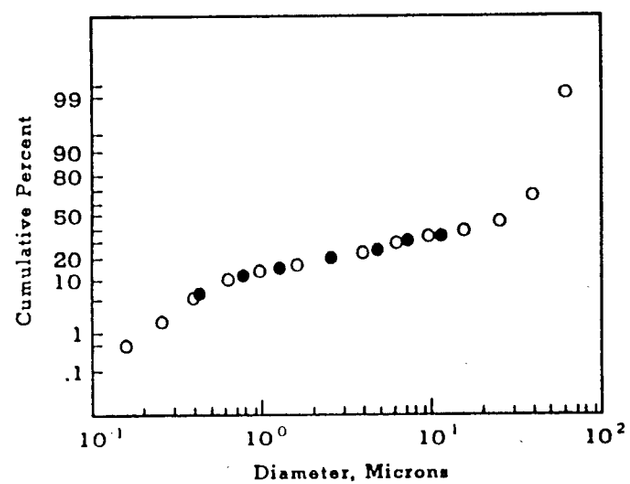


Legend: MI-S: Mist Eliminator Inlet MI-O: Mist Eliminator Outlet

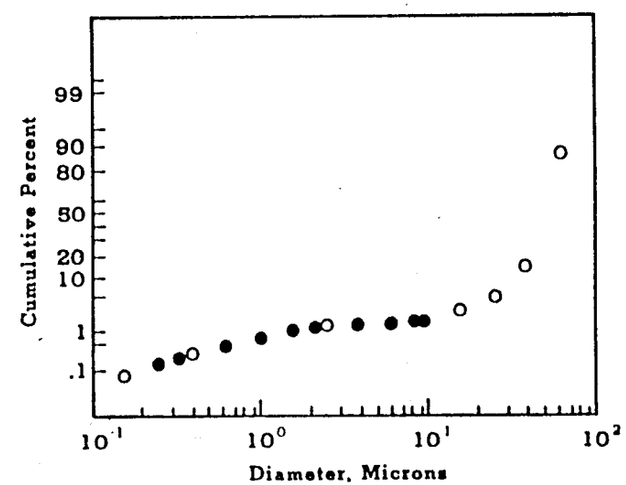
△ MI-S1 ▽ MI-S2 ▲ MI-S3 ○ MO-S1 ● MO-S2 ⬡ MO-S3

Figure 6

Particle Size Distribution Able Machine Company - Taylors, South Carolina



Particle size distribution for mist eliminator outlet Run PSO-2.



Particle size distribution for mist eliminator inlet Run PSI-2.

Note: Open circles are interpolated data points and filled circles are actual data points.

Table 6

Particle Size Distributions for
Able Machine Company and Greensboro Industrial Platers

	Percent of Particulate Mass[1] Less Than Indicated Size	Size Microns		Percent of Particulate Mass[1] Less than Indicated Size	Microns
Greensboro[2] Industrial Platers					
Inlet	30	12	Outlet	2	Less than 1
	10	5		30	11
	1	4		10	3
Able Machine Company	**Cumulate Percent**	**Size Microns**		**Cumulative Percent**	**Size Microns**
Inlet	30	35	Outlet	1	Less than 0.1
	10	30		30	8
	1	2		10	Less than 1

1 Average, D_{50} Cutpoint

2 Due to extraction problems the above data are for total chromium only. Hexavalent chromium is expected to account for most of the collected particles since it comprised most of the mass emitted.

NOTE: These values are derived from reading Figures 5 and 6.

sizing run 1) the two extreme curves from Figure 5, the remaining data are in good agreement with each other. Outlet emissions tend to have a slightly larger percentage of smaller particles, which connotes that smaller particles (less than 10 microns) in the air stream are not being intercepted by the control device. This is consistant with the fact that at both facilities the control devices were inertial impaction devices (chevron-blade demisters). Principles of control equipment operation are presented later in this paper.

It is important that particle sizing data be carefully reviewed before it is used to predict emission control efficiencies or to design control equipment. Difficulties in sampling mists limit the absolute accuracy of such measurements; consequently, control device design using this data should be conservative.

For instance, the particle sizing data displayed in Figures 5 and 6 show that a large part of the mass emissions exist as small particles. Although the absolute accuracy of these data is inherently limited, the data give an indication of the size range of particles a control device will have to remove in order to attain high efficiencies or low mass emission limits.

In addition to particle size distribution, inlet grain loading has been observed to affect the removal efficiencies of commonly used inertial impaction control equipment. If the gas stream contains a small mass of

particulate matter relative to the volume of gas, i.e., inlet loadings in the range of 1×10^{-4} grains/ft^3 of air or less, removal efficiencies may be poor. In general, this can be related to the fact that inertial impaction devices do not achieve high particle removal efficiencies for small particles (less than 10 microns), and low grain loadings can be taken as indicators of a particle size distribution shifted to small particles.