A mini-sampler for welding aerosol mounted in close vicinity of the mouth/nose

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Abstract. A small personal aerosol mini-sampler to be used inside modern welding visors has been developed. The main object of the mini-sampler has been to sample manganese. The sampler is based on commercially available 13 mm filter holders but modified to incorporate an inlet nozzle made of aluminium. The nominal flow rate of the mini-sampler is 0.75 l/min. The sampler is to be worn mounted on a headset, modified from professional microphone headsets. The headset mounting arrangement was accepted by the welders. The sampling bias of the mini sampler versus the IOM sampler depends on the coarseness of the sampled aerosol. At the lowest concentration ratio of the open-face 25 mm filter holder to the IOM sampler equal to 0.65, the bias of the mini sampler is approximately -26% versus the IOM. The RMS sampling bias of the mini sampler versus the IOM sampler for manganese is -4.6%. The inhalable fraction of welding aerosol mass consists only of 25-55% of welding fume. The rest of the mass is made up of spatter particles and grinding particles. For manganese generally more than 65% is found in the fume.

1. Introduction

Personal aerosol sampling at workplaces is performed with the samplers mounted in what is termed the breathing zone, generally defined as a hemisphere with its centre between the nose and mouth and with a 25 or 30 cm radius. This definition accepts samplers mounted both at the lapel/collar and at the top of the head. Many scientific reports have demonstrated that the concentration of a workplace air pollutant in general is not constant within this zone [1-8]. Several suggestions have been presented over the years to sample aerosols closer to the mouth/nose [9-14]. Of these only HSL’s measurement procedure for resin acids in solder fume seems to have gained wider application [14].

In welding sampling has for a long time preferably been carried out with samplers mounted at the lapel/collar bone. Since the early seventies only a few investigations have been published on the possible concentration bias between samplers mounted behind the welders visor and at the lapel/collar [15, 16]. With the adoption of the international standard on the sampling of welding fumes [17] several countries have begun changing the mounting of samplers. Chung et al. [18] investigated the relationship between the concentration sampled by several different samplers mounted behind a welders visor and the concentration inhaled by a breathing (inhalation only) mannequin during welding.

In this paper the design and validation of a headset-mounted mini-sampler for manganese in welding aerosols is described.
2. Background
The Swedish Work Environment Authority (SWEA) decided to reduce the occupational exposure limit (OEL) for manganese sampled as total dust from 400 $\mu$g/m$^3$ to 200 $\mu$g/m$^3$. This change became effective as of 1 January 2007. Welders were considered as practically the only occupation for which the new OEL might require measures to reduce the exposure. Due to the low value of the new OEL it was considered necessary to investigate whether the sampling position could be changed from close to the lapel/collar bone to inside the welder’s visor. This would make it more reasonable to assume that the sampler actually sampled from the air actually inhaled by the welder. This would also comply with the ISO standard for welding fume, ISO 10882-1. [17]

3. Methods and materials
The collection efficiency of the mini sampler was determined by static parallel sampling with the IOM sampler and the open-face 25 mm filter holder at five welding plants. The practical usability of the headset-mounted mini sampler was evaluated by personal sampling at three welding plants.

3.1. The mini-sampler
The mini sampler is based on the 13 mm Swinnex filter holder. The filter holder has been modified from being a closed-face filter holder to being a open-face filter holder by incorporating an entry nozzle in aluminium with an inner diameter of 10 mm and a length of 9 mm. In the work reported here Millipore 13 mm mixed cellulose ester (MCE) filters with a nominal pore size of 8 $\mu$m (SCWP) have been used. In this work the nominal flow rate has been 0.75 l/min, generally as low as the pumps used were able to operate for 6-8 h.

3.2. Headset mounting systems
Four different commercial headsets with professional microphones intended for musicians, TV commentators etc. were bought; IsoMax HH (Countryman), WH20QTR (Shure), HT2 (AUDIX) and C420III (AKG). These models were all hung over the ears with a mounting around the back of the head, but not over the top of the head, and with a beam holding the microphone close to the mouth. The mounting around the back of the head is needed to increase the vertical and lateral stability of the beam. The headsets were stripped of the microphone and the electrical cables. A PVC tubing was fastened with shrinking tubing onto the beam of each headset. The headset mounting system allowed the welder to work with or without the visor, with the visor in the up or down position, and to wear ear protectors (either inside the ear canal or as an ear-muff), and still the sampler could be sturdy positioned close to the mouth/nose.

3.3. Visited plants
The mini sampler has been evaluated at five manufacturing companies (A – E) based on welding. Static rig sampling was performed at all five plants. Personal sampling was performed on 5-10 of the welders at plants C – E. MIG welding was the main type of welding performed at the plants.

3.4. Aerosol sampling
Static rig parallel sampling was performed with the mini-sampler, the IOM sampler, the Millipore open-face 25 mm filter holder (FH25OF) and SIMPEDS cyclones operated at the flow rate 5 l/min in order to obtain information on the fraction of particles smaller than 2 $\mu$m. The air flow was supplied by personal sampling pumps of various makes, for the mini-sampler the AirChek2000 (SKC) was used.

Personal sampling was carried out only with headset-mounted mini-samplers behind the welder’s visor. Apex pumps (Casella) were employed for the personal sampling with the mini-sampler. In total, 43 personal samples were taken on 23 welders over 34 work shifts.
3.5. Static rig sampling
The static rig sampling was performed with horizontal rods mounted on a vertical rod. The horizontal rods were mounted approximately in the height of the breathing zone of a standing man. On each rod were two samplers mounted on each side of the vertical rod. The rig was not rotated but at some workplaces was turned at regular intervals. The total number of samplers of the different types mounted in the rig varied between plants. In each test 5-12 mini-samplers were compared to five samplers each of FH25OF and IOM samplers. All filter samples were weighed and selected samples additionally analysed by inductively coupled plasma/mass spectrometry (ICP/MS) and/or by portable X-ray fluorescence spectrometers (XRFS).

The concentration ratio FH25OF/IOM is used as an indicator of the coarseness of the sampled aerosol, and be termed the “aerosol coarseness ratio”.

3.6. Laboratory analyses

3.6.1. Filter weighing. The collection substrates were weighed before and after sampling in an air-conditioned room using a MT5 balance. The temperature is controlled to 21±0.5°C and the relative humidity to 50±2%. Tests were performed to determine the weighing uncertainty of 13 mm filters having been mounted in the mini-sampler for 2-3, 10 and 15 weeks.

3.6.2. Analyses for manganese by ICP/MS and XRFS. For each run with the rig one sample per cyclone flow rate and two filter samples each for the IOM sampler and the FH25OF were selected for analysis with ICP/MS. Some static samples and most of the personal samples were analysed by XFRS, Niton XLT-700.

3.6.3. Transport test of loaded 13 mm filters mounted in mini-samplers. Loss of the deposit from filters mounted in mini-samplers by ordinary mail has been determined. Twenty samples each from plants C – E, were collected by static sampling with five different nominal flow rates. After sampling the mini-samplers were transported to the weighing lab, weighed and mounted anew in the original mini-samplers. Then the samplers were packed in a padded envelope and sent by ordinary mail a distance of approximately 500 km and back again. Upon return the filters were weighed anew. The transport loss was determined as the change in sample weight between the second and the first weighing.

4. Results

4.1. Static sampling
At the first run at plant B the concentration was approximately 20 mg/m³, and almost all pumps had stopped within one hour. With the exception of run B#1, the measured inhalable welding aerosol concentrations are in the range 0.7-3.3 mg/m³. The standard deviations for the IOM sampler, the FH25OF and the mini sampler are generally in the range 2-10%, apart from the first run at plant A.

The biases between the mini-sampler, the IOM sampler and the FH25OF are generally twice as large for welding aerosol mass as for manganese.

Proper welding fume (submicron particles or at least particles smaller than 2 µm) at these workplaces did not constitute more than 25-55% of the inhalable fraction, the rest is particles generated by spattering, grinding or slagging. Proper manganese fume for all but one run at the workplaces at plants C – E constituted more than 88% of the inhalable manganese.

4.2. Laboratory evaluations of the mini-sampler

4.2.1. Precision of weighing for 13 mm MCE filters with nominal pore size 8 µm mounted in mini-samplers for a period of two to fifteen weeks. The pooled standard deviation for weighing 13 mm fil-
ters mounted in mini-samplers was 2.2 µg. The standard deviation did not increase with longer shelf life between weighing. This corresponds to a limit of quantification of 22 µg.

4.2.2. Transport loss. The maximum filter loadings obtained for this experiment were 0.9, 1.5 and 0.8 mg, for plants C – E respectively, and the lowest loading was 10 µg (plant E). The minimum and maximum values of the transport loss are -5 and +19 µg, respectively. The average transport loss is 3.7 µg with a standard error of 0.6 µg. The RMS transport loss is 6.0 µg.

4.3. Bias of the mini-sampler versus the IOM sampler

Figure 1 shows the dependence of the concentration ratio of the mini sampler to the IOM sampler for welding aerosol mass and manganese on the aerosol coarseness ratio for each substance. The mini sampler undersamples relative to the IOM sampler, significantly for aerosol mass, but much less for manganese as the coarseness ratio for manganese is closer to unity. The regression line plotted is forced through \((x; y) = (1;1)\) and has been determined by the model

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\left(1 - \frac{C_{\text{mS}}}{C_{\text{IOM}}}\right) = k \left(1 - \frac{C_{\text{FH25OF}}}{C_{\text{IOM}}}\right)
\]

where \(C_{\text{mS}}, C_{\text{IOM}}\) and \(C_{\text{FH25OF}}\) are the concentration (welding aerosol mass and manganese respectively) for the mini-sampler, the IOM sampler and the open-face 25 mm filter holder, respectively. The obtained value for the regression coefficient \((k)\) is 0.750, and for the residual standard deviation 0.051, respectively.

![Figure 1](image)

Figure 1. Concentration ratio mini sampler/IOM sampler for welding aerosol mass and manganese versus the aerosol coarseness ratio for each substance. NB! Only the filter of the IOM sampling cassette has been analysed for manganese.

4.4. Personal sampling

Samplers mounted on a modified headset were accepted by the welders. No big problems were encountered by the welders, even though they at rare occasions had to take them off or on by themselves, for example sometimes when going to the lavatory or at a coffee break. None of the headsets broke during this project. Distributions of personal samples of welding aerosol mass and manganese are shown in figure 2. The limits of quantification for mass (gravimetric) and manganese (XRFS) were
0.022 and 0.004 mg, respectively. Only the lowest manganese sample was below the corresponding limit of quantification. For five of the welders did the exposure on eight of nine sampled shifts exceed the current Swedish OEL for manganese, 0.2 mg/m³.

![Figure 2. Distribution of personal 43 samples for welding aerosol mass and manganese](image)

### 5. Discussion

#### 5.1. The headset

It has been shown that aerosol sampling by a mini sampler mounted on a headset behind a welders visor is possible and does not unduly disturb the welders. Of the four tested versions, three were possible to mount in such a way that they were not felt uncomfortable by the welders. Headset-mounted samplers is preferable to the mounting arrangements shown in the year 2000 edition of the EN ISO 10882-1 standard on sampling airborne particles during welding⁹ as the sampler is positioned close to the mouth/nose whether the visor or other face shield is worn or not, and whether it is in the up or down position.

#### 5.2. Uncertainties of sample analyses versus sample transport loss

The weighing uncertainty for 13 mm filters was found to be 2.2 µg, considerably less than the uncertainty due to transport by ordinary mail, 6.0 µg. Both of these uncertainties are small compared to the amount of welding aerosol mass obtained by personal sampling in this project, which are at least 25 times larger than the transport uncertainty. For the personal samples, manganese constituted on average 3.5% of the welding aerosol mass collected, and therefore the transport loss is negligible also for manganese.

#### 5.3. Sampling bias of the mini sampler versus the IOM sampler

##### 5.3.1. Welding aerosol mass

At personal sampling for welding aerosol larger particles can be expected than encountered at static rig sampling. Within a reasonable coarseness ratio range of [0.50;1.00] for the welding aerosol mass, i.e. implying that welding aerosol is not coarser than for example flour dust, the average bias of the mini-sampler, based on the regression model above, would
be -0.193. This bias is so large that in order to use the mini-sampler for sampling inhalable dust, it would first need to somehow be optimized to that sampling convention.

5.3.2. Manganese. Manganese mainly exists as fume and to a minor fraction as spatter particles, but constitutes a negligible fraction of grinding dust. Therefore the range of coarseness ratios to be expected at personal sampling of manganese will be similar to that was encountered in our static sampling, [0.88;1.02]. Within a coarseness ratio range of [0.85;1.00] for manganese, the average bias of the mini sampler, based on the regression model above, would be -0.056. This bias less than 10% need not be further reduced by optimization of the sampler. This bias is of the same order as Chung et al. [18] found among samplers mounted behind a welder’s visor.

6. Conclusions
• Headsets for mounting a mini sampler behind a welder’s visor have been manufactured from commercial headsets and were found to be acceptable by the welders.
• At the visited plants the inhalable fraction of welding aerosol mass only consisted of 25-55% of welding fume. The remainder was welding spatter, grinding dust and slagging dust. However, more than 65% of the manganese is found in the fume proper.
• The mini sampler exhibited for welding aerosol mass a negative bias versus the IOM sampler. The value of the sampling bias depended on the coarseness of the welding aerosol sampled. For a coarser welding aerosol the absolute value of the bias increased. For a welding aerosol with an aerosol coarseness ratio of 0.65, the bias of the mini sampler versus the IOM sampler was approximately -0.26.
• The weighing precision for 13 mm MCE filters was found to be 2.2 µg and the RMS transport losses of 13 mm filters mounted in mini samplers transported by mail 500 km there and back was 6.0 µg. Both of these values are small compared to the range of personal samples collected.
• The sampling bias of the mini sampler versus the IOM sampler for manganese was for all eight sampled welding aerosols numerically less than -0.14, and does not depend on the aerosol coarseness ratio of the sampled manganese aerosol. The average sampling bias of the mini sampler versus the IOM sampler for manganese, (with a negative RMS value of -0.046) is not statistically significant.

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