

CHARACTERIZATION OF PARTICULATES AND LEAD IN A BRASS FOUNDRY  
USING A CLOSE CAPTURE EXHAUST SYSTEM

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ABSTRACT

Housekeeping, work practices, layout of facilities, and ventilation controls have a substantial impact on lead levels in brass melting and pouring operations. The study reported here was undertaken to characterize lead levels in a brass foundry employing Hawley ventilation systems to control fume emissions during furnace operations, as well as hot metal transport and mold pouring of an alloy containing 5% lead. Personal exposures ranged from 57 - 173  $\mu\text{g}/\text{m}^3$ , depending on the work task involved. The overall average personal lead concentration was 110 $\mu\text{g}/\text{m}^3$ . Measurements of particle size distribution and segregation of lead among the particle sizes in the samples are also reported.

INTRODUCTION

General Considerations

This paper will address the problems that brass foundries face in reaching the low lead level required by OSHA (time-weighted-average of 50 $\mu\text{g}/\text{m}^3$ ). After many years of observing foundry and brass mill operations, we can point to many variables to be overcome in reducing airborne particulate to acceptable and safe levels.

The problem of housekeeping is a contributor to high lead levels: floors may be dust laden; lead-bearing dust can drift down from ceiling beams and overhead cranes.

The problem of work practices and layout of facilities presents a variety of difficulties that contribute to high lead levels. These can relate to widely separated pouring and melting operations, methods of ladle transport, ways of operating different kinds of furnaces or a variety of methods for charging furnaces (by hand, by shovel, by barrels, by chutes or by drop bottom buckets). There can also be difficulties caused by worker attitudes.

When the term engineering control is used it usually relates to exhaust systems designed to capture and control airborne contaminants. In the past the foundry industry had little concern about the amount of air discharged from a building. Installation of a canopy hood or roof exhauster might have been considered as making progress in clearing away dust and smoke. Air was cheap; energy to power big fans was no problem; and fuel to heat make-up air was plentiful. Unfortunately, these things are no longer true. Today the cost of cleaning dirty air is very expensive. Consequently, we have learned how to conserve the amount of air being discharged that has to be cleaned on the outside and replaced on the inside.

The average cost of installing a complete hood and duct system five years ago together with air pollution control equipment on the outside cost \$1.50/m<sup>3</sup>/hr (\$2.50/cfm). Today, the expense of cleaning air has doubled and it is still increasing every year. Reducing the amount of air to be exhausted is important. If a company can save 34,000m<sup>3</sup>/hr (20,000 cfm), it means \$50,000 to \$100,000 when the cost of air pollution control equipment is considered. This savings can be put back into capital budgets for productive equipment.

Canopy hoods for melting, pouring, and shakeout use many times more air than necessary and seldom are effective. Experience has shown that lead particulate levels can be controlled most effectively by capturing and exhausting brass fume at the source using close-capture, high velocity hoods with in-draft velocities sufficiently high to entrain fume which rises in the thermal draft.

Control of fume during both hot metal transport and pouring operations is possible with a close-capture hood coupled to a mobile exhaust system. Only 3400 m<sup>3</sup>/hr (2000 cfm) per ladle may be needed to clean up an entire room, with subsequent shut down of most of the roof ventilators, thus reducing the waste of reheating outside air.

Reduction of lead levels can be obtained in ways that will save money on total systems by conserving on exhaust air volumes. It results in reducing the size and cost of air pollution control equipment and the amount of heated make-up air needed to make systems operate efficiently, thus lowering the cost of fuel and energy.

The last thing a worker wants to be wearing, when pulling or pushing a heavy ladle of hot metal, is a respirator. Keeping the exhaust systems, fans, and baghouses well-maintained and in good repair will help to assure the worker's personal protection and good health.

#### A Study to Quantify Particulate and Lead Concentrations

Remembering that good housekeeping, work practices, and plant layout also play a big part in holding lead levels to a minimum, we can ask how effective can engineering controls be? Keeping in mind the problems with many variables that exist from one foundry to another, Hawley wanted to know what results might be attainable under normal rates of foundry production. Therefore, Dr. Robert B. Jacko was asked to conduct a study to characterize

the particulates and lead fume in a brass foundry employing a mobile ventilation system. The following measurements were made:

1. Workplace concentrations of total suspended particulates and lead fume by taking personal samples in areas of highest expected lead concentrations.
2. General area concentration of particulates and lead fume.
3. Particulate and lead aero-dynamic particle size distribution in two critical areas of the foundry.

#### PROCESS AND FACILITY DESCRIPTION

The facility chosen for study was a modern brass foundry employing electric induction-type furnaces. The general layout of the furnace and pouring lines is shown in Figure 1. Molten metal is transported via 136 Kg (300 lb) ladles to each of three pouring lines labeled as lines "A", "B", and "C" in Figure 1. The lead content in the alloy being melted and poured was 5% by weight during all tests.

The entire furnace and pouring area is controlled for particulates and fume with both a fixed and mobile arrangement of Hawley ventilation hoods. The fixed ventilation hoods are attached to each of the furnaces and control particulates during charging, meltdown and tapping.

A separate mobile ventilation system is employed to control fume from the individual ladles as they are charged at the furnace, transported to the mold pouring area, and poured at the mold pouring line. In this way total particulate control is maintained in the workplace for all molten metal operations.

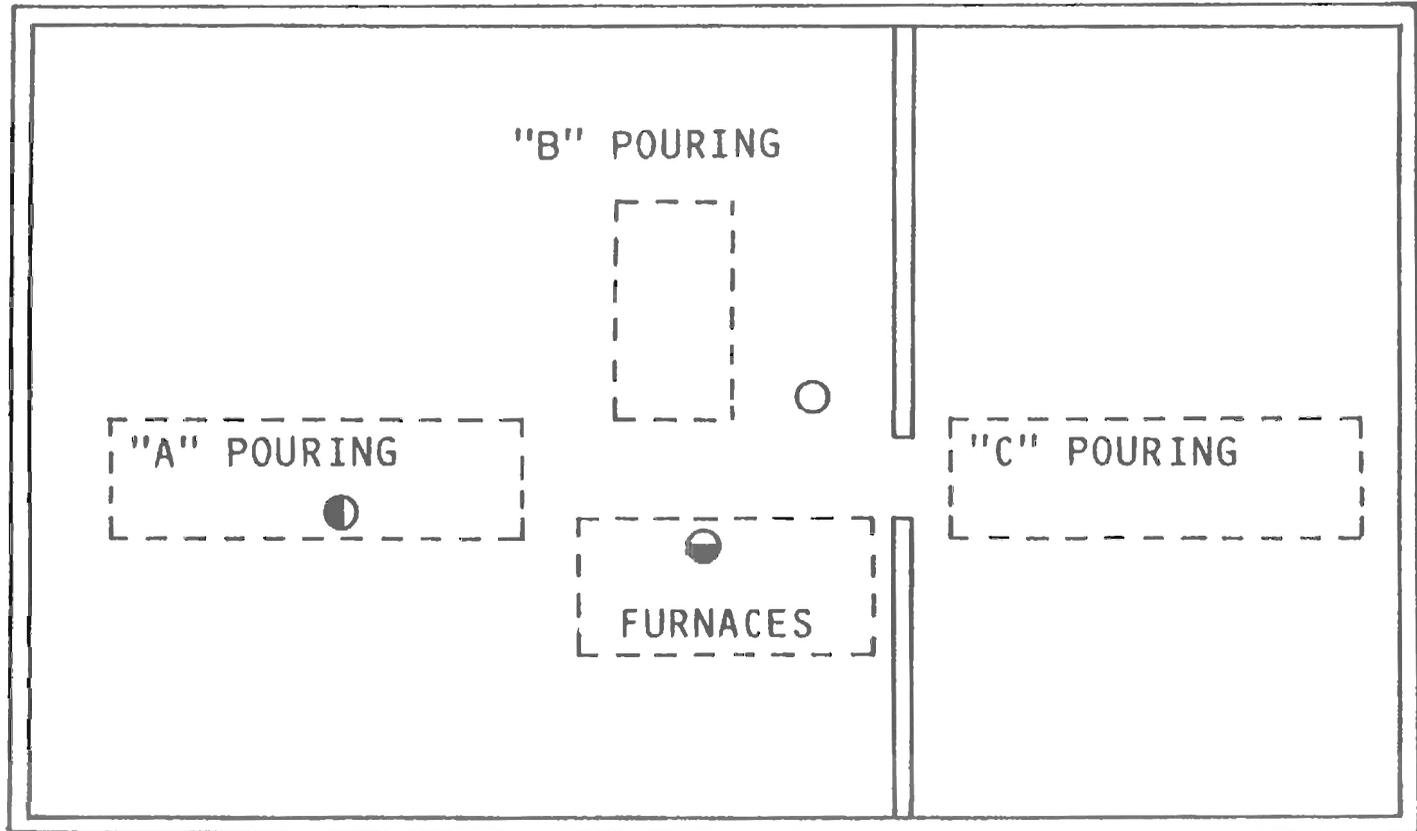
#### EXPERIMENTAL PROCEDURE

##### Sampling Methodology

Eight-hour personal and area air samples were taken throughout the foundry where molten metal operations were in progress. In this area three tasks are carried out and have been identified as the furnace charger, ladle pourer and the pourer's helper. These workers perform tasks which place them in the areas of highest expected concentrations of lead fume.

The furnace charger is responsible for the electric furnace operation. This worker is, for the most part, adjacent to the furnace during the work day. Charging, meltdown, and tapping are his major functions.

The ladle pourer transports the ladle to and from the furnaces and molds. Throughout this operation a mobile ventilation hood travels with the ladle, thus reducing worker exposure to fume. The ladle pourer has assistance from a worker described as the pourer's helper. This involves movement of the ladle, slag removal and, depending on the work load, pouring.



- LEGEND ○ BACKGROUND TSP SAMPLE  
● FURNACE AREA TSP AND SIZE DIST. SAMPLE  
● POURING AREA TSP AND SIZE DIST. SAMPLE

Figure 1. Brass foundry layout.

Personal samples were taken in accordance with NIOSH Method No. S341 for lead and inorganic lead compounds. Eight hour personal samples were taken at a flow rate of 1.5 liters/min. into a 37 mm diameter three piece cassette filter holder using 37 mm/0.8 micrometer mixed cellulose ester membrane filters. The filter was supported by a cellulose backup pad. Both RAC and MSA sample pumps and rotameters were utilized. The rotameters were calibrated with a soap film flowmeter prior to the testing program.

Sampling strategy was such that each of the worker categories defined earlier was sampled three times. In this way, a greater confidence can be placed on the averaged particulate and lead concentration values.

In addition to the personal samples, a number of area samples were taken at fixed locations. A high volume air sample was taken just north of the furnace area (refer to Figure 1). Particle size distribution samples were taken in the "A" pouring line area and the furnace area. Overall, three high volume total suspended particulate samples and two particle size distribution samples were taken.

The area sample taken north of the furnaces in the core storage area was taken over the 8 hour period of the first shift as were all samples. The sample flow rate was 14 liters/min and the 37 mm cassette filter holder inlet orifice was enlarged proportionally. In this way, the entrance velocity to the filter was the same as the personal samples and no particle size bias therefore occurred.

The size distribution samples in the furnace and "A" pouring line areas were taken with a seven stage Andersen impactor. The same sampling head and flow rates were used for both samples. The impactor was equipped with a backup filter. The average flow rate for the size distribution samples was approximately 20 liters/min.

The study was conducted in the fall and because of the cool temperatures, overhead and other access doors were closed. The foundry was in essence a "closed environment .

#### Sample Analysis

All filters were analyzed gravimetrically according to standard procedures. The handling of the 37 mm cassettes was in accordance with NIOSH Method No. S341.

The samples were prepared for lead analysis by digestion in nitric acid. Five milliliters of concentrated analytical reagent grade acid were added to each sample in a 125 ml Ehrlemeyer flask. Each flask was covered with a watch glass and heated at low temperature on a hotplate until complete digestion was observed, usually in about 12 hours. The resulting solutions were then filtered through 0.45 micron membrane filters and diluted to 100 ml in volumetric flasks using glass distilled deionized water.

Measurement of the metals was accomplished using a Perkin Elmer atomic absorption spectrometer, model 5000, utilizing the background detection option. Five standards of lead prepared using Harleco (trademark) concentrated atomic absorption standards and dilute nitric acid solution, and a blank

option. Five standards of lead prepared using Harleco (trademark) concentrated atomic absorption standards and dilute nitric acid solution, and a blank standard of the dilute acid solution were used in preparing calibration curves for lead. Solutions were diluted when necessary so that the resulting concentrations fell within the range of the standards. Concentrations were calculated using a least squares linear regression method. A clean filter pad, handled in the same way as the actual particulate filter pads, was also analyzed for lead.

The particle size samples were also analyzed gravimetrically for total particulates and then for lead. In this way total particulates as well as segregation of lead among the particle sizes could be determined.

## RESULTS AND DISCUSSION

### Personal Air Samples

Table 1 contains the results of the 8-hour personal samples for total suspended particulate (TSP) and lead fume concentration. All samples were taken during the first shift and reflect normal work activities under typical process load conditions. Note in Table 1 that the total suspended particulate concentration was relatively low, ranging from 1.05 to 5.36 mg/m<sup>3</sup>. The pourer receives the lowest average TSP concentration of 1.83 mg/m<sup>3</sup> followed by the charger at 2.36 mg/m<sup>3</sup> with the pourer's helper receiving the highest TSP concentration of 3.72 mg/m<sup>3</sup>.

The corresponding lead concentration in Table 1 shows that the charger receives the lowest average lead concentration of 90.3 µg/m<sup>3</sup> followed by the pourer at 97.5 µg/m<sup>3</sup>. The highest lead concentration and the highest TSP concentration is received by the pourer's helper. The variations are attributed to a number of factors, among them: differences in ventilation at each work station, differences in production rates on each line, differences in task being performed, and differences in work habits of each employee.

In the case of the pourer's helper, as compared to the pourer and the charger, the higher exposure is probably due to a different work task. The helper is usually following the pouring ladle and as such comes into contact with any plume that is emitted from the ladle as it is moved.

Table 2 contains a summary of the personal TSP and lead concentrations. It is clear that the pourer's helper receives the highest concentration of 142 µg lead/m<sup>3</sup>. It should be mentioned that the pourer's helper in this study is a unique work task not necessarily found in other foundries. The pourer and the charger are the more common work tasks found in most other brass foundries and it is interesting to note that both are below 100 µg lead/m<sup>3</sup>.

The overall average personal TSP and lead concentrations are 2.64 mg/m<sup>3</sup> and 110 µg/m<sup>3</sup>, respectively, for the three worker categories sampled.

Table 1. Secondary brass foundry  
personal air samples for particulates and lead

Task	Total suspended particulate concentration, milligrams/m <sup>3</sup>	Lead concentration, micrograms/m <sup>3</sup>
Pourer:		
"A" Line	3.20	141
"B" Line	1.05	57.0
"C" Line	1.25	94.5
	average 1.83	97.5
Pourer's helper:		
"A" Line	2.30	111
"A" Line	3.49	141
"A" Line	5.36	173
	average 3.72	142
Charger:		
Furnace area	1.61	84.8
Furnace area	3.10	95.8
	average 2.36	90.3

8-hour samples, 1st shift, per NIOSH method no. S341.

Table 2. Secondary brass foundry  
summary of personal air samples  
for particulates and lead.

Task	Total suspended particulates, milligrams/m <sup>3</sup>	Lead concentration, micrograms/m <sup>3</sup>
Pourer	1.83	97.5
Pourer's helper	3.72	142.0
Charger	2.36	90.3
	Overall avg. 2.64	110.0

#### Area Samples

Table 3 contains ambient background concentrations of TSP and lead. Fixed in space samples were taken in the core storage, furnace, and pouring areas as previously discussed and shown in Figure 1. These samples were taken over the 8-hour first shift at a relatively high sampling rate and, therefore, represent a relatively large volume of sampled air. For this reason, these samples are considered to be very representative of each respective area. Note that the TSP concentration was relatively constant, ranging from 2.53 to 3.23 mg/m<sup>3</sup>, with an overall average of 2.77 mg/m<sup>3</sup>.

Table 3. Secondary brass foundry ambient area concentrations of total particulates and lead.

	Total suspended particulates, milligrams/m <sup>3</sup>	Lead concentration, micrograms/m <sup>3</sup>
Core storage <sup>1</sup>	2.54	71.6
Furnace area <sup>2</sup>	2.53	98.0
Pouring area <sup>3</sup>	3.23	76.7
average	2.77	82.1

<sup>1</sup>8-hour hi-volume sample, total volume = 6.8m<sup>3</sup>, rate = 14 liters/min.

<sup>2</sup>8-hour hi-volume sample, total volume = 11.0m<sup>3</sup>, rate = 22.8 liters/min.

<sup>3</sup>8-hour hi-volume sample, total volume = 11.7m<sup>3</sup>, rate = 23.9 liters/min.

The lead concentration was highest in the furnace area at 98µg/m<sup>3</sup> followed by the pouring area at 76.7µg/m<sup>3</sup> and lowest in the core storage area with 71.6µg/m<sup>3</sup>. These values suggest that the background lead concentration is highest near the furnaces and decreases as the distance from the furnaces increases, which is a reasonable expectation.

#### Aerodynamic Particle Size Distribution

Figures 2, 3, and 4 contain the aerodynamic particle size distributions of the suspended particulates in the pouring and furnace areas. These areas are shown in Figure 1, along with the sampling site location. In Figure 2, the TSP size distribution indicates that the mass median diameter is 8 microns in the pouring area. The size distribution in the furnace area (Figure 3) is very similar and shows a mass median diameter of 10 microns. The similarity of the two distributions is further evident in Figure 4 where the data from both distributions is plotted. The aggregate size distribution indicates a mass median diameter of 9 microns. The aggregate distribution indicates that 13% by weight of the pouring and furnace area particulate matter is less than 2 microns aerodynamic diameter.

The aggregate mass median diameter of 9 microns is relatively large considering that metallic fume is typically submicron in size. Since these background samples were taken not in the near vicinity of fume formation, agglomeration of the submicron particulate into larger sizes may be responsible for the high mass median diameter. In addition, since most of the fume is controlled in close capture hoods and the use of sand is prevalent throughout the foundry, the large diameter may reflect the general foundry sand particulate matter, although this is probably not the case as will be discussed shortly.

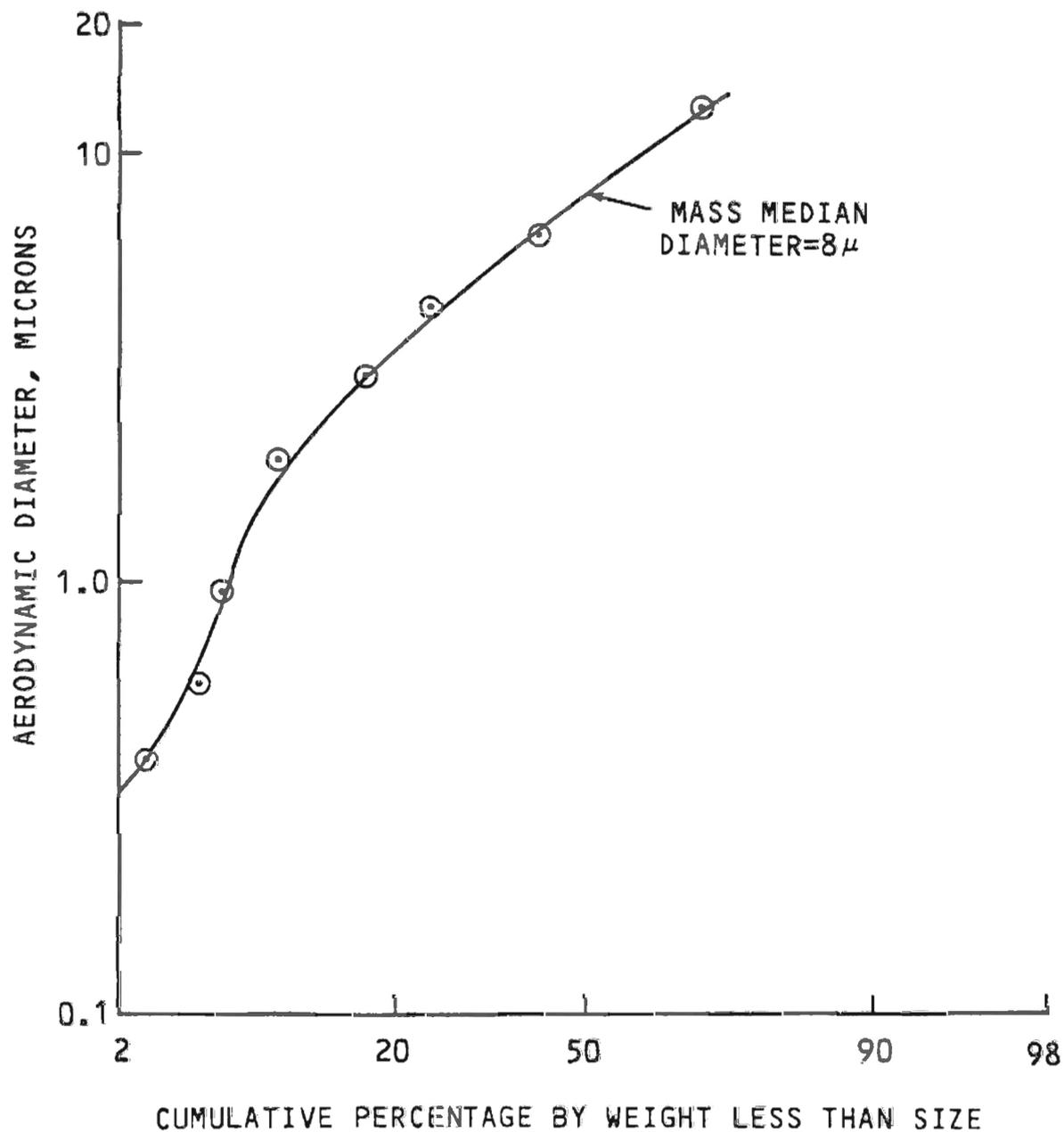


Figure 2. Aerodynamic particle size distribution in pouring area.

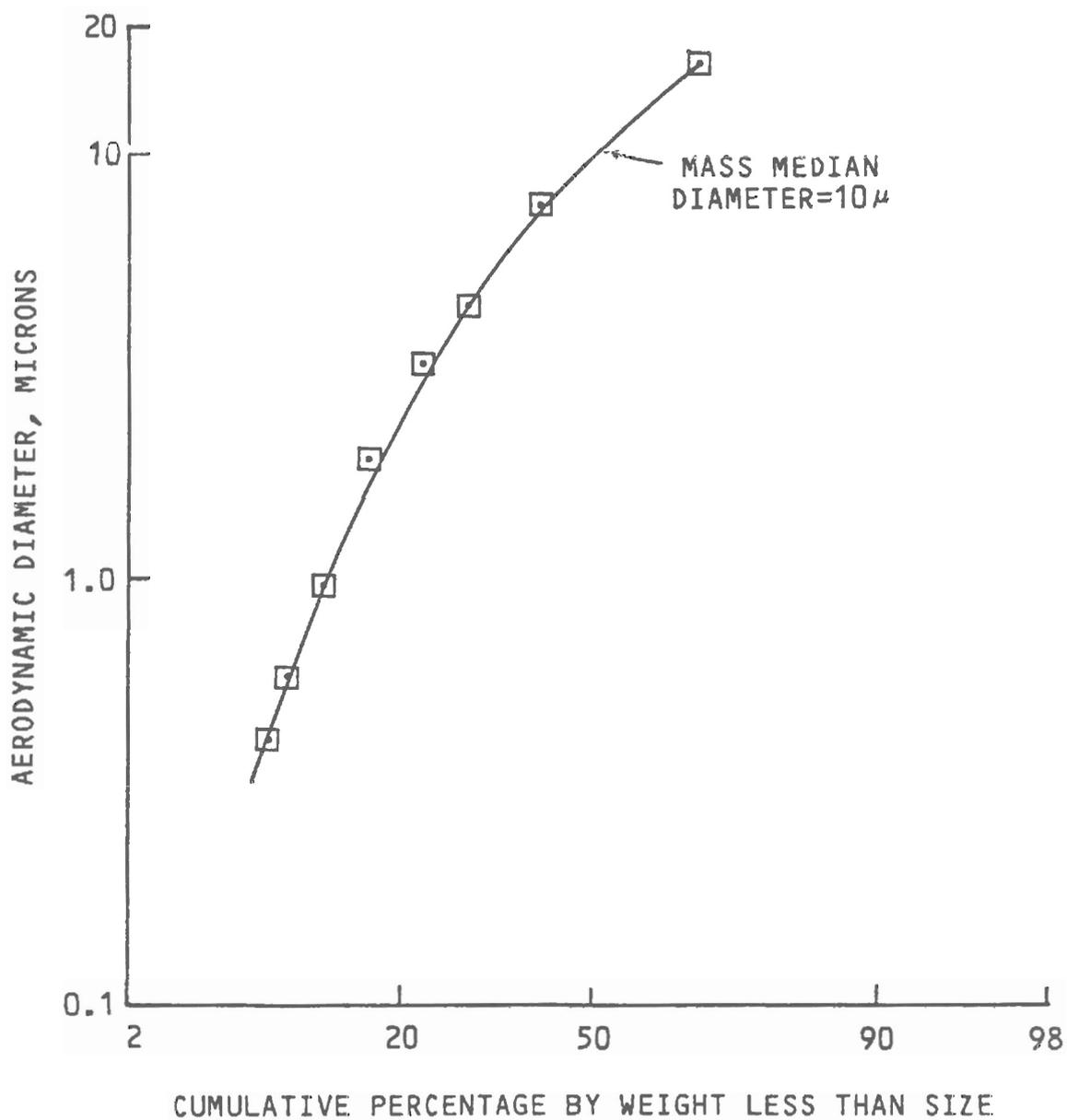


Figure 3. Aerodynamic particle size distribution in furnace area.

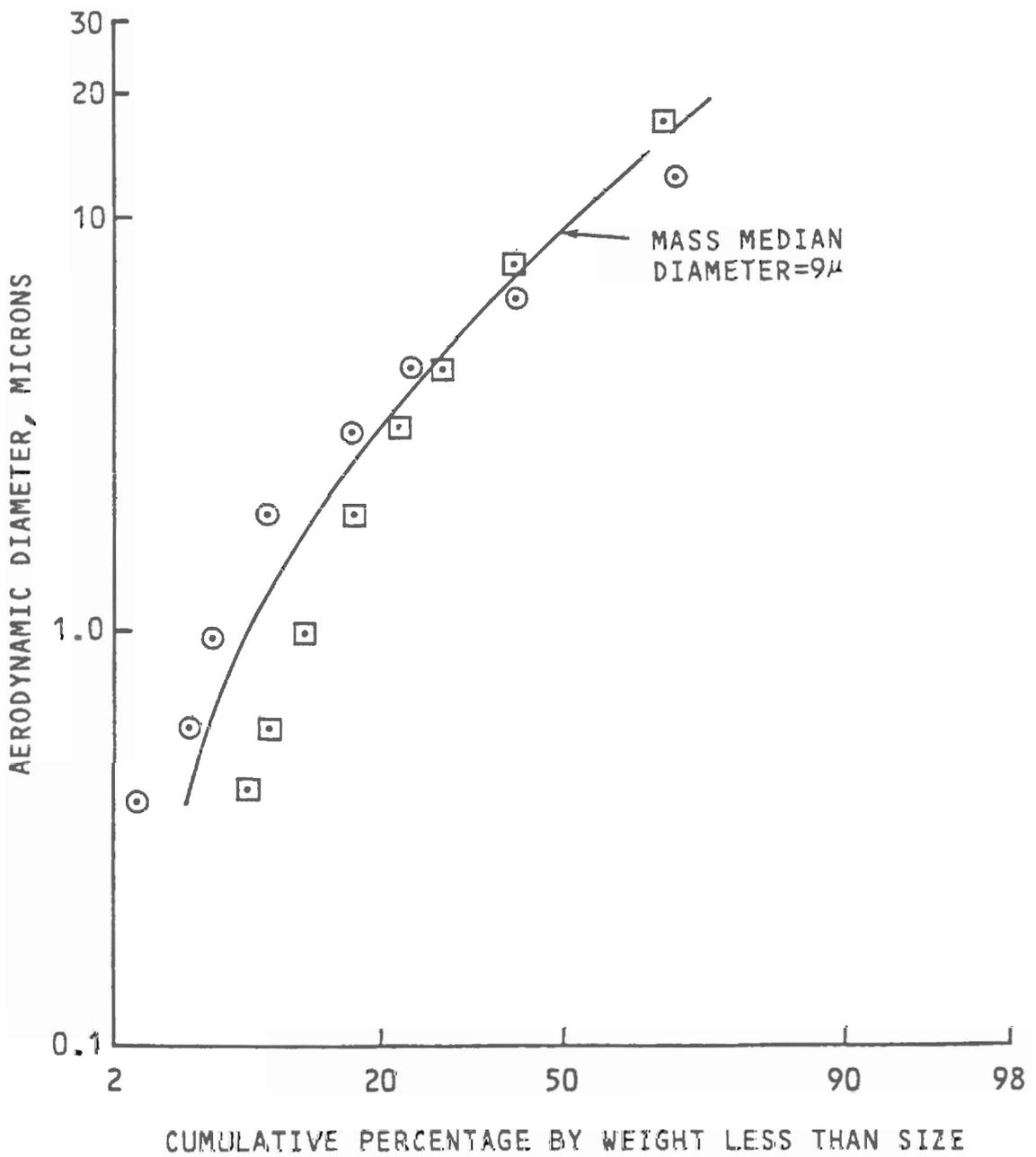


Figure 4. Aggregate aerodynamic particle size distribution of furnace and pouring area.

## Lead Distribution in Particle Sizes

Figure 5 shows the percentage of lead found at each particle size in the Andersen impactor. As a percentage of the total particulate, the lead is seen to increase markedly below a 2 micron aerodynamic diameter. Note that the lead percentage increases from about 2% at a 2 micron diameter to more than 20% lead at a 0.5 micron particle diameter. Lead fume is typically submicron in nature and, therefore, the smaller particulate matter would be expected to have a high percentage of lead. The second reason is that small non-lead particulate matter has a relatively high surface-area-to-volume ratio and acts as an effective adsorber for smaller lead fume and as nucleation sites for lead vapor condensation. This segregation of toxic metals in the smaller particle sizes has been found in other studies (2, 3).

Beyond a 2 micron aerodynamic diameter (Figure 5) the lead percentage appears to be on the increase in the furnace area and from 2 to 6 microns in the pouring area. This lead percentage increase may be due to agglomeration of the less than 2 micron particles of high % lead into larger apparent particles above 2 microns.

Expressing the lead as a concentration in air with the units  $\mu\text{g-Pb}/\text{m}^3\text{-air}$  and plotting these values versus aerodynamic diameter is shown in Figures 6 and 7. In addition to the sharp lead concentration increase below a 2 micron diameter, which has already been explained, a rapid increase is also evident above the 3 to 4 micron diameter range. This rapid lead concentration increase in the larger sizes is due to agglomeration of particles less than 2 microns in diameter into larger apparent particles. Furthermore, the unexpected large mass median diameter of 9 microns from the size distribution plot in Figure 4 is answered by this agglomeration phenomenon evident in Figures 6 and 7.

### SUMMARY

This study has shown that a close capture exhaust system can be relatively effective in reducing TSP and lead concentrations in a brass foundry. It must be pointed out, however, that the TSP and lead concentrations and particle size distributions reported here are unique to the brass foundry studied. Extrapolations or interpretations of this data to other foundries must be made with great care and a full realization that no two foundries are alike.

Specific results are as follows:

1. Personal samples indicated that total suspended particulates ranged from  $1.05 \text{ mg}/\text{m}^3$  to  $5.36 \text{ mg}/\text{m}^3$  depending on the worker task involved.
2. Personal lead samples indicated a range from  $57 \mu\text{g}/\text{m}^3$  to  $173 \mu\text{g}/\text{m}^3$ , depending on the worker task involved. The overall average personal lead concentration was  $110 \mu\text{g}/\text{m}^3$ .

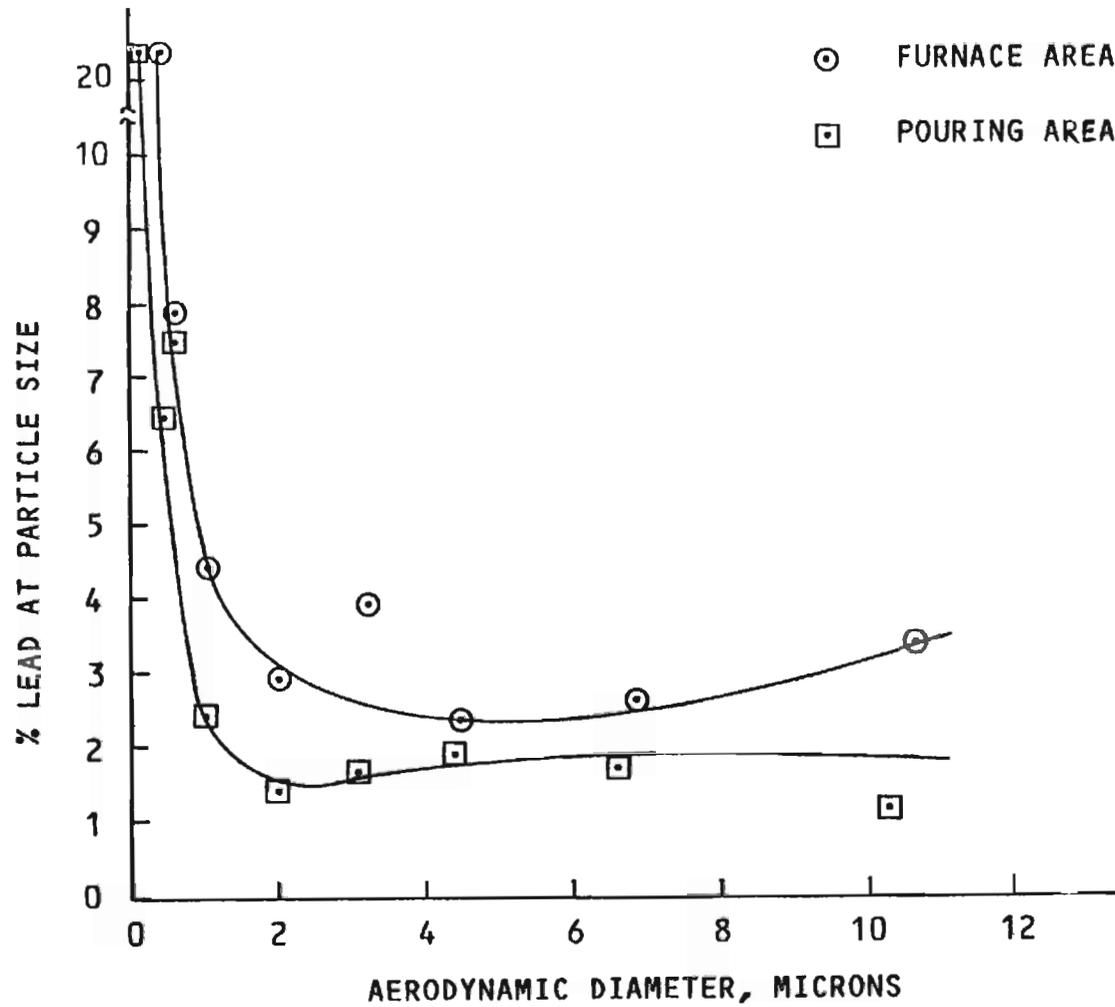


Figure 5. Aerodynamic particle size distribution of lead in brass foundry melting area.

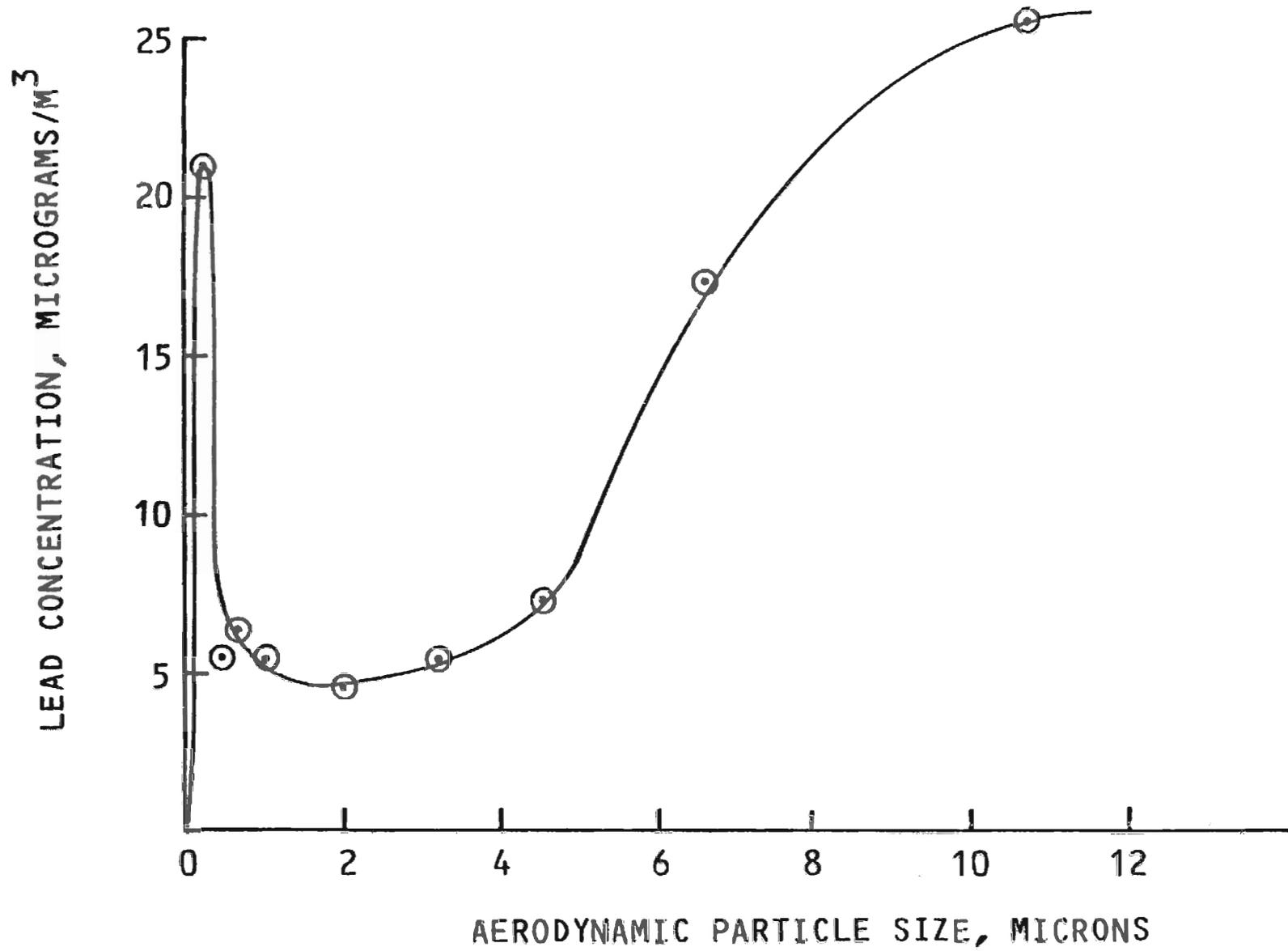


Figure 6. Lead concentration among particle sizes in the furnace area.

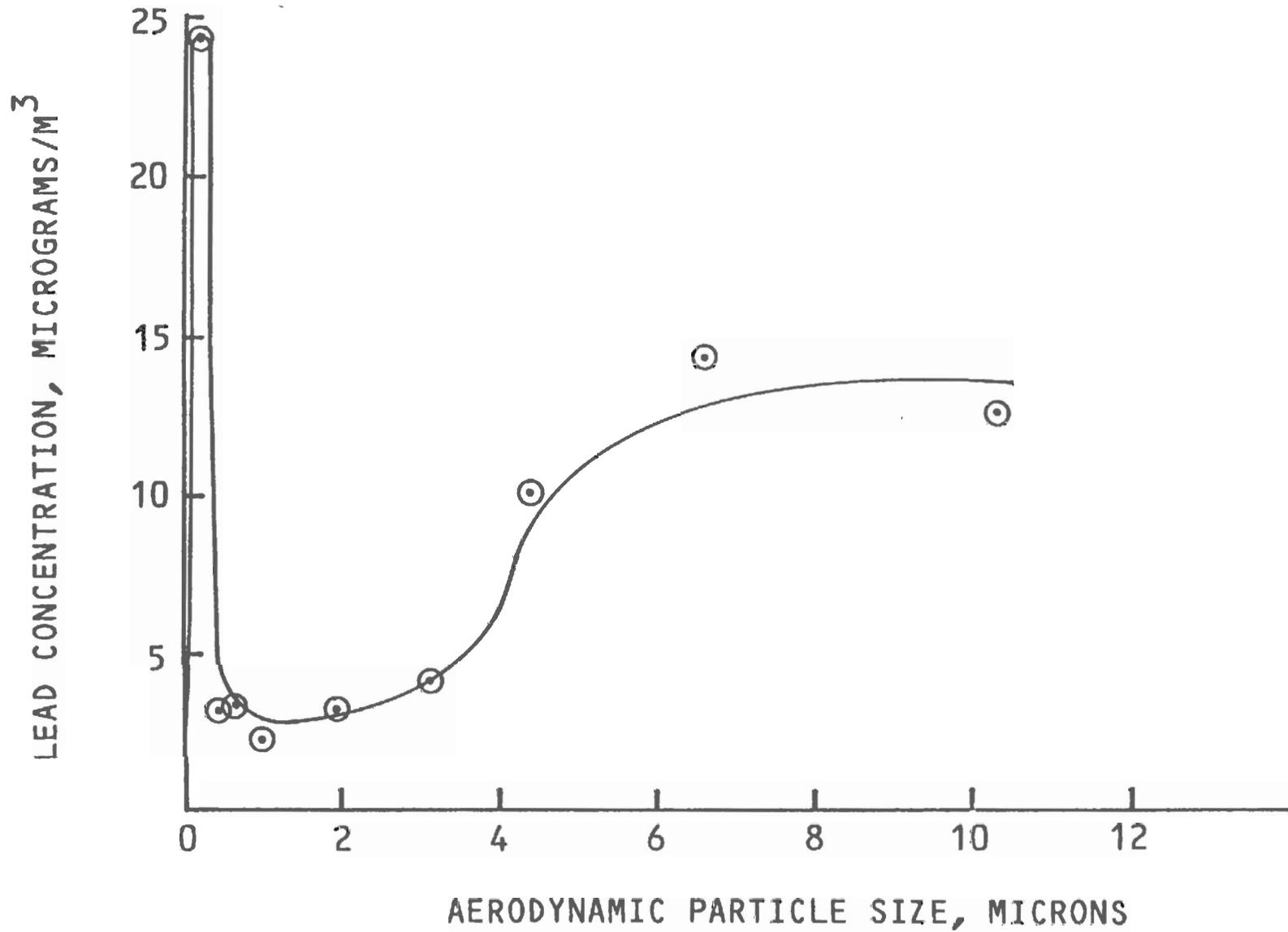


Figure 7. Lead concentration among particle sizes in the pouring area.

3. Area TSP concentrations ranged from 2.53 mg/m<sup>3</sup> to 3.23 mg/m<sup>3</sup> with an average of 2.77 mg/m<sup>3</sup>.
4. Background lead concentrations ranged from 71.6 µg/m<sup>3</sup> to 98 µg/m<sup>3</sup> and averaged 82.1 µg/m<sup>3</sup>. As expected, lead area concentrations were highest in the furnace area and decreased with distance from the furnace.
5. Area particle size distributions were very similar in the pouring and furnace areas. Aggregate particle size distributions indicated the aerodynamic mass median diameter to be 9 microns. The large mass median diameter was attributed to agglomeration of fine particulates.
6. The distribution of lead among the particle sizes expressed as a percentage by weight of the total particulate at that size indicated a strong segregation of lead in the particle sizes less than a 2 micron diameter. In the submicron size range the lead percentage exceeded 20%. Submicron lead fume and effective adsorption of lead vapor and fume on the fine non-lead particulate are given as the reasons for this segregation.
7. Lead air concentration increased sharply at the submicron sizes and above the 3 to 4 micron diameter range. The rise in lead in the submicron sizes is attributed to lead fume and non-lead particulate adsorption of lead vapors and fume. The lead increase in the larger sizes is attributed to agglomeration of the submicron, high lead particulate into larger apparent sizes. This agglomeration also answers the unexpected large mass median particle diameter of 9 microns.

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3. Greenberg, R. R., Gordon, G. E., Zoller, W. H., Jacko, R. B., Neuendorf, D. W., and Yost, K. J., "Composition of Particles Emitted from the Nicosia Municipal Incinerator", Environmental Science and Technology, Vol. 12, No. 12, November 1978.

QUESTIONS, ANSWERS AND COMMENTARY

Question (G. Mosher, American Foundrymen's Society):

Was the same alloy poured during all of the air sampling or did the alloy change?

Answer (R. Jacko):

I am not sure what the variation was, but the average lead content was 5%. (Editor's note: The point was later confirmed by R. Overmyer that the lead content in the brass was consistently 5% during all the tests. This statement appears in the technical paper submitted for publication).

Comment (R. Wilson, PEDCO Environmental, Inc.):

I have a comment for Mr. Overmyer and an admonition for the audience.

I'm glad to see people such as Hawley bringing out the close capture systems because they work extremely well. My admonition to the audience is to do a good job on your own system analysis. And I have a particular example.

This is not to cast any stones at Hawley or any other close capture manufacturer. But I'm working with a brass foundry right now that installed a close capture system and solved their lead problem very nicely. But the equipment manufacturer installed the fan right out in the middle of the foundry floor up on a pedestal, adding one more ninety-five dBA source into the room and bringing another OSHA citation.

The fan was put there to shorten the ductwork on the suction side of the fan so that they could get by with a less expensive fan. This worked fine for the manufacturer and not so well for the foundry.

My advice to foundry operators is to do your own inhouse work and consider putting your own very stringent noise and other requirements on your specification to the suppliers.

In other words, make them prove to you that they re not going to create another problem for you by solving one.

Editor s note: The next question is in regard to a concluding comment made by Dr. Jacko after presenting his summary results.

"Most of the brass foundry people that I've talked to using the close-capture system feel that enactment of standards below the levels that we have measured here with very good engineering practice, may well be unrealistic .

Question (M. Lane, Davy McKee Corp).

You stated at the end of your conclusions, that you felt that lower lead levels were impractical from what was achieved. Do you feel that they're impossible or should we still strive to meet the 50  $\mu\text{g}/\text{m}^3$  level?

Dr. Jacko:

It would be ludicrous for me to say that anything is impossible. The term that I used was "unrealistic". After looking at the data and becoming intimately involved with the system and seeing how it operated, that it is a state-of-the-art technique, I felt that at this point in time it would be unrealistic to enact standards that would be much lower than the levels that I measured. This was my observation after analyzing the data.

PROCEEDINGS OF THE SYMPOSIUM ON OCCUPATIONAL HEALTH  
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