EMISSIONS FROM HOT-DIP GALVANIZING PROCESSES

FINAL REPORT

EPA - 905/4-76-002

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by

Peter J. Drivas
Pacific Environmental Services, Inc.
1930 14th Street
Santa Monica, California 90404
213-393-9449

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Project Officer: William E. Beyer
U.S. Environmental Protection Agency
Region V
230 South Dearborn Street
Chicago, Illinois 60604

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This report has been reviewed by the Environmental Protection Agency, Region V, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

In keeping with the stated policy of the EPA, the metric system is used almost exclusively in this report. However, equivalent English units are presented, in addition to metric units, for the emission factors derived in this work. Also, the following conversion factors are presented for convenience in making other conversions:

To Convert From	To	Multiply by
kg	lb	2.205
metric ton	short ton	1.102
kg/metric ton	lb/short ton	2
meters	feet	3.281
sq. meters	sq. feet	10.764
kg/m^2	lb/ft^2	0.205

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1. INTRODUCTION

1.1 Project Background

A number of state and local agencies, concerned with visible emissions from galvanizing plants, have asked the Environmental Protection Agency for more information on the nature and amounts of galvanizing emissions. A limited survey by the EPA revealed that very little had been published in respect to galvanizing operations or evaluation of the particulate emissions from galvanizing plants. Thus, although a need for control had been indicated by some agencies, the enforcement position was weakened by a lack of information.

In response to a request from the EPA, Region V, Pacific Environmental Services, Inc. (PES) conducted a thorough investigation of the hot-dip galvanizing process to determine the quantity and characteristics of particulate emissions from the process. The main purpose was to develop an emission factor as a function of process rates, procedures, or equipment. The study focused on the actual galvanizing step, and was not concerned with the cleaning operations preparatory to galvanizing.

The scope of effort was as follows:

(1) Perform a complete literature search to locate and identify all sources of information.

(2) Observe current galvanizing practices, procedures, and equipment through plant visits.

(3) Collect all data from actual source tests which measured emission rates from hot-dip galvanizing operations.

(4) Perform source testing of current galvanizing operations, using EPA Method 5, to determine accurate emissions of particulates.

(5) Analyze and review all available literature and test data to develop an accurate emission factor.

1.2 The Hot-Dip Galvanizing Process

Hot-dip galvanizing is the art of coating clean, oxide-free iron or steel with a thin layer of zinc by immersion of the iron or steel in a bath of molten zinc. The article to be coated is properly cleaned, completely immersed in the molten zinc bath, and withdrawn with enough of the molten zinc adhering as a surface film to give the desired coating. The molten zinc bath is usually operated at temperatures between 445° and 460° C. (1).

In 1973, a total of 511,505 metric tons of zinc were consumed by galvanizing in the United States; this amount is 37.5% of the total U.S. zinc consumption in 1973 (2). The zinc consumption by galvanized product category is given in Table 1-1. Sheet and strip iron and steel accounted for over half of the total zinc used in galvanizing.

Typically, the basic steps which are followed in cleaning and coating an iron or steel article are the following:

(1) Degreasing in a hot, alkaline solution;
(2) Rinsing thoroughly in a water rinse;
(3) Pickling in a hot, acid bath;
(4) Rinsing thoroughly in a water rinse;
(5) Prefluxing in a zinc ammonium chloride solution;
(6) Immersing the article in the molten zinc through a molten flux cover (usually zinc ammonium chloride);
(7) Finishing (dusting with ammonium chloride to produce a smooth finish).

Some steps may be omitted in individual galvanizing processes; such differences are noted in Section 4, "Observation of Current Galvanizing Practices."

1.3 Galvanizing Emissions

The main emission problem in the galvanizing process is caused by the last two steps, (6) and (7) above. It has been observed that grayish-white

Table 1-1

1973 U.S. ZINC CONSUMPTION BY GALVANIZING (2)

Galvanized Product Category	Zinc Consumed, Metric Tons	Percent of Total
Sheet and strip	292,047	57.1
Tubes and pipe	61,732	12.1
Wire and wire rope	31,130	6.1
Fencing, cloth, and netting	23,059	4.5
Structural shapes	19,699	3.9
Fittings (for tubes and pipe)	10,858	2.1
Pole-line hardware	7,433	1.5
Fasteners	4,338	0.8
Tanks and containers	2,668	0.5
Other and unspecified uses	58,541	11.4
TOTAL	511,505	100.0

particulate fumes are discharged whenever the kettle flux cover is disturbed, when fresh flux is added, and when galvanized articles are dusted with ammonium chloride (1).

Flux agitation occurs to some extent each time an object is immersed in the molten zinc through the flux cover. If the objects are smooth and dry, the agitation is not great and the amount of fuming is low. When the agitation of the flux cover is severe, a correspondingly larger amount of fumes is discharged.

When fresh flux is placed on a kettle, it takes some time to form a foaming cover. During this time dense fumes escape. Also, when fresh flux is stirred into the existing flux cover, fumes are discharged due to both the agitation and the time necessary for the fresh flux to be absorbed by and become part of the foam.

To obtain brighter, smoother finishes, especially on small items, they are dusted with finely ground ammonium chloride immediately after being removed from the molten zinc bath. The articles dusted are still at a temperature well above the decomposition temperature of ammonium chloride, thus, much of the NH_4Cl is converted to fumes by the operation. Although only small amounts of dusting fluxes are used, dense fumes are normally created.

2. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A comprehensive literature search was performed to locate and identify all sources of information on emissions from hot-dip galvanizing processes. Observations of current galvanizing practices, procedures, and equipment were made in a total of five plant visits - two in the Los Angeles area and three in the Chicago area. To determine accurate emissions of particulates from current galvanizing operations, the PES staff performed three separate source tests, using EPA Method 5, on one galvanizing plant in the Los Angeles area.

Particulate emission data from a total of seventeen source tests on hot-dip galvanizing plants were considered relevant in developing an emission factor for galvanizing kettles. Fourteen of the source tests measured both kettle emissions and emissions from control devices; the control devices tested were mainly water scrubbers and baghouses. There was no significant difference between the kettle and control device emissions.

An averaged emission factor based on galvanized product process weight was calculated, considering both kettle and control device emissions as one data base:

Emission factor = 0.26 kg/metric ton galvanized product (σ=0.28)
(0.52 lb/short ton galvanized product)

or, assuming 8% zinc by weight in the galvanized product,

Emission factor = 3.3 kg/metric ton of zinc used (σ = 3.5)
(6.6 lb/short ton of zinc used)

It is recommended that an emission factor in terms of process weight be defined per weight of galvanized product, since only this quantity is normally measured by galvanizing plants.

A linear regression analysis indicated that a slightly more accurate emission factor is one based on the hours of kettle operation. Considering both kettle and control device emissions as one data base, an emission factor which is independent of process weight was calculated:

Emission factor = 0.51 kg/hr per kettle (σ = 0.44)

(1.12 lb/hr per kettle)

The rather large standard deviation (σ) indicates the considerable scatter in the data base, and this approach is only slightly more accurate than the emission factor based on process weight.

From the source tests conducted by the PES staff, a relationship can be derived between galvanizing emissions and the surface area of the galvanized product. However, this data base is too limited for confident characterization of an emission factor.

Due to the nature of the galvanizing process, intermittent visible emissions are released when the kettle flux cover is disturbed and when galvanized articles are dusted with ammonium chloride. These intermittent emissions, when averaged over a one-hour period, result in fairly low uncontrolled emission rates. Using the derived emission factors, the total annual amount of particulate emissions produced by hot-dip galvanizing operations in the United States is estimated to be about 1,600 metric tons (1,800 short tons) which is negligible when compared with the total particulate emissions from other sources.

Since available control devices have not been shown to be particularly effective in reducing galvanizing emissions, it is recommended that control devices for galvanizing operations be required only in the case of severe visible emissions. A reduction in the amount of ammonium chloride used for finishing galvanized articles will significantly reduce visible emissions from galvanizing kettles.

3. LITERATURE REVIEW

3.1 Extent of Review

The literature review, which was concerned mainly with information on galvanizing emissions, encompassed a wide variety of sources. Books and journal articles were obtained from a number of library systems, including:

- University of California, Los Angeles (UCLA) Libraries
- University of Southern California (USC) Libraries
- California Institute of Technology (Caltech) Libraries
- Los Angeles Public Library.

A literature search was requested from the Air Pollution Technical Information Center (APTIC) on zinc and metal fabrication, which resulted in a total of 44 references. However, only five of these references pertained specifically to emissions from hot-dip galvanizing operations. Other abstracting services which were checked year-by-year included:

- Air Pollution Control Association Abstracts, 1952-1970
- Air Pollution Abstracts, 1970-1975
- Metal Finishing Abstracts, 1965-1975
- Zinc Abstracts, 1965-1975.

Contact with industrial organizations was quite rewarding. The American Hot-Dip Galvanizers Association (AHDGA) provided a number of unpublished preprints concerned with galvanizing emissions, in addition to a directory of AHDGA members in the United States. The DuPont Industrial Chemicals Department provided a data sheet on the various types of kettle fluxes and prefluxes which they manufacture (see Appendix A-1).

The Los Angeles County Air Pollution Control District (APCD) provided by far the most relevant data for determining an emission factor - the

results of 21 source and chemical tests on galvanizing kettles conducted over a 25-year period. Not all tests were relevant and some information which was considered confidential was not provided; however, these data provided by the Los Angeles County APCD were the largest single source of particulate emission data from galvanizing kettles.

The San Francisco Bay Area Air Pollution Control District provided the results of one particulate emission source test on a galvanizing kettle. A computer search of the National Emission Data System (NEDS) for all source tests on galvanizing kettles produced only one test result; this test was performed on a galvanizing furnace, which is not a hot-dip operation. Neither the Los Angeles County tests nor the San Francisco test were listed in the NEDS computer search.

3.2 General Process and Emission Control Information

There are a number of books which describe the hot-dip galvanizing process in some detail (3, 4, 5). However, these sources do not even discuss the emission problem. The most recent (1974) and probably the most technical discussion of the galvanizing process is "The Galvanizing Manual" published by the St. Joe Minerals Corporation (6). A good technical discussion of the various alloy layers which make up the zinc coating in galvanizing is given by Mohler (7). Most galvanizers use a zinc ammonium chloride kettle flux known as "ZACLON," which is manufactured by DuPont; a data summary listing the chemical composition and properties of the various types of "ZACLON" galvanizing fluxes is given in Appendix A-1.

Most available publications discussed the galvanizing emission problem in fairly general terms and did not list specific particulate emission data. The consensus was that grayish-white particulate fumes are discharged whenever the kettle flux cover is disturbed, when fresh flux is added, and when galvanized articles are dusted with ammonium chloride (1). Lemke et al. (8) presented the results of a chemical analysis of particulate emissions from a galvanizing kettle. The probable

composition of the emissions was estimated as follows:

NH_4Cl	-	68.0% by weight
ZnO	-	15.8% by weight
Zn	-	4.9% by weight
$ZnCl_2$	-	3.6% by weight
C	-	2.8% by weight
H_2O	-	2.5% by weight
Oil	-	1.4% by weight
NH_3	-	1.0% by weight

Since ammonium chloride (NH_4Cl) vaporizes at 350° C and the zinc bath temperature is usually between 445° and 460° C, it is not surprising that NH_4Cl makes up the bulk of the particulate emissions. However, zinc and zinc chloride have very low vapor pressures at normal galvanizing temperatures, and one would expect neither of them to vaporize to any great extent. It is believed that the discharge of these materials is the result of mechanical entrainment, and occurs when wet objects are galvanized or when objects are immersed rapidly through the flux layer (8).

A number of articles discuss the size distribution of the particles emitted from the hot-dip galvanizing process and methods of controlling the emissions. Size distributions of galvanizing kettle emissions have been estimated as averaging 2.0 microns (8), between 0.5 and 2.0 microns (9), and between 0.1 and 1.0 microns (10). For these extremely fine particulate emissions, three types of control equipment have been recommended (9, 10, 11):

(1) Electrostatic precipitators;

(2) High pressure-drop water scrubbers;

(3) Fabric filters (baghouses).

Of these three methods, fabric filters are considered the most economical in terms of operating cost.

Lynam (12) discusses the health problem of the particulate galvanizing emissions. The main health problems are zinc chloride ($Zn\ Cl_2$) and zinc oxide ($Zn\ O$), which can cause metal fume fever when high concentrations are inhaled. The Occupational Safety and Health Association (OSHA) threshold limit values are:

$$Zn\ Cl_2 \quad - \quad 1\ mg/m^3;$$
$$Zn\ O \quad - \quad 5\ mg/m^3.$$

However, the literature search did not reveal any measurements of the airborne concentrations of these compounds in the vicinity of a galvanizing kettle.

3.3 Specific Particulate Emission Data

Attempts to find data from actual source tests in the literature did not prove very successful. As discussed in Section 3.2 , all available books, journal articles, industrial publications, and preprints on hot-dip galvanizing processes discussed the emission problem in fairly general terms and did not list specific emission data. Two possibly relevant journal articles, one in German (13) and one in Japanese (14), were unavailable in Los Angeles area libraries and in the statewide University of California library system. Vandegrift el al. (15) estimated the annual particulate emissions from secondary zinc processes in the United States as 4,500 metric tons/year; however, the percentage of this amount due to galvanizing emissions was not stated.

The emission factor listed in "Compilation of Air Pollutant Emission Factors" (16) for galvanizing kettles is 2.5 kg particulates/ metric ton of zinc used or 5 lb/short ton of zinc used. The listed reference for this figure is a report by the Los Angeles County Air Pollution Control District (APCD) written in 1966 (17). Contact with the Los Angeles County APCD revealed that this report, probably unbound, is no longer available; also, the reported data were most probably source tests conducted on galvanizing plants in the Los Angeles area before 1960 (18).

As previously mentioned, the Los Angeles County APCD provided the results of 21 source and chemical tests on galvanizing kettles conducted since 1950. One test result was provided by the San Francisco Bay Area Air Pollution Control District. These data are reported and discussed in Section 5, "Particulate Emission Source Test Data." A NEDS computer search for all source tests on galvanizing kettles produced only one test result; this test was performed on a galvanizing furnace, which is not a hot-dip operation. Neither the Los Angeles County tests nor the San Francisco test were listed in the NEDS computer search.

4. OBSERVATION OF CURRENT GALVANIZING PRACTICES

4.1 Los Angeles Area

4.1.1 Los Angeles Galvanizing Company

Visits were made to five different galvanizing plants, two in the Los Angeles area and three in the Chicago area, to observe current hot-dip galvanizing practices, procedures, and equipment. The first plant visited was Los Angeles Galvanizing Company, 2524 East 52nd Street, Huntington Park, California, on October 15, 1975. As discussed in Section 5, three source tests for particulate emissions were carried out by the PES staff on this plant.

Galvanizing kettles are usually about 1.2 meters in width and 1.5 meters deep, and vary only in length. This plant has one kettle 9.5 meters long which is run at a temperature between 443° and 449° C. The kettle flux used was zinc ammonium chloride, ZACLON Type 2N (See Appendix A-1). Contrary to typical galvanizing procedures, no rinsing or prefluxing steps were used in article preparation; the sequence of steps in preparation for galvanizing were as follows:

(1) Degreasing in a hot, alkaline solution;

(2) Pickling in a hot, sulfuric acid bath;

(3) Pickling in a hot, hydrochloric acid bath.

The main particulate emissions, consisting of grayish-white fumes, were observed when an article was immersed through the kettle flux layer, when the flux layer was agitated, and when a galvanized article was dusted with NH_4Cl. This plant uses a canopy hood over the kettle and a lime-injected baghouse for emission control. The baghouse was designed by Industrial Clean Air (ICA) and employs 1,152 nylon bags. The bags are coated with Flintkote Type S lime, which is a mixture of 60% $Ca(OH)_2$ and 40% $Mg(OH)_2$. No visible emissions were observed from the baghouse exhaust. As discussed in Section 5, this baghouse was tested for efficiency and particulate emissions by the PES staff.

4.1.2 Joslyn Manufacturing and Supply Company, Dominguez Galvanizing Plant

A visit was made to the Dominguez Galvanizing Plant of Joslyn Manufacturing and Supply Company, 2226 East Dominguez Street, Long Beach, California on October 31, 1975. This is a large plant which has three galvanizing kettles: one 13.7 meters long, one 7.9 meters long, and one 4.5 meters long. The kettle flux used for all three kettles was zinc ammonium chloride, ZACLON Type 2N (see Appendix A-1). All kettles were run at a temperature between 450° and 454° C.

The sequence of steps in preparation for galvanizing were as follows:

(1) Degreasing in a hot, alkaline solution;

(2) Rinsing thoroughly in a water bath;

(3) Pickling in a hot, sulfuric acid bath;

(4) Rinsing thoroughly in a water bath;

(5) Prefluxing in a zinc ammonium chloride solution (ZACLON Type F; see Appendix A-1).

The main particulate emissions, consisting of grayish-white fumes, were observed when an article was immersed through the kettle flux layer or the flux layer was agitated, and especially when a galvanized object was sprayed with NH_4Cl. All other plants which were observed in finishing articles sprinkled NH_4Cl on the galvanized article by hand; this plant used a spray-gun technique with large quantities of NH_4Cl, creating dense grayish-white fumes.

For emission control, this plant uses three individual lime-injected baghouses, all designed by ICA. The smallest kettle (4.6 meters long) had a direct hood over the kettle leading to a small baghouse. The two larger kettles, which were in individual large rooms, employed roof-level exhausts leading to a baghouse (a separate baghouse for each kettle). Thus, the entire room air was exhausted for the two larger kettles. The three

baghouses all used Dacron bags and were injected with Flintkote Type S lime (60% Ca $(OH)_2$, 40% Mg $(OH)_2$). No visible emissions were observed from any of the baghouse exhausts.

4.1 Chicago Area

4.1.1 Reliable Galvanizing Company

A visit was made to Reliable Galvanizing Company, 8800 South Genoa Avenue, Chicago, Illinois on November 6, 1975. This plant has one galvanizing kettle 12.8 meters long which is run at about 454° C. The unusual aspect of this plant's operation was that no kettle flux was used; in the galvanizing literature, this is termed "dry" galvanizing, as opposed to the normal "wet" galvanizing technique using a kettle flux. A preflux was used just before the galvanizing kettle.

The sequence of steps in preparation for galvanizing were as follows:

(1) Degreasing in a hot, alkaline solution;

(2) Pickling in a hot, sulfuric acid bath;

(3) Prefluxing in a zinc ammonium chloride solution (manufactured by Stauffer Chemical Company).

The main particulate emissions, consisting of grayish-white fumes, were observed when an article was dipped into the molten zinc, apparently vaporizing some of the zinc ammonium chloride preflux. No finishing of galvanizing articles with NH_4 Cl was done at this plant. No particulate emission control device was used; emissions were simply vented to the atmosphere.

4.2.2 Joslyn Manufacturing and Supply Company, Morgan Street Division

A visit was made to the Morgan Street Division of Joslyn Manufacturing and Supply Company, 3700 South Morgan Street, Chicago, Illinois on

November 6, 1975. This plant had three kettles, each 4.9 meters long, which were in operation; one kettle 7.9 meters long, was being repaired. The kettles were operated at a temperature between 449° to 454° C, and used a zinc ammonium chloride kettle flux, ZACLON Type F (see Appendix A-1).

The sequence of steps in preparation for galvanizing were as follows:

(1) Degreasing in a hot, alkaline solution;

(2) Rinsing thoroughly in a water bath;

(3) Pickling in a hot, sulfuric acid bath;

(4) Rinsing thoroughly in a water bath;

(5) Prefluxing in a zinc ammonium chloride solution (ZACLON Type F; see Appendix A-1).

The main particulate emissions, consisting of grayish-white fumes, were observed when an article was immersed through the kettle flux layer or the flux layer was agitated, and when galvanized objects were dusted with NH_4Cl. Canopy or side hoods were used over the galvanizing kettles; however, no control device was used and the particulate emissions were simply vented to the atmosphere from roof vents.

4.2.3 Joslyn Manufacturing and Supply Company, Empire Galvanizing Division

A visit was made to the Empire Galvanizing Division of Joslyn Manufacturing and Supply Company, 10909 Franklin Avenue, Franklin Park, Illinois on November 7, 1975. This plant had one galvanizing kettle 15.9 meters long, which was kept at a temperature of 449° - 454° C. The kettle flux used was zinc ammonium chloride, ZACLON Type F (see Appendix A-1).

The sequence of steps in preparation for galvanizing were as follows:

(1) Degreasing in a hot, alkaline solution;

(2) Rinsing thoroughly in a water bath;

(3) Pickling in a hot, sulfuric acid bath;

(4) Rinsing thoroughly in a water bath;

(5) Prefluxing in a zinc ammonium chloride solution (ZACLON Type F; see Appendix A-1).

The main particulate emissions, consisting of grayish-white fumes, were observed when an article was immersed through the kettle flux layer or the flux layer was agitated, and when a galvanized article was dusted with NH_4Cl. As in Joslyn's Dominguez Galvanizing Plant, the entire room air was vented to a lime-injected baghouse for emission control. The baghouse was designed by Industrial Clean Air (ICA), and the polyester bags were injected with Hydrofol Type S lime. No visible emissions were observed from the baghouse exhausts.

It should be noted that an observation that a plant is operating with or without controls or visible emissions is not sufficient information to determine whether a plant is in compliance with all applicable emissions regulations. Normally, emission regulations are given in terms of a specific particulate emission rate, and source tests are usually necessary to determine whether a plant is in compliance.

5. PARTICULATE EMISSION SOURCE TEST DATA

5.1 Existing Source Test Data

5.1.1 Los Angeles County Air Pollution Control District

The Los Angeles County Air Pollution Control District (APCD) provided by far the most relevant data for determining an emission factor - the results of 21 source and chemical tests on galvanizing kettles conducted in the Los Angeles area over a 25-year period. Some information which was considered confidential was not provided; however, these data provided by the Los Angeles County APCD were the largest single source of particulate emission data from galvanizing kettles. As discussed in Section 3.3, the Los Angeles County data before 1960 were the probable source of the emission factor listed in "Compilation of Air Pollutant Emission Factors" (16).

Of the 21 source and chemical tests provided, three tests were concerned only with chemical analysis and one source test was on a galvanizing furnace, which is not a hot-dip operation. Of the remaining 17 source tests on galvanizing kettles, two tests did not measure process weight, and two very early tests, done in 1950 and 1951, listed extremely low and questionable process weights. Thus, there were thirteen source tests which were considered relevant in determining an emission factor based on process weight.

The results of the thirteen relevant source tests conducted by the Los Angeles County APCD are given in Table 5-1, along with the type of control device tested. The main control devices used for galvanizing emissions were baghouses and water scrubbers; as shown in Table 5-1, with a few exceptions, the control devices did not work very well for galvanizing emissions. Reasons for the relatively poor efficiency are discussed in section 6.1. Four of the thirteen tests, as indicated in Table 5-1, were on continuous process operations which galvanized chain-link fencing. The other tests were on batch-operation, hot-dip galvanizing processes. Names and addresses of the

plants tested in Table 5-1 are given in Appendix A-4.

The Los Angeles County APCD did not use EPA Method 5 in their testing, but used a similar method. The APCD test procedure prior to 1971 differed from later procedures in the method of collection of particulates which are volatile at the exhaust temperature (19). However, since galvanizing emissions are mainly solid particles and are normally at ambient temperature, all of the Los Angeles County APCD tests can be considered to accurately represent total particulate emissions.

5.1.2 San Francisco Bay Area Air Pollution Control District

One source test on emissions from a galvanizing kettle was received from the San Francisco Bay Area Air Pollution Control District. This source test, done in 1970 in the San Francisco area, measured particulate emissions only from the exhaust of a water scrubber control system. The results of this test, which used not EPA Method 5 but a similar method, are shown in Table 5-1.

5.2 Source Tests Conducted by Pacific Environmental Services, Inc.

On December 2 and 3, 1975, the PES staff conducted three separate source tests on one galvanizing plant in the Los Angeles area, Los Angeles Galvanizing Company in Huntington Park, California. This plant uses a canopy hood over the galvanizing kettle and a lime-injected baghouse for emission control. The three source tests used EPA Method 5, and two of the tests measured particulates simultaneously from both the inlet and exhaust of the baghouse; on one test, only the baghouse exhaust was tested due to equipment malfunction. Details of the source tests are given in Appendix A-2.

The main results of the PES source tests are given in Table 5-1, for ready comparison with the other source test results. The baghouse did not work very well; this fact is discussed in Section 6. One parameter which was measured in the PES tests was the surface area of the galvanized product. Table 5-2 compares the product surface area with the measured emission rates.

Table 5-1 SUMMARY OF GALVANIZING SOURCE TESTS

Test Date	Agency	Galvanized Product Process Weight (metric tons/hr)	Control Device	Kettle Emissions (kg/hr)	Emissions From Control Device (kg/hr)	Efficiency (%)
2/13/57	L.A. APCD	4.04	Water scrubber	0.24	0.26	(Negative)
3/17/58	L.A. APCD	0.69	Water scrubber	0.54	0.73	(Negative)
10/22/58*	L.A. APCD	2.33	Electrostatic precipitator	0.64	0.033	95
3/10/59*	L.A. APCD	1.00	Water scrubber	0.32	0.007	98
3/26/59	L.A. APCD	0.56	Baghouse (heated)	0.30	0.15	51
4/16/59	L.A. APCD	3.71	Water scrubber	0.52	0.71	(Negative)
5/11/59	L.A. APCD	1.36	None	0.25	-	-
9/14/59*	L.A. APCD	2.59	Electrostatic precipitator	0.70	0.15	79
4/30/70	L.A. APCD	4.57	Water scrubber	0.077	0.064	18
2/24/72*	L.A. APCD	1.77	Baghouse (heated)	0.091	0.10	(Negative)
6/6/73	L.A. APCD	11.81	Baghouse (lime-injected)	0.65	0.30	53
10/15/73	L.A. APCD	4.87	Baghouse (lime-injected)	0.95	0.11	88
4/4/74	L.A. APCD	3.58	Baghouse (lime-injected)	0.46	0.43	6
2/5/70	S.F. APCD	2.72	Water scrubber	-	0.66	-
12/2/75	PES	2.11	Baghouse (lime-injected)	1.47	1.46	0
12/3/75	PES	2.27	Baghouse (lime-injected)	-	0.75	-
12/3/75	PES	2.08	Baghouse (lime-injected)	1.23	1.48	(Negative)

*Continuous process (chain-link fencing)

Table 5-2. RESULTS OF PES SOURCE TESTS

Test Date	Product Surface Area (m^2/hr)	Kettle Emissions (kg/hr)	Emissions from Control Device (kg/hr)
12/2/75	79.0	1.47	1.46
12/3/75	52.5	-	0.75
12/3/75	72.3	1.23	1.48

In section 6.4, the results of Table 5-2 are discussed in the possible development of an emission factor based on surface area.

6. DATA ANALYSIS

6.1 Controlled vs. Uncontrolled Emissions

The most striking feature about Table 5-1 is the fact that there was not a significant difference between kettle emissions and emissions from control devices. The control devices tested, mainly water scrubbers and baghouses, did not work very well for galvanizing emissions. Of the fourteen cases in which efficiency of the control device was tested, eight cases had efficiencies less than 20%, and five cases had apparently negative efficiencies.

The probable explanation for the low efficiencies is the fact that the control devices are not designed to control the fairly low and unsteady emission rates characteristic of galvanizing processes, but are designed to control higher, continuous emission rates. Also, in the case of lime-injected baghouses, it is possible that some of the added powdered lime escapes into the atmosphere from the baghouse exhaust. In the tests conducted by PES, a qualitative chemical analysis indicated a different chemical composition of the material collected at the inlet and exhaust of a lime-injected baghouse (see Appendix A-2).

From observations of galvanizing plants, it is evident that visible emissions are released only at certain intervals, when the kettle flux cover is disturbed or when galvanized articles are dusted with ammonium chloride. These intermittent emissions, when averaged over a one-hour period, result in fairly low kettle emission rates, as shown in Table 5-1. Thus, control devices are likely to function mainly to reduce visible emissions rather than to achieve significant quantitative reductions in average emissions from galvanizing processes.

Since no significant differences were found between kettle emissions and emissions from control devices, in the analyses below, both kettle and control device emissions will be considered together as one data base. As will be demonstrated, the differences involved in considering

kettle and control device emissions separately are much less than the differences between individual data points.

6.2 Emission Factor Based on Process Weight

In an assessment of local air pollution, there is a need to estimate the emissions from galvanizing plants as a function of process rates, procedures, or equipment. For such an estimation, a useful tool is an emission factor which relates the quantity of pollutants emitted to some easily measurable activity level or rate. Typically, emission factors are estimated as arithmetic averages of a number of data points from source tests.

In "Compilation of Air Pollutant Emission Factors" (16), the emission factor listed for galvanizing kettles is 2.5 kg particulates/metric ton of zinc used or 5 lb/short ton of zinc used. The listed reference for this figure is a report by the Los Angeles County APCD, written in 1966 (17). Contact with the Los Angles County APCD revealed that this report, probably unbound, is no longer available; also, the reported data were most probably source tests conducted on galvanizing plants in the Los Angeles area before 1960 (18).

The problem with having an emission factor based on the amount of zinc used is that this quantity is rarely measured and usually must be estimated. In all the galvanizing plants which the PES staff has visited and in the majority of the source tests, only the total galvanized product weight was measured. Galvanizing plants base their financial charges on measurement of galvanized product weight, and do not normally measure the amount of zinc used, except over a long period of time, such as monthly or yearly. Thus, it is recommended that an emission factor in terms of process weight be defined per weight of galvanized product and not per weight of zinc used.

Only four of the source test results estimated the amount of zinc added. It should be noted that even in these four tests, the amount of zinc added was estimated, not measured, as a function of the total amount galvanized. The results of these four tests, all conducted by the Los Angeles County APCD, are given in Table 6-1. As can be seen, typically the amount of zinc in the finished galvanized product is about 8% by weight. All other source tests measured only the galvanized product process weight.

Table 6-1

SOURCE TESTS WHICH ESTIMATED AMOUNT OF ZINC ADDED

Test Date	Galvanized Product Process Weight (metric ton/hour)	Estimated Zinc Added (metric ton/hr)	Zinc in Galvanized Product (% by weight)
2/24/72*	1.77	0.132	7.44
4/4/74	3.58	0.326	9.09
10/15/73	4.87	0.376	7.73
6/6/73	11.81	0.826	6.99
			Ave. = 7.81
			(σ = 0.90)

*Continuous process (chain-link fencing)

From the data in Table 5-1, emission factors based on galvanized product process weight can be calculated. The results are shown in Table 6-2, with the emission factors in units of kg particulates/ metric ton galvanized product. As can be seen, there is not a significant difference between the kettle and control device emission factors. Considering both kettle and control device emissions as one data base, an averaged emission factor can be calculated:

Emission factor = 0.26 kg/metric ton galvanized product
(0.52 lb/short ton galvanized product)
σ = 0.28 kg/metric ton galvanized product

It should be noted that the standard deviation (σ) is of the same order of magnitude as the averaged emission factor, indicating the considerable scatter in the data base. The standard deviation (σ) is a measure of the spread of a statistical distribution, and is defined as,

$$\sigma = \sqrt{\frac{\Sigma \ (x_i - \bar{x})^2}{N-1}}$$

where N is the total number of data points and $\bar{x}$ is the arithmetic average. If a Gaussian distribution is assumed, approximately 95% of the data points can be expected to lie within $\pm 2\sigma$ of the arithmetic average.

In order to compare the calculated result with the emission factor, 2.5 kg/metric ton zinc, listed in "Compilation of Air Pollutant Emission Factors" (16), the typical factor of 8% zinc (by weight) in the finished galvanized product can be used, i.e., the equivalent number would be (2.5 x 0.08) = 0.2 kg/metric ton galvanized product. Likewise, the

new averaged emission factor can be expressed in terms of the amount of zinc added:

$$\text{Emission factor} = 3.3 \text{ kg/metric ton zinc used}$$
$$(6.6 \text{ lb/short ton zinc used})$$
$$\sigma = 3.5 \text{ kg/metric ton zinc used}$$

Thus, the new averaged emission factor, based on process weight, is only slightly higher than the listed number in "Compilation of Air Pollutant Emission Factors" (16). This fact is not surprising, since both numbers are based on some of the same data, namely the eight Los Angeles County APCD tests before 1960.

6.3 Emission Factor Based on Hours of Operation

The data points in Table 5-1, including both kettle and control device emissions, are plotted in Figure 6-1, as emissions vs. galvanized product process weight. The solid line indicates the averaged emission factor of 0.26 kg/metric ton galvanized product. However, in order to determine the best fit to the data, a linear least squares regression analysis was run on the data points; the regression analysis is described in Appendix A-3.

Considering all the data points in Figure 6-1, if emissions in kg/hr are designated as y, and the process weight in metric ton/hr of galvanized product is designated as x, then the best-fit straight line (see Appendix A-3) is given by:

$$y = 0.54 - 0.009\,x \qquad (1)$$

This relationship is plotted as the dashed line in Figure 6-1. Due to the very slight dependence on x, it is essentially a horizontal straight line.

Table 6-2. EMISSION FACTORS BASED ON PROCESS WEIGHT

Units: kg particulates/metric ton galvanized product			
Test Date	Agency	Kettle Emission Factor	Control Device Emission Factor
2/13/57	L.A. APCD	0.061	0.064
3/17/58	L.A. APCD	0.790	1.053
10/22/58*	L.A. APCD	0.273	0.014
3/10/59*	L.A. APCD	0.323	0.007
3/26/59	L.A. APCD	0.545	0.269
4/16/59	L.A. APCD	0.141	0.191
5/11/59	L.A. APCD	0.187	-
9/14/59*	L.A. APCD	0.270	0.056
4/30/70	L.A. APCD	0.017	0.014
2/24/72*	L.A. APCD	0.052	0.057
6/6/73	L.A. APCD	0.056	0.026
10/15/73	L.A. APCD	0.196	0.024
4/4/74	L.A. APCD	0.128	0.120
2/5/70	S.F. APCD	-	0.244
12/2/75	PES	0.693	0.691
12/3/75	PES	-	0.332
12/3/75	PES	0.592	0.714
		Ave. = 0.288 (0.58 lb/short ton) σ = 0.250	Ave. = 0.242 (0.48 lb/ short ton) σ = 0.312

*Continuous process (chain-link fencing)

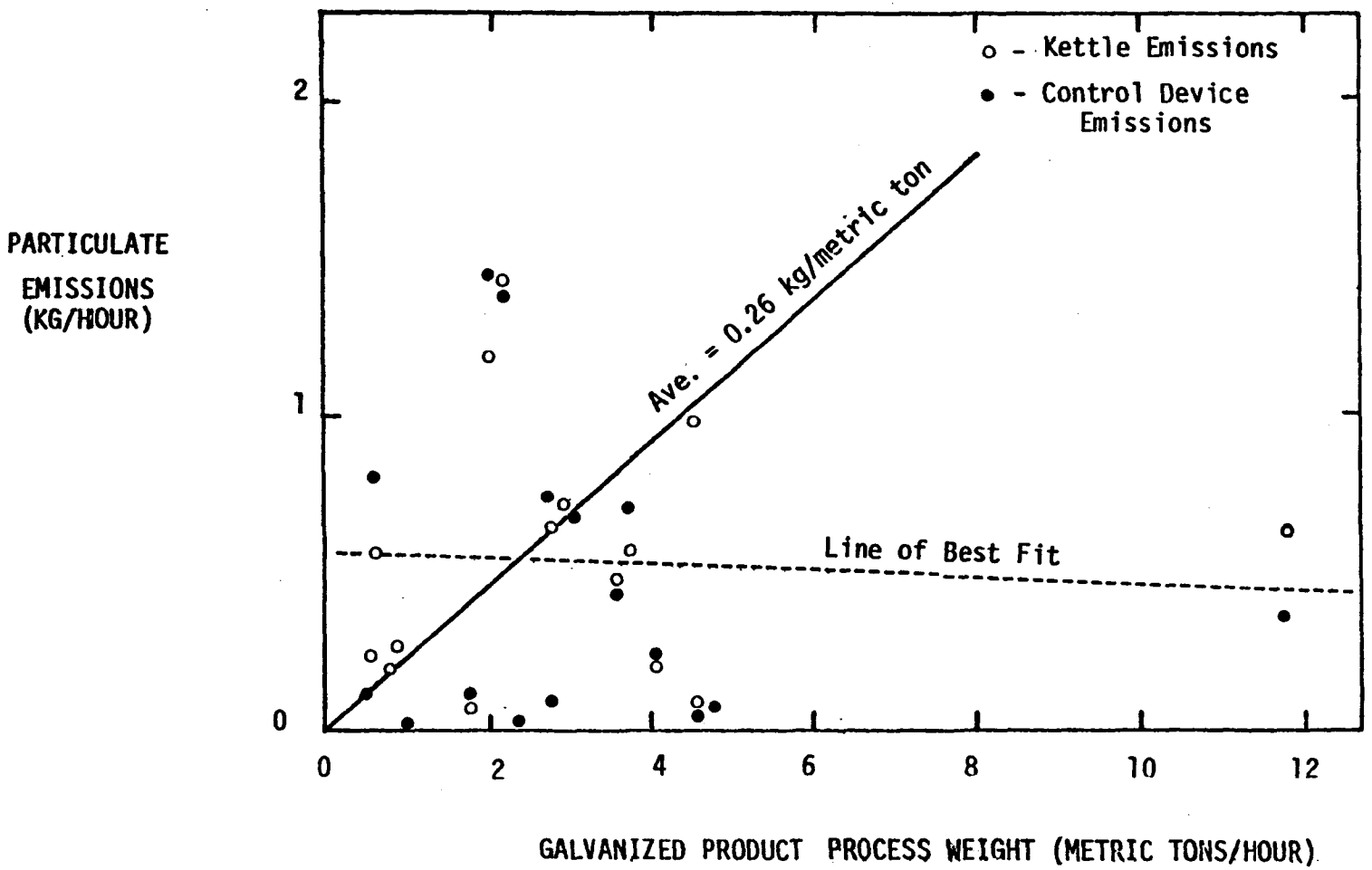

Figure 6-1. PARTICULATE EMISSIONS VS. GALVANIZED PRODUCT PROCESS WEIGHT

The best fit straight line draws the conclusion that particulate emissions are essentially independent of the amount of material processed. As discussed in Appendix A-3, similar linear least-squares regression analyses were run on the kettle and control device emissions separately, and were also run neglecting the two data points at the very high process weight (11.81 metric ton/hr). In all cases, very similar, almost horizontal straight lines were found, indicating that galvanizing emissions are substantially independent of process weight. This conclusion is supported by the fact that, in the hot-dip galvanizing process, the main emissions are caused by articles entering and exiting the kettle, i.e., the process of disturbing the kettle flux layer on entering and exiting the kettle is more important than the absolute weight of the article galvanized.

Equation (1) could be used as an emission factor equation, however, due to the very small dependence on process weight, a simpler approach is to assume an emission factor which is independent of process weight. Simply averaging both kettle and control device emission data points in Table 5-1 yields the following result:

Emission factor = 0.51 kg/hr per kettle
(1.12 lb/hr per kettle)

σ = 0.44 kg/hr per kettle

This approach thus uses the conclusion that galvanizing emissions are independent of process weight, and relates emissions simply to the total time of kettle operation and the number of kettles in operation. Again, the rather large standard deviation (σ) indicates the considerable scatter in the data base, even though this approach is essentially the best linear fit mathematically.

6.4 Emission Factor Based on Surface Area

From the three source tests conducted by the PES staff, a relationship can be derived between galvanizing emissions and the surface area of the galvanized product. From the data given in Table 5-2, emission factors based on galvanized product surface area can be calculated. The results are shown in Table 6-3, with the emission factors in units of kg particulate/m^2 galvanized product.

Table 6-3. EMISSION FACTORS BASED ON SURFACE AREA

Units: kg particulates/m^2 galvanized product		
Test Date	Kettle Emission Factor	Control Device Emission Factor
12/2/75	0.0185	0.0185
12/3/75	-	0.0143
12/3/75	0.0170	0.0205

Considering both kettle and control device emissions, an averaged emission factor can be calculated:

$$\text{Emission factor} = 0.0178\ kg/m^2\ (0.0036\ lb/ft^2)$$
$$\sigma = 0.0023\ kg/m^2$$

It should be noted that this emission factor is based on data from only <u>one</u> galvanizing plant and only five data points. The emission factors in Sections 6.2 and 6.3 are based on data from eleven different plants and 31 data points. Thus, this approach based on surface area should only be considered as a preliminary conclusion. Also, since no records are kept of galvanized product surface area, this type of emission factor would be difficult to use in practice.

6.5 Total Galvanizing Emissions in the U.S.

Using the emission factors generated in Sections 6.2 and 6.3, it is possible to estimate the total annual amount of particulate emissions produced by galvanizing plants in the United States. From U.S. Bureau of Mines data (2), the amount of zinc consumed by galvanizing in the U.S. was 511,505 metric tons in 1973. Using the estimated emission factor of 3.3 kg/metric ton of zinc used, the total galvanizing emissions in the U.S. can be estimated at 1,690 metric tons in 1973. This number is negligible when compared to the total particulate emissions from all sources, estimated as about 16,000,000 metric tons/yr in the U.S. by Vandegrift et al. (15)

Another way of determining the total annual emission rate for galvanizing is to consider the total hours of operation and the number of kettles. Galvanizing kettles are operated, on the average, 16 hours per day, 6 days per week, and 50 weeks per year, or a total of 4,800 hours per year. Using the emission factor of 0.51 kg/hr, each galvanizing kettle produces 2,450 kg or 2.45 metric tons of particulates annually. The America Hot Dip Galvanizers Association (AHDGA) lists about 100 members who operate approximately 200 galvanizing kettles. However, many galvanizers do not belong to the AHDGA, in particular large steel companies who have extensive in-house galvanizing operations.

If the assumption is made that the AHDGA membership represents one-third of the galvanizing kettles in the U.S., i.e., a total of 600 kettles are in operation in the U.S., then the annual particulate emissions would be (600 x 2.45) = 1,470 metric tons from galvanizing operations. This number is very close to the previous estimate of 1,690 metric tons annually. Thus, a plausible estimate of the total amount of particulate emissions in the United States from galvanizing operations is 1,600 metric tons (1,800 short tons) per year.

APPENDICES

A-1. DESCRIPTION OF ZACLON GALVANIZING FLUXES

DATA SHEET

ZACLON® GALVANIZING FLUXES

Pont manufactures a series of *ZACLON** galva-
ng fluxes to meet the needs of the industry.
materials are available with varying degrees of
ammonium chloride activity, additives, and
sical forms. They are used during the galva-
ng process in the prefluxing, galvanizing, and
shing steps.

LON galvanizing fluxes protect steel and zinc
nst oxidation, reduce dross formation, mini-
mize ammonium chloride fume losses and insure good galvanizing. They are economical and easy to use.

Du Pont's products for the galvanizing industry include pickling acids, ammonium chloride fluxes, and *ZACLON* galvanizing fluxes. Additional information on these products is available from any sales office of Du Pont's Industrial Chemicals Department listed on the back page.

ERAGE ANALYSES - GENERAL PURPOSE GRADES

	Grade of *ZACLON*®			
	C, CS[a]	F	K	2N[b]
ammonium chloride				
$ZnCl_2 \cdot 2\ NH_4Cl$, %	99.5			
$ZnCl_2 \cdot 3NH_4Cl$, %		99.4	99.7	
$ZnCl_2 \cdot 6NH_4Cl$, %				99.0
as $ZnCl_2$, %	56.0	45.8	45.9	30.0
nonia as NH_4Cl, %	43.5	53.6	53.8	69.0
o, $ZnCl_2:NH_4Cl$	1.29	0.85	0.85	0.43
l iron as Fe, %		0.004	0.004	0.004
tes as SO_3, %		0.03	0.03	0.02
as $PbCl_2$, %		0.02	0.02	0.06
r insoluble matter, %		0.04	0.03	0.04
ture, %	0.3	0.03	0.2	0.6

PERTIES

	yellowish white	off white	off white	off white
x. density, lb/ft³				
e	53	56	57	51
ed	69	63	63	59

U.S. Pat. Off.
alent to *ZACLON* C but includes a wetting agent.
vailable in Rod Form.

Information set forth herein is furnished free of charge and is based on technical data that Du Pont believes to be reliable. It is ded for use by persons having technical skill and at their own discretion and risk. Since conditions of use are outside our control, ake no warranties, express or implied, and assume no liability in connection with any use of this information. Nothing herein is to en as a license to operate under or a recommendation to infringe any patents.

THE GALVANIZING PROCESS

Clean, oxide-free iron or steel is galvanized by coating it with a thin layer of zinc. This protects the iron or steel by shielding it from the atmosphere, as well as providing cathodic or sacrificial protection. Even if the surface is scratched, exposing the base metal, the more electronegative zinc is slowly consumed while the iron or steel is protected. The most important galvanizing method is the hot dip process which is adaptable to coating nearly all fabricated and nonfabricated products such as wire, tanks, sheets, strip, pipes and tubes, fittings, hardware, wire cloth, hollow ware, and structural assemblies.

Hot dip galvanizing consists of these fundamental steps:

- surface preparation – The surface is degreased and pickled to free it of dirt, grease, rust, and scale.
- prefluxing – The surface is coated with a thin layer of *ZACLON** galvanizing flux which prevents rust and dissolves light oxides that may have formed since pickling.
- galvanizing – Clean, oxide-free work is immersed into molten zinc. It may be immersed through a blanket of *ZACLON* galvanizing flux.
- finishing – Excess zinc is removed, the piece is quenched and inspected. *ZACLON* galvanizing fluxes or ammonium chloride may be used as a dusting sprinkle in some operations.

APPLICATIONS

General Purpose Fluxes

ZACLON F galvanizing flux is the basic flux used in the industry. It serves either as an aqueous preflux for work prior to galvanizing or as a direct addition to the kettle to maintain a foaming top flux. As a preflux it insures uniform zinc coverage, reduces dross formation and constantly activates the top flux. The foam blanket produced by *ZACLON* F reduces fuming, zinc spatter, and prolongs the life of the flux. Galvanizers of structural shapes, pipe and conduit, tanks, wire, and basket work generally use this grade.

ZACLON K is similar to *ZACLON* F as a preflux, but does not produce a foaming flux blanket – it leaves a thin, fluid cover. *ZACLON* K is generally preferred by galvanizers of fittings processed on automatic continuous equipment, structural shapes and nails.

ZACLON 2N is formulated with the high activity usually obtainable only by separate additions of ammonium chloride. This flux contains a very efficient foaming agent. *ZACLON* 2N can be used alone as the top flux, or with other fluxes to maintain an active flux blanket. When using *ZACLON* 2N, it is recommended that a few shovelfuls of *ZACLON* HV or the heel of an old flux be used to start the top flux. It is not recommended for use as a preflux.

ZACLON 2N (nonfoaming) is similar to *ZACLON* 2N, but does not contain a foaming agent. It is used to maintain activity in a top flux blanket and as a replacement for ammonium chloride.

ZACLON CS is specially formulated for use as an aqueous preflux in continuous strip galvanizing. It protects the steel against oxidation at the higher preheat temperatures required in this process. *ZACLON* CS has lower fluxing activity than either *ZACLON* F or *ZACLON* K but generates less fuming and provides a more stable coating when preheat is used.

Solutions of *ZACLON* CS are also available.

Special Purpose Fluxes

ZACLON A is a nonfuming flux that can be used as an aqueous preflux or as a fluid cover on molten zinc. It is useful where strict control of fuming is necessary. However, *ZACLON* A is a less active flux and careful practice is required to insure galvanizing quality.

ZACLON AF is a nonfuming flux similar to *ZACLON* A. *ZACLON* AF forms a foamed cover on the molten zinc and is recommended as a top flux instead of *ZACLON* A. *ZACLON* AF can also be used in an aqueous preflux solution. As with *ZACLON* A, careful galvanizing practice is necessary because of its lower activity.

ZACLON C is generally used in the formulation of other fluxes for special tinning and soldering applications. *ZACLON* C is similar in fluxing activity to *ZACLON* CS.

ZACLON HV is specially formulated to permit building an active zinc ammonium chloride top flux without generating excess smoke. The formulation includes an efficient foaming agent that provides an insulating blanket and further suppresses fuming. A more active flux, such as *ZACLON* F can then be used as an aqueous preflux, or as an addition to the top flux for maintaining activity.

*Reg. U.S. Pat. Off.

PACKAGES

Du Pont ships *ZACLON*.* C, CS, F, K, 2N and 2N (nonfoaming) in 100-lb (net) paper bags. *ZACLON* F and K are also available in 400-lb (net) fiber drums. The grades containing higher amounts of zinc chloride such as *ZALCON* A, AF, and HV are shipped in 525-lb (net) steel drums. Bulk solution shipments of certain grades are available.

STORAGE AND HANDLING

All solid grades of *ZACLON* galvanizing fluxes should be stored so as to avoid moisture pickup. The grades containing higher amounts of zinc chloride, such as *ZACLON* A, AF and HV, should be stored in tightly closed containers in a dry place. An inventory turnover rate of 2-3 months is recommended to minimize caking.

Unheated solutions of *ZACLON* slowly corrode steel. Rubber-lined steel tanks or fiber-glass reinforced polyester tanks are recommended for storage.

All persons handling *ZACLON* galvanizing fluxes should be thoroughly familiar with the additional information on Storage and Handling and Personal Safety and First Aid in Du Pont's Galvanizing Handbook. This handbook is available from any sales office listed on the back page.

*Reg. U.S. Pat. Off.

PERSONAL SAFETY AND FIRST AID

Health Hazards

ZACLON galvanizing fluxes, generally zinc ammonium chloride mixtures, are acidic and can cause severe skin or eye injury. The principal hazard is to the eye, since even brief contact of the undiluted product may produce permanent damage.

The U.S. Department of Labor has issued the regulation that an employee's exposure to zinc chloride fumes in any 8-hour shift of a 40-hour work week shall not exceed the 8-hour time-weighted average of 1 mg/m^3. (Title 29, Part 1910.93 Air Contaminants).

Safety Precautions

All persons handling *ZACLON* should avoid contact with the powders or solutions. Do not get in eyes, on skin or on clothing. Avoid breathing dusts, mists or fumes. Wash thoroughly after handling. Contaminated clothing should be washed before reuse. Adequate ventilation should be provided.

First Aid

In case of contact of *ZACLON* with skin, immediately flush with plenty of water while removing contaminated clothing and shoes. For eyes, flush with water for at least 15 minutes and call a physician. If dusts, mists or fumes are inhaled, remove person to fresh air immediately and contact a physician.

A-2. DETAILS OF PARTICULATE EMISSION SOURCE TESTS CONDUCTED BY THE PES STAFF

I. DESCRIPTION OF SOURCE TESTS

On December 2 and 3, 1975, Pacific Environmental Services, Inc. (PES) conducted three separate source tests for particulate emissions at Los Angeles Galvanizing Company in Huntington Park, California. This plant uses a canopy hood over the galvanizing kettle and a lime-injected baghouse for emission control. The three source tests used EPA Method 5, and two of the tests measured particulates simultaneously from both the inlet and exhaust of the baghouse; on one test, only the baghouse exhaust was tested due to equipment malfunction. The test team was coordinated by Dr. Peter Drivas and included Robert Norton, Robert Missen, Joseph Boyd, and Bansi Parekh, all staff members of Pacific Environmental Services.

The baghouse was designed by Industrial Clean Air (ICA) and employs 1,152 nylon bags. The bags are coated with Flintkote Type S lime, which is a mixture of 60% $Ca(OH)_2$ and 40% $Mg(OH)_2$. The baghouse inlet which was tested consists of one 1.1 m by 1.5 m rectangular duct. The exhaust of the baghouse consists of two identical 0.6 m by 0.6 m square ducts. Only one of the baghouse exhausts (the north one) was tested; it was assumed that the other exhaust was operating at an identical velocity and emission rate. This assumption was verified by a comparison of the inlet and outlet volumetric flow rates. In the discussions below, all calculated values consider the operation of both exhausts.

The first test (Run No. 1) on December 2, 1975, tested both the inlet and exhaust of the baghouse simultaneously. The second test (Run No. 2) on December 3, 1975, tested only the baghouse exhaust; due to equipment trouble (a broken glass liner in the probe), the inlet data were considered invalid. The third test (Run No. 3) on December 3, 1975 tested both the inlet and exhaust of the baghouse simultaneously.

II. SUMMARY AND DISCUSSION OF RESULTS

Pertinent data and calculated values for the three source tests are tabulated in Section III. From the exhaust volumetric flow rates, the exhaust particulate concentrations can be compared with those cited in the regulations of the Los Angeles County Air Pollution Control District (APCD). The allowable particulate concentrations, as given by Rule 52, are compared with the measured values below:

Run No.	Allowable conc., grains/ft^3 *	Measured outlet conc., grains/ft^3 *
1	0.0622	0.0176
2	0.0562	0.0069
3	0.0559	0.0135

Thus, the exhaust particulate concentrations comply with the Los Angeles County APCD regulations (Rule 52). The particulate concentrations at the baghouse inlet, given in Section III, also comply with this rule.

From the estimated process weights, the exhaust particulate emission rates can be compared with those cited in the Los Angeles County APCD regulations (Rule 54). The allowable particulate emission rates, as given by Rule 54, are compared with the measured values below:

Run No.	Allowable emission rate, lb/hr	Measured outlet emission rate, lb/hr
1	6.20	3.22
2	6.49	1.66
3	6.14	3.27

*Dry gas at standard conditions: T = 15.6° C, p = 76.0 cm Hg.

Thus, the exhaust particulate emission rates comply with the Los Angeles County APCD regulations (Rule 54). The inlet emission rates, given in Section III, also comply with this rule.

From the simultaneous testing in Run 1 and Run 3, the efficiency of the baghouse can be determined. The testing revealed that the baghouse was very inefficient:

Run No.	Inlet emission rate, kg/hr	Outlet emission rate, kg/hr	Efficiency (%)
1	1.47	1.46	0.3
3	1.23	1.48	Negative

A probable explanation for the poor efficiency is the fact that the baghouse employs a powdered lime injection system; it is possible that some of this powdered lime escapes into the atmosphere from the baghouse exhaust. A qualitative examination of the inlet and outlet filters resulted in a substantial difference in the pH values of the collected material, indicating a different chemical composition at the inlet and outlet. The collected material on the outlet filter was more basic than the material on the inlet filter, possibly indicating the presence of lime particles on the outlet filter.

III. DATA TABULATION

A. Run No. 1 - 12/2/75

	Baghouse Inlet	Baghouse Outlet
Time of sampling, PST (24-hour clock)	13:50-14:50	13:50-14:50
Total time of test, min	60	60
Number of sampling points	12	12
Area of sampling location, m^2	1.63	0.74
Sampling nozzle diameter, cm	0.90	0.64
Pitot tube coefficient	0.747	0.790
Process rate, metric ton/hr galvanized product (approximate)	2.11	2.11
CO_2 in stack gas, % by volume (dry)	0.5	0.5
O_2 in stack gas, % by volume (dry)	21.0	21.0
N_2 in stack gas, % by volume (dry)	78.5	78.5
Total H_2O collected in impingers and silica gel, ml	1.4	7.7
Volume of water vapor collected at standard conditions,* m^3	0.0019	0.0102
Moisture in stack gas, % by volume	0.18	0.73
Gas molecular weight, dry basis, g/g-mole	28.92	28.92
Gas molecular weight, wet basis, g/g-mole	28.90	28.84
Volume of dry gas sampled at meter conditions, m^3	1.044	1.462
Average gas meter temperature, ^oC	30.6	37.6

Run No. 1 (continued)

	Baghouse Inlet	Baghouse Outlet
Absolute barometric pressure, cm Hg	75.84	75.84
Average orifice pressure drop, cm H_2O	3.40	6.86
Volume of dry gas sampled at standard conditions*, m^3	1.010	1.386
Average stack gas temperature, ^oC	32.8	35.3
Absolute stack gas pressure, cm Hg	75.84	75.84
Stack gas velocity at stack conditions, m/sec	6.19	14.65
Dry stack gas volumetric flow rate at standard conditions, $^*m^3$/min	578	614
Isokinetic sampling, %	75	88
Particulate weight: filter, mg	2.0	5.5
Particulate weight: probe and cyclone, mg	33.6	39.6
Particulate weight: impingers, mg	7.2	9.8
Total particulate weight, mg	42.8	54.9
Total particulate concentration at standard conditions*, g/m^3	0.0423	0.0396
Total particulate emission rate, kg/hr	1.47	1.46

*Standard conditions: $T = 20^o$ C, p = 76.0 cm Hg.

B. Run No. 2 - 12/3/75

	Baghouse Outlet
Time of sampling, PST (24-hour clock)	11:00-12:00
Total time of test, min	60
Number of sampling points	12
Area of sampling location, m^2	0.74
Sampling nozzle diameter, cm	0.64
Pitot tube coefficient	0.790
Process rate, metric ton/hr galvanized product (approximate)	2.27
CO_2 in stack gas, % by volume (dry)	0
O_2 in stack gas, % by volume (dry)	20
N_2 in stack gas, % by volume (dry)	80
Total H_2O collected in impingers and silica gel, ml	11.1
Volume of water vapor collected at standard conditions,* m^3	0.0147
Moisture in stack gas, % by volume	0.92
Gas molecular weight, dry basis, g/g-mole	28.80
Gas molecular weight, wet basis, g/g-mole	28.70
Volume of dry gas sampled at meter conditions, m^3	1.632
Average gas meter temperature, °C	29.4
Absolute barometric pressure, cm Hg	75.92
Average orifice pressure drop, cm H_2O	9.12
Volume of dry gas sampled at standard conditions,* m^3	1.594

Run No. 2 (continued)

	Baghouse Outlet
Average stack gas temperature, ^{o} C	28.9
Absolute stack gas pressure, cm Hg	75.92
Stack gas velocity at stack conditions, m/sec	18.78
Dry stack gas volumetric flow rate at standard conditions, * m^3/min	804
Isokinetic sampling, %	78
Particulate weight: filter, mg	0.0
Particulate weight: probe and cyclone, mg	21.9
Particulate weight: impingers, mg	2.9
Total particulate weight, mg	24.8
Total particulate concentration at standard conditions, * g/m^3	0.0156
Total particulate emission rate, kg/hr	0.753

*Standard conditions: T = 20° C, p = 76.0 cm Hg.

C. Run No. 3 - 12/3/75

	Baghouse Inlet	Baghouse Outlet
Time of sampling, PST (24-hour clock)	15:00-15:50	15:00-16:00
Total time of test, min	50	60
Number of sampling points	10	12
Area of sampling location, m^2	1.63	0.74
Sampling nozzle diameter, cm	0.90	0.64
Pitot tube coefficient	0.804	0.790
Process rate, metric ton/hr galvanized product (approximate)	2.08	2.08
CO_2 in stack gas, % by volume (dry)	0	0
O_2 in stack gas, % by volume (dry)	20	20
N_2 in stack gas, % by volume (dry	80	80
Total H_2O collected in impingers and silica gel, ml	11.7	11.3
Volume of water vapor collected at standard conditions, * m^3	0.0156	0.0150
Moisture in stack gas, % by volume	1.14	1.15
Gas molecular weight, dry basis, g/g-mole	28.80	28.80
Gas molecular weight, wet basis, g/g-mole	28.68	28.68
Volume of dry gas sampled at meter conditions, m^3	1.409	1.316
Average gas meter temperatue, ^oC	35.0	27.3
Absolute barometric pressure, cm Hg	75.79	75.79
Average orifice pressure drop, cm H_2O	11.94	7.57
Volume of dry gas sampled at standard conditions, * m^3	1.353	1.290

Run No. 3 (continued)

	Baghouse Inlet	Baghouse Outlet
Average stack gas temperature, ^{o}C	26.7	28.3
Absolute stack gas pressure, cm Hg	75.79	75.79
Stack gas velocity at stack conditions, m/sec	7.84	19.02
Dry stack gas volumetric flow rate at standard conditions,* m^3/min	736	813
Isokinetic sampling, %	94	62
Particulate weight: filter, mg	15.3	0.0
Particulate weight: probe and cyclone, mg	13.0	29.6
Particulate weight: impingers, mg	9.3	9.6
Total particulate weight, mg	37.6	39.2
Total particulate concentration at standard conditions,* g/m^3	0.0277	0.0304
Total particulate emission rate, kg/hr	1.23	1.48

*Standard conditions: $T = 20^{o}$ C, p = 76.0 cm Hg.

A-3. LINEAR LEAST SQUARES REGRESSION ANALYSIS

To fit data with a linear equation of the form,

$$y = a + bx$$

the optimal technique is to find the values of a and b which minimize the sum of the squares of the deviations from the actual data points (20). The best values of the coefficients a and b are mathematically,

$$a = \frac{\Sigma x_i^2 \Sigma y_i - \Sigma x_i \Sigma(x_i y_i)}{N \Sigma x_i^2 - (\Sigma x_i)^2}$$

$$b = \frac{N \Sigma(x_i y_i) - \Sigma x_i \Sigma y_i}{N \Sigma x_i^2 - (\Sigma x_i)^2}$$

where N is the total number of data points.

The best fit least squares line for four cases was calculated using the data points listed in Table 5-1.. The results were as follows:

Case 1. Kettle emissions (Y) vs. Process weight (X):

$$y = 0.53 + 0.010\ x$$

Case 2. Control device emissions (y) vs. Process weight (x):

$$y = 0.55 - 0.028\ x$$

Case 3. Kettle and control device emissions (y) vs. Process weight (x):

$$y = 0.54 - 0.009x$$

Case 4. Kettle and control device emission (y) vs. Process weight (x), neglecting the (11.81, 0.65) and (11.81, 0.30) data points:

$$y = 0.58 - 0.024x$$

As can be seen, there was no significant difference in considering the kettle and control device emissions separately (Cases 1 and 2). Likewise, neglecting the two data points at the very high process weight (11.81 metric ton/hr) did not change the best fit line significantly (Case 4). In all cases, there was very little dependence on the process weight (x), indicating that galvanizing emissions are essentially independent of the process weight.

A-4. ADDRESSES OF TESTED GALVANIZING PLANTS

1. Test Date: 2/13/57
   Anchor Post Products, Inc.
   620 Putman Drive
   Whittier, Ca.

2. Test Dates: 3/17/59; 3/26/59
   Superior Pacific Galvanizing Company
   1711 East 61st Street
   Los Angeles, Ca.

3. Test Dates: 10/22/58; 9/14/59
   Advance Galvanizing Company
   5232 Alcoa Avenue
   Vernon, Ca.

4. Test Date: 3/10/59
   Western Galvanizing Company
   2701 South Soto Street
   Los Angeles, Ca.

5. Test Dates: 4/16/59; 4/30/70
   Emsco Steel Products Company
   6811 Alameda Street
   Los Angeles, Ca.

6. Test Dates: 5/11/59; 12/2/75; 12/3/75
   Los Angeles Galvanizing Company
   2524 East 52nd Street
   Huntington Park, Ca. 90255

7. Test Date: 2/24/72
   Davis Wire Corporation
   6315 Bandini Boulevard
   Los Angeles Ca. 90040

8. Test Date: 6/6/73
   Joslyn-Pacific Company
   2226 East Dominguez St.
   Long Beach, Ca. 90810

9. Test Date: 10/15/73
   Western Galvanizing Company
   9719 Santa Fe Springs Road
   Santa Fe Springs, Ca. 90670

10. Test Date: 4/4/74
    Emsco Galvanizing Company
    7001 South Alameda St.
    Huntington Park, Ca. 90255

11. Test Date: 2/5/70
    Triangle Conduit and Cable Company
    Western Steel Conduit Division
    1666 Willow Pass Road
    Pittsburg, Ca. 94565

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16. ABSTRACT A literature review and source tests were performed in order to accurately characterize emissions from hot-dip galvanizing processes. Particulate emission data from seventeen source tests on hot-dip galvanizing plants were considered relevant in developing an emission factor for galvanizing kettles. There was no significant difference between kettle emissions and emissions from control devices. Considering both kettle and control device emissions as one data base, two types of emission factors were calculated:

(1) An emission factor based on process weight, equal to 0.26 kg/metric ton galvanized product (σ =0.28), or assuming 8% zinc by weight in the galvanized product, 3.3 kg/metric ton zinc used (σ = 3.5).

(2) An emission factor based on the hours of kettle operation, equal to 0.51 kg/hr per kettle (σ = 0.44).

Using the derived emission factors, the total amount of particulate emissions produced by hot-dip galvanizing operations in the United States is estimated to be approximately 1,600 metric tons per year.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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