Scand J Work Environ Health 1976;2(1):42-49

<https://doi.org/10.5271/sjweh.2833>

Issue date: 1976

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Key terms: [foundry](#); [metal analysis](#); [metal fume](#)

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/968464

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Metal fumes in foundries

by ANTTI TOSSAVAINEN, Lic.Sc. (Eng.)¹

TOSSAVAINEN, A. Metal fumes in foundries. *Scand. j. work environ. & health* 2 (1976): suppl. 1, 42—49. The metal content of melting and casting fumes was analyzed with X-ray fluorescence, atomic absorption, and mass spectrometric methods. The composition of fumes varied with the kind of alloy, the quality of scrap, and the type of melting process. In addition foundry workers' exposure to metal fumes was evaluated. The measurements of airborne metal concentrations in 10 steel foundries, 15 iron foundries, and 11 copper alloy foundries showed that exposure to lead, copper, and zinc may present a health hazard.

Key words: metal analysis, metal fumes, foundry.

Metal fumes are formed by the evaporation, condensation, and oxidation of metals in air. In foundries furnace tenders, melters, casters, ladlemen, pourers, and crane operators are exposed to the smoke and fumes from molten metal.

The total emission of smoke and fumes depends upon the quality of the scrap charged. If the scrap contains large quantities of impurities, high concentrations of organic and inorganic compounds are emitted to the workroom air, unless the exhaust system is extremely efficient.

Inorganic material emitted from furnaces, ladles, and castings in iron foundries is primarily composed of oxides of iron, manganese, calcium, magnesium, aluminium, and silicon. The fumes of steel melting contain the same oxides plus those of chromium and nickel. Table 1 shows the composition of dust sam-

ples from an electric furnace shop in a steel foundry (7).

In iron and steel foundries, the oxides of lead and zinc are the predominant minor constituents in the fumes (3, 6, 8). Lead and zinc come from galvanized or painted scrap and from nonferrous alloys or automation steels that are occasionally present in the charge. Table 2 presents estimates of minor constituents in fumes from electric arc furnaces (15). Neutron activation analyses have indicated the presence of 34 elements in cast iron fumes (21).

The pyrolysis of oil, grease, and rubber in the furnace during the melting and the decomposition of the organic ingredients of molding sand in the casting process may produce a complex mixture of organic compounds, including polyaromatic hydrocarbons (13, 17).

In the melting of metals various types of furnaces are used, e.g., cupolas, electric arc and electric induction furnaces, and each has its own emission problems. Most of the cast iron produced in Finland is melted in cupolas, which emit mainly such gases as carbon dioxide, carbon

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monoxide, sulfur dioxide, nitrogen, and oxygen (16). The flue gas volume from an electric furnace is low, except when oxygen is lanced into the furnace, but the furnace workers may be exposed to extremely fine metal oxide with 90 to 95 % of the particles below 0.5 μm in size (6). Exposure to zinc and other metals around the electric furnaces is likely to be so high that the installation and maintenance of efficient fume collection equipment is necessary (2, 4, 5, 12).

In the production of nodular iron abundant metal fumes are released by the triggering process. The composition of this smoke and its effect on man were investigated by Vanhoorne et al. (21). The subjects showed a decrease in vital capacity shortly after exposure to the smoke.

In a British study of industrial lung diseases of iron and steel foundry workers it was concluded that after some years furnace workers develop abnormal X-ray appearances, probably due to siderosis, and that the abnormal changes are more pronounced in steel furnacemen than in furnacemen in iron foundries (14).

The melting of copper alloys in induction furnaces or crucibles heated by oil burners may present health hazards due

to the high concentration of zinc, copper, and lead oxides in the fumes. One such health hazard, zinc fume fever or "Brass founder's ague," which occurs from inhaling metal fumes, especially zinc oxide, has been described by Drinker (9). Several observers have found that, although concentrations of zinc fume rarely exceed

Table 1. Chemical analysis range of electric furnace dust (7).

Component	Range (%)
Fe ₂ O ₃	19—44
FeO	4—10
Total Fe	16—36
SiO ₂	2—9
Al ₂ O ₃	1—13
CaO	5—22
MgO	2—15
MnO	3—12
Cr ₂ O ₃	0—12
CuO	< 1
NiO	0—3
PbO	0—4
ZnO	0—44
Alkalis	1—11
P	< 1
S	< 1
C	2—4

Table 2. Qualitative spectrochemical analysis of fumes from electric arc furnaces (15).

Element	Concentration Range (%)		
	Plant A	Plant B	Plant C
Iron	5 — 50	Major constituent	Major constituent
Calcium	3 — 30	0.05 — 0.05	0.05 — 0.50
Silicon	0.10 — 1.00	2.0 — 20	2.0 — 20
Zinc	0.01 — 0.10	0.30 — 3.0	0.05 — 0.50
Manganese	0.50 — 5	0.20 — 2.0	0.20 — 2.0
Magnesium	0.50 — 5	0.010 — 0.10	0.005 — 0.05
Sodium	0.50 — 5		0.010 — 0.10
Chromium	0.30 — 3.0	0.5 — 0.50	0.10 — 1.00
Nickel	0.05 — 0.50	0.02 — 0.20	0.05 — 0.50
Aluminum	0.05 — 0.50	0.20 — 2.0	0.05 — 0.10
Lead	0.05 — 0.50	0.20 — 2.0	0.01 — 0.10
Molybdenum	0.05 — 0.50	0.005 — 0.05	0.005 — 0.05
Copper	0.02 — 0.20	0.03 — 0.30	0.03 — 0.30
Tin	0.01 — 0.10	0.01 — 0.10	0.01 — 0.10
Titanium	0.0005— 0.005	0.01 — 0.10	0.01 — 0.10
Vanadium	0.005 — 0.05	0.001 — 0.01	0.01 — 0.10
Bismuth	0.005 — 0.05		
Strontium	0.005 — 0.05		
Cobalt	0.0005— 0.005	0.003 — 0.03	0.001 — 0.01
Silver	0.001 — 0.01	0.0005— 0.005	0.0005— 0.005
Cadmium	0.001 — 0.01	0.003 — 0.03	0.0005— 0.005
Potassium	0.30 — 3.0		

Table 3. Number and production of Finnish foundries and the number of foundry workers in 1972.

Type of production	Number of foundries	Annual production (tons)	Number of workers	Number of workers exposed to metal fumes
Steel castings	10	18,000	1,200	150
Iron castings	53	120,000	3,100	300
Copper alloy castings	{ 64	6,600	{ 950	{ 500
Aluminium alloy castings		3,300		
Total	127		5,250	950

15 mg/m³ in nonferrous foundries, metal fume fever frequently occurs in such establishments and has even been reported from foundries with concentrations below 5 mg/m³ (1). Gleason found a condition similar to metal fume fever in workers exposed to metallic copper dust in concentrations of the order of 0.1 mg/m³ (10). It has also been suggested that the increased zinc concentration in the gastric secretion of furnace operators in brass foundries might account, in part, for the gastric complaints among them (11). High blood lead concentrations have also been reported among brass founders (18).

The main objective of the present study was to characterize the metal content of melting and casting fumes from various types of foundries. In addition the exposure of furnace workers to metals was evaluated.

MATERIAL AND METHODS

The metal fume surveys were made in 10 steel foundries, 15 iron foundries, and 11 copper alloy foundries in 1973 and 1974. The number of Finnish foundries and foundry workers and the production of the foundry industry are presented in table 3. The number of workers exposed to metal fumes was estimated after the foundry workers were divided into an exposed and nonexposed group on the basis of job classification. Fettlers and welders were not included in the exposed group because they are mainly exposed to metal fumes from other sources, i.e., from welding and flame cutting activities.

Sampling

Three types of particulate monitoring samplers were used in the study. High-volume samplers (sampling rate 500 l/min) with Delbag Microsorb polystyrene filters and low-volume samplers (sampling rate 20 l/min) with Millipore membrane filters were operated at fixed positions in the melting and casting areas. The worker's exposure to dust was measured by means of personal samplers (sampling rate 2 l/min) equipped with Millipore filters. In each foundry a number of air samplers were in operation during two work shifts. The accuracy and precision of the sampling instruments and dust exposure estimates have been discussed elsewhere (20).

Analysis of dust samples

The present investigation was directed partly toward ascertaining which of the elements present in metal fumes can be

Table 4. Relative standard deviation of the X-ray fluorescence analyses in comparison to corresponding atomic absorption analyses. (Number of samples analyzed = 120)

Metal analyzed	Relative standard deviation (%)
Lead	13.7
Zinc	14.3
Copper	13.2
Nickel	15.8
Iron	15.4
Manganese	18.4

determined to the desired precision and accuracy at the expected level of contamination. Atomic absorption, X-ray fluorescence, and mass spectroscopic methods were found suitable for determining several major and trace components of the particulate matter collected on a filter.

Atomic absorption analysis requires destruction of the filter and dissolution of the dust sample. For the wet ashing and dissolving, nitric acid and hydrochloric acid were used. The solubilities of the 10 metals analyzed (calcium, chromium, manganese, iron, cobalt, nickel, copper, zinc, cadmium, and lead) were over 95 %, except when calcium, chromium, or iron were present as compounds coming

from foundry sand. The interferences in the analysis were established as less than 15 % for most of the metal fume samples (19).

X-ray fluorescence spectrometry can nondestructively analyze dust samples without the need for chemical processing. The method was applied in determining 23 elements heavier than silicon in the high-volume samples. The X-ray methodology was based on the mathematical correction of the sample matrix effect.

The agreement between the atomic absorption and the X-ray fluorescence analyses was very satisfactory. A comparison of the methods is presented in table 4. The mean standard deviation in per cent was calculated by:

Table 5. Composition of metal fumes in high-volume samples. Average percentage concentrations of the elements in samples collected in the work areas of furnacemen. (SI = steel foundry, electric induction furnace; SA = steel foundry, electric arc furnace; II = iron foundry, electric induction furnace; IC = iron foundry, cupola; CC = copper alloy foundry, crucible; AA = atomic absorption analysis; RF = X-ray fluorescence analysis)

Element	Average concentration (%)					Analytical method
	SI	SA	II	IC	CC	
Lead	1.2	1.7	0.78	0.70	2.5	AA
Barium	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	RF
Antimony	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	RF
Tin	< 0.05	< 0.05	< 0.05	< 0.05	1.6	RF
Cadmium	0.006	0.019	0.004	0.002	0.033	AA
Silver	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	RF
Molybdenum	< 0.03	0.15	< 0.03	< 0.03	< 0.03	RF
Zirconium	2.1	0.57	0.35	0.11	0.01	RF
Strontium	0.01	0.02	< 0.01	< 0.01	< 0.01	RF
Zinc	2.0	7.8	4.1	0.84	24.4	AA ^a
Copper	0.097	0.10	0.078	0.049	4.0	AA
Nickel	0.15	0.045	0.038	0.013	0.020	AA
Cobalt	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	AA
Iron	10.2	15.5	20.5	11.3	2.0	AA
Manganese	1.7	2.6	2.1	0.50	0.071	AA
Chromium	1.4	0.30	0.19	0.029	0.021	RF
Chromium ^a	0.13	0.082	0.043	0.013	0.013	AA
Titanium	0.098	0.060	0.092	0.25	0.046	RF
Calcium ^a	3.5	11.2	3.0	1.4	1.7	AA
Potassium	1.0	1.7	0.7	2.0	1.2	RF
Sulfur	0.11	0.22	0.57	0.63	1.5	RF
Phosphorus	0.29	0.52	0.18	0.33	0.69	RF
Silicon	20	15	20	30	15	RF
Number of foundries	7	3	6	12	12	
Number of samples	35	32	42	19	36	AA
	31	21	40	12	24	RF

^a Acid soluble.

$$SD = 100 \sqrt{\frac{1}{2n} \sum_i \left(\frac{C_{RF} - C_{AA}}{C_{AA}} \right)_i^2},$$

where C_{RF} = concentration obtained from the X-ray analysis, C_{AA} = concentration obtained from the atomic absorption analysis, and n = number of samples. The standard deviation is primarily affected by the precisions of the two methods. There

was no systematic difference, except in cases of the previously mentioned limited solubility.

The accuracy of the trace element determinations was checked also by spark-source mass spectrometry. X-ray diffraction was used for the identification of crystalline compounds in the fume samples. These analytical methods have been described in detail elsewhere (19).

Table 6. Composition of metal fumes (ppm) determined in spark source mass spectroscopic analyses of typical fume samples. (SA = steel foundry, electric arc furnace; SI = steel foundry, electric induction furnace; CC = copper alloy foundry, crucible)

Element	SA sample 1	SA sample 2	SI	CC
Bismuth	20	80	100	10
Lead	20,000	30,000	8,300	1,000
Wolfram	10	30	50	100
Hafnium	5	10	800	5
Dysprosium	5	5	10	30
Neodymium	10	20	30	20
Praseodymium	5	5	50	20
Lanthanum	5	10	30	60
Barium	150	700	1,000	700
Cesium	30	80	20	150
Iodine	20	10	20	70
Tellurium	5	5	5	5
Antimony	100	200	1,500	300
Tin	700	1,000	800	500
Indium	5	10	20	15
Silver	60	150	350	30
Molybdenum	150	100	500	200
Niobium	10	30	70	20
Zirconium	80	200	35,000	100
Strontium	100	400	800	1,000
Rubidium	300	1,000	800	1,200
Bromine	200	500	500	400
Selenium	50	90	70	50
Arsenic	500	1,000	1,300	700
Germanium	50	30	150	100
Gallium	50	100	200	100
Zinc	40,000	9,000	1,800	1,200
Copper	730	1,600	1,000	150
Nickel	300	400	500	50
Cobalt	200	300	500	400
Iron	90,000	150,000	100,000	100,000
Manganese	12,000	15,000	10,000	8,000
Chromium	400	700	1,600	400
Vanadium	150	250	300	400
Titanium	300	700	1,500	1,000
Scandium	20	30	10	20
Calcium	> 10,000	> 10,000	> 10,000	> 10,000
Potassium	> 10,000	> 10,000	> 10,000	> 10,000
Chlorine	1,000	1,000	1,000	5,000
Sulfur	5,000	5,000	3,000	10,000
Phosphorus	5,000	5,000	5,000	5,000
Silicon	> 100,000	> 100,000	> 100,000	> 50,000
Aluminium	> 100,000	> 100,000	> 100,000	> 100,000
Magnesium	> 10,000	> 10,000	> 10,000	> 50,000
Sodium	> 10,000	> 10,000	> 10,000	> 10,000
Fluorine	1,000	1,000	500	500

Table 7. Average metal concentrations in the air ($\mu\text{g}/\text{m}^3$) and the percentage of samples exceeding (exc.) the threshold limit value (TLV) during melting and casting — Personal sampling. (SI = steel foundry, electric induction furnace; SA = steel foundry, electric arc furnace; II = iron foundry, electric induction furnace; IC = iron foundry, cupola; CC = copper alloy foundry, crucible)

Metal	TLV $\mu\text{g}/\text{m}^3$	SI		SA		II		IC		CC	
		Mean	% exc. TLV	Mean	% exc. TLV	Mean	% exc. TLV	Mean	% exc. TLV	Mean	% exc. TLV
Lead	150	50	8	49	10	41	5	15	0	100	25
Cadmium	10	< 2	0	< 2	0	< 2	0	< 2	0	1.0	0
Zinc	4,000	110	0	220	0	220	0	47	0	880	5
Copper	100	8.3	0	5.8	0	7.9	0	9.2	0	210	53
Nickel	1,000	10.9	0	2.0	0	< 5	0	< 5	0	< 5	0
Cobalt	100	< 5	0	< 5	0	< 5	0	< 5	0	< 5	0
Iron	7,000	1,050	0	620	0	1,590	3	860	0	120	0
Manganese	5,000	80	0	190	0	130	0	32	0	1.3	0
Chromium ^a	1,000	5	0	6	0	3	0	4	0	1	0
Calcium ^a		150		710		230		140		84	
Total dust	10,000	5,100	4	6,100	14	8,600	36	10,000	39	6,700	20
Number of foundries		7		3		7		10		11	
Number of samples		23		22		41		26		59	

^a Acid soluble.

RESULTS

Composition of metal fumes

The composition of fumes varied not only with the kind of metal melted, such as carbon steel, high alloy steel, cast iron, bronze, or brass, but also with the quality of scrap used and the type of melting process (table 5). Table 6 shows the concentrations of the 46 elements found in four typical fume samples examined by semiquantitative mass spectroscopy. The results are comparable with earlier analyses (21) (tables 1 and 2). The compounds identified by X-ray diffraction were iron oxides (Fe_2O_3 , Fe_3O_4), manganese oxide (Mn_3O_4), zinc oxide (ZnO), and calcium oxide (CaO). In addition molding and parting materials (quartz, feldspar, chromite, olivine, zircon, talc or graphite) were found in the dust samples taken from the different work areas.

The count median particle diameter of the fumes and dust was determined to be below $1\ \mu\text{m}$ by light microscopy. The number of dust count samples was 60;

they were taken from 15 foundries. The type of melting process did not seem to have an appreciable effect upon the distribution of the particle size.

Metal concentrations in the ambient air during melting and casting operations

The average metal concentrations in the ambient air, as measured by personal samplers during various melting processes, are presented in table 7. The percentage of samples with concentrations exceeding the Finnish threshold limit value (TLV) for workroom air is also shown in the table. The sampling period was 6 h during a work shift. The prevalence of overexposure to lead, i.e., exposure to levels over the TLV of $150\ \mu\text{g}/\text{m}^3$, among the exposed was from 5 to 10 % in steel and iron melting with electric furnaces and 25 % in copper alloy melting and casting. In the copper alloy foundries, the prevalence of workers exposed excessively (levels above the TLV of $100\ \mu\text{g}/\text{m}^3$) to copper was 53 %, and

Table 8. Temporal variation of airborne metal concentrations during melting and casting. (Logarithmic standard deviation of concentrations)

Metal	Personal sampling (6-h period)	Low-volume sampling (6-h period)	High-volume sampling (1.4-h period)
Lead	0.23	0.31	0.28
Zinc	0.26	0.28	0.34
Copper	0.21	0.24	0.25
Iron	0.20	0.21	0.24
Manganese	0.25	0.27	0.33
Chromium ^a	0.21	0.25	0.25
Calcium ^a	0.21	0.25	0.29
Average of metals	0.23	0.26	0.29
Total dust	0.18	0.16	0.20
Degrees of freedom	51	45	101

^a Acid soluble.

that of workers with overexposure (above the TLV of 4,000 $\mu\text{g}/\text{m}^3$) to zinc, 5 %. These prevalence figures are based on the assumption that the use of a uniform sampling scheme in each foundry produced a representative and unbiased sample.

The temporal variation of a contaminant concentration in an environment, as measured by repeated sampling, is described by the logarithmic standard deviation of the samples, i.e., the standard deviation of the logarithms of the concentrations. The log-normal distribution of concentrations in time may be applied to the statistical treatment of air sampling data when an estimation is made of the confidence intervals of the sampling results or when the prevalence of different exposure levels is estimated for a group of workers (20). The logarithmic standard deviations of metal concentrations during melting and casting are presented in table 8. The remarkable stability of the parameter can be noted. The calculations showed that the standard deviations were mainly affected by the characteristics of the melting process and the contaminant, as well as the length of the sampling period, and to a lesser degree by the precision of the dust sampling devices and metal analyses.

CONCLUSIONS

Analysis of the measurements of airborne metal concentrations from 36 foundries revealed that exposure to lead, copper, and zinc may present an appreciable health hazard to workers during melting and casting operations. This finding and the high blood lead concentrations found in furnace workers have resulted in the recommendation of periodical health examinations for melters and casters in cases when iron or steel scrap is melted in electric induction or electric arc furnaces and when copper alloy castings are melted, poured, or ground.

It is important that workers' exposure to metal fumes be prevented. Enclosing the furnace, removing the fumes during pouring and casting with efficient local exhaust systems, and attending to the general ventilation of melting and casting areas are all procedures which should help prevent such exposure.

ACKNOWLEDGMENTS

The author wishes to thank Mr. Juhani Ruishalme for his technical assistance.

This study has been aided by grants from the Finnish Foundation for the Advancement of Engineering and the Finnish Cultural Foundation.

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