

A new measuring method to detect the emissions of metal working fluid mist

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Abstract

During metal machining the rotating machine tool or grinding wheel is generating fine droplets and vapor which can cause occupational health problems. A new continuous measuring method was developed to detect both droplets and vapor of metalworking fluid mist and to provide information about the droplet size distribution. According to this method, an air sample of the metalworking fluid mist is segregated by impactors of different cut sizes, carried out in several successive passes. In each pass the droplets that are not collected in the impactor are fed into an evaporator that immediately evaporates all droplets, and subsequently the sample is analyzed in-line by a Flame Ionization Detector (FID). By subtraction of the value measured at the respectively next smaller fraction, the oil amount of the metalworking fluid mist found in a certain droplet size range is obtained. The metalworking fluid mist is thus segregated according to the droplet size, and a definite cut size between droplet and vapor can be defined, below which we can say “vapor”. This method was calibrated with Di-2-Ethylhexyl-Sebacat (DEHS) as equivalence substance for further measurements applied on various metalworking fluids.

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1. Introduction

In metal machining operations such as drilling, turning, grinding and milling metalworking fluids (MWF) are used to cool and lubricate tools and workpieces. In addition, the fluids remove metal chips generated by the cut. By reducing heat generation and tool wear, MWFs allow significantly faster machining speeds and therefore increased production rates [1].

Metalworking fluids, also called cutting fluids, machining fluids, or metalworking coolants, are complex mixtures that may contain petroleum products, vegetable and animal fats and a variety of additives to improve their properties. They are utilized either as straight oils or as emulsions of oil in water called “soluble oils”.

MWF can be delivered to the tool–workpiece interface either manually or by an automated system. Flooding, in which the fluid is pumped at low pressure through one or several nozzles directed at the cutting zone, is the most common application method [2]. Application of MWFs during the machining pro-

cess onto the rotating machine tool or grinding wheel generates fine droplets and vapor which can cause occupational health problems.

The National Institute for Occupational Safety and Health (NIOSH) estimates that 1.2 million employees in the United States are potentially exposed to straight oils, with many more exposed to soluble oils [3]. Workers are most commonly exposed to MWFs by inhalation of aerosols and through skin contact, which can cause a variety of health problems. Worker exposure to cutting fluids can result in dermatitis [4] and respiratory problems [5]. Studies indicate that long-term exposure to MWFs can lead to increased incidence of several types of cancer [6].

To reduce the potential health risks associated with MWFs, the U.S. Occupational Safety and Health Administration (OSHA) presently regulates occupational exposures to MWFs. The current permissible exposure limit for mineral oil mists is 5 mg/m³ as an 8-h time-weighted average [7]. NIOSH currently recommends an exposure limit of 0.4 mg/m³ for the thoracic fraction of MWF, which is equivalent to a total particulate mass of 0.5 mg/m³ [8]. The Austrian regulation however currently has separated limits for vapor and mist and differentiates between mineral oil and soluble oil. The exposure limits for mist are presently 5 mg/m³ for mineral oil and 1 mg/m³ for soluble oil.

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Additionally there is a limit of 20 mg/m³ for the sum of vapor and mist valid for mineral oil and soluble oil [9]. In Germany the current exposure limit valid for all MWFs is 10 mg/m³ vapor and mist together [10].

Machine enclosures, local exhaust ventilation and mist collectors are used to reduce metalworking fluid aerosols in the work environment. Ideally, proper ventilation should transport the mist from the generation site to a mist collector for removal of the droplets from the airstream. The clean air could then be recirculated safely to the workroom. The mist however will partially evaporate before reaching the collector [11]. Even if the mist is captured by the collector, some of the oil droplets retained on the collector's filters will partially evaporate as air passes through [12].

Assessment of workplace exposure in plant practice has revealed that exposure limits are often exceeded. So there is a call for action regarding the MWF mist from metal machining and the applied collectors. An appropriate continuous measuring method is a precondition for the assessment of the MWF emissions and the improvement of oil-mist collectors.

2. Current methods

Oil mist can be detected by means of optical particle counting systems, for example using scattered light. But it must be pointed out that with these measuring devices the vapor component of the MWF emission cannot in principal be detected. Furthermore there is always a certain fraction of mist with droplet diameters below the measurement range of these instruments. Consequently optical particle counting systems alone are not sufficient to assess a MWF emission.

To determine the concentrations of both oil mist and vapors currently devices like the American NIOSH Method 5026 [13] or the German BGIA Method 3110 [14] are used. These samplers consist of a filter connected to a downstream adsorbent such as XAD-2 or activated carbon. The airborne mist droplets are collected onto the filter, whereas the gas-phase can pass through the filter and is captured onto the adsorbent. The MWF then is eluted from these two collector phases and subsequently the mass of oil is measured by IR spectroscopic methods.

This procedure is currently used to assess workplace exposure to MWF mist in many countries. But for applying it to measure the mist and vapor emissions from machining and for filter-testing there are some limitations:

- (1) The sampling time of these methods must be long enough to get a sufficient load onto filter and resin. On the other hand the sampling time must be limited to avoid droplets being evaporated after being collected on the filter.
- (2) According to this configuration the cut diameter of the filter sets the boundary between mist and vapor. The cut diameter as well as the filter efficiency however may change whilst in use, so that a clear and constant distinction between mist droplets and vapor, which is demanded by the exposure limits in occupational safety regulations, cannot be given.

- (3) By collecting all mist droplets onto a filter no information is given about the droplet size distribution of the mist.
- (4) Finally this method does not provide continuous real-time measurements and needs a complex and time-consuming post-processing of the samples.

The purpose of this work was to develop a continuous easy to handle laboratory measuring method that allows the determination of both droplets and vapor and gives information about the droplet size distribution.

3. New concept

Fig. 1 shows a schematic drawing of the three-step measuring concept [15]. An air sample of the metalworking fluid mist is directed to cut-off-impactors of different cut sizes by a multi-way valve in several successive passes. In the different cut-off-impactors all droplets larger than the respective cut size are segregated, whereas all smaller droplets and vapor can pass.

In each pass the droplets that are not collected in the impactor and the vapor are fed into an evaporator, operated at up to 400 °C, thus immediately evaporating all droplets. Consequently behind the evaporator the complete droplet mass of the respective mist-fraction and the originally vaporous amount are in the vapor state.

The sample is subsequently analyzed by an in-line Flame Ionization Detector (FID). In case of soluble oil MWFs only the oil phase of the emulsion is measured. Water contained in the droplets is not detected. This is in accordance with the requirements of exposure limit regulations, where also only the oil content of soluble oil mist is examined.

When mist of soluble oils is assessed it is convenient to have another measurement by an optical particle counting system (PCS) in addition. In doing so the oil mass is detected by FID and the total mass of the droplets (water and oil) is measured by PCS. Then the mass fraction of oil within the droplets can be determined for the given droplet size classes.

3.1. Procedure

By switching to the different cut-off-impactors, different FID values according to the oil mass in the corresponding fraction are obtained. Fig. 2 illustrates the measurement procedure applied to five different impactors. For example when the cut-off-impactor with cut size 5 µm is charged the total fraction below 5 µm and vapor are observed by the FID. Likewise for all other fractions down to cut-off 0.25 µm where only droplets below 0.25 µm and vapor are measured.

3.2. Analysis

The different FID values derived from switching to different cut-off-impactors actually provide the cumulative distribution of oil mass versus droplet diameter (in case of soluble oils versus diameter of the droplets in which this oil is contained).

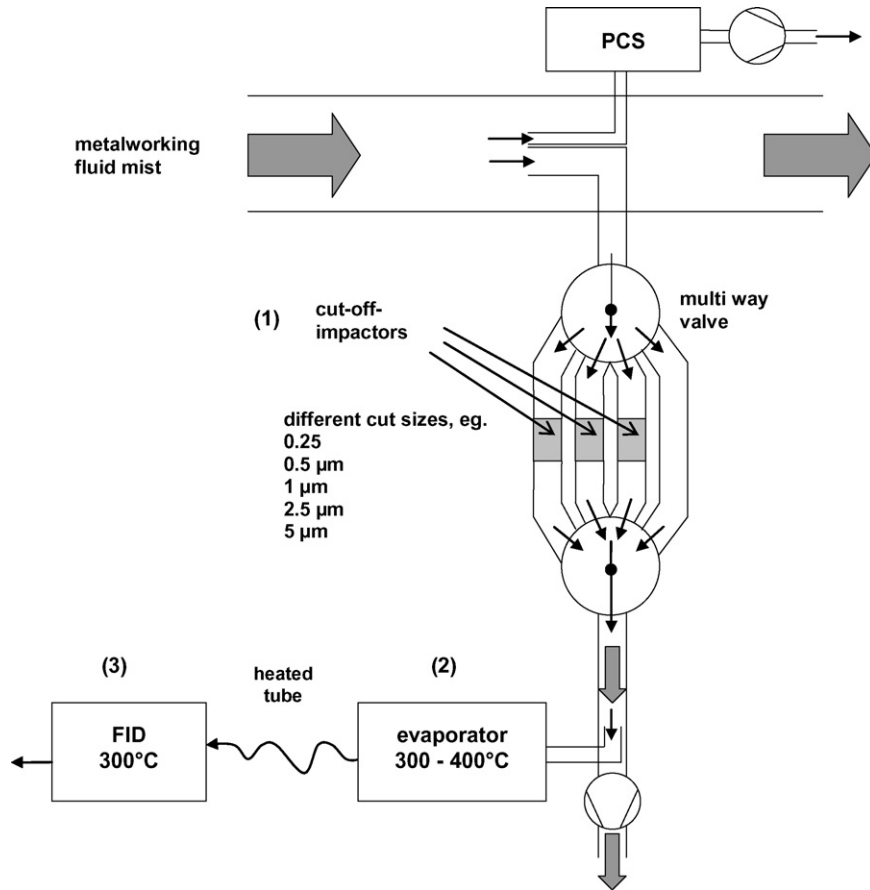


Fig. 1. Schematic representation of the measuring system [15].

It has to be pointed out that the smallest fraction, in this example the fraction below 0.25 μm , contains both droplets in that size range and all vapor.

More interesting however may be the oil mass contained in different droplet size ranges. Therefore, subtracting one FID value from the value measured at the respectively next larger fraction gives the oil amount of the MWF mist found in a

certain droplet size range (Fig. 3). So the distribution of oil mass versus droplet diameter is obtained (in case of soluble oils versus diameter of the droplets in which this oil is contained).

The MWF mist is hence segregated according to the droplet size and a definite cut size between droplet and vapor can be defined, below which we can say “vapor” assuming that droplets

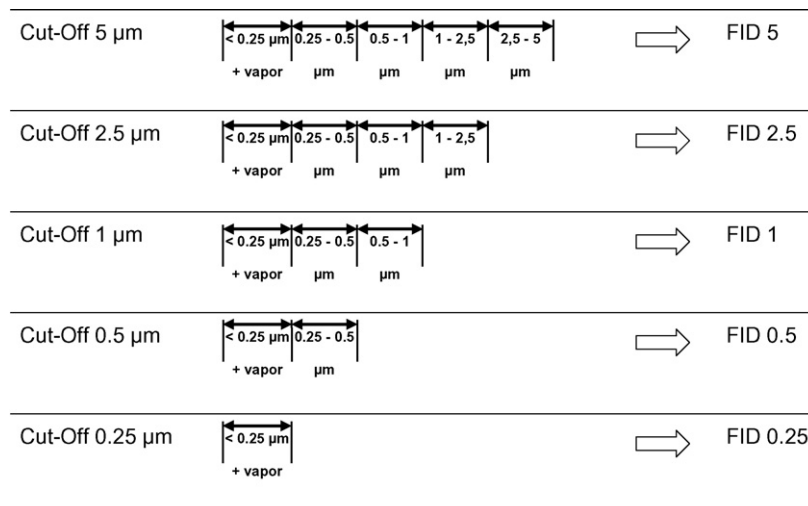


Fig. 2. Schematic illustration of the measurement procedure.

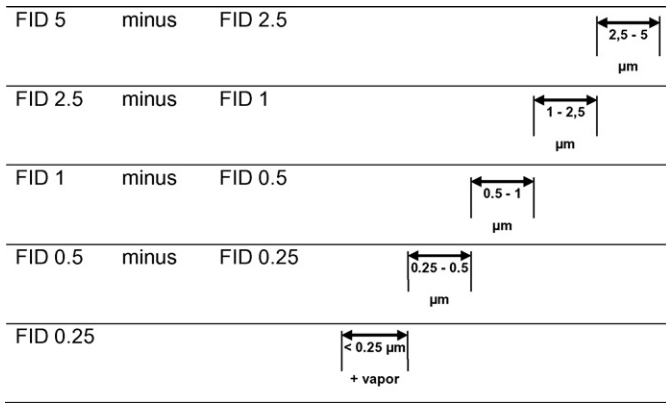


Fig. 3. Analysis of the measurements.

with diameters smaller than a certain size (in this example 0.25 μm) are counted as vapor.

3.3. Experimental setup

In a first approach instead of a multi-way valve connected to different cut-off-impactors a nine-stage cascade impactor (type Berner) was adapted for the given requirements (Fig. 4). Intermediate rings were mounted between the appropriate cascade impactor stages. Each ring is equipped with a sampling probe and a gate valve. By opening a certain gate valve a sample of the corresponding aerosol fraction is taken. The aerosol fraction contains all droplets with diameters smaller than the cut size of the impactor stage above the respective ring as well as the vapor. The received aerosol fraction then passes the evaporator and is analyzed by the FID (TESTA 2010T) as explained above.

3.4. Determining the calibration factor

Metalworking fluids can have many different compositions. Hence to obtain information about the airborne concentration

from the measured FID values it would be necessary to calibrate for every single metalworking fluid, of which the airborne concentration shall be measured.

In order to avoid extensive calibration work an equivalence substance was established. The FID measurement value is once calibrated for this substance and all further measurements with different metalworking fluids can be related to this substance. Di-2-Ethylhexyl-Sebacat (DEHS) was defined as equivalence substance. Due to its low vapor pressure and high boiling point we can assume that there is no evaporation during the calibration.

The calibration was conducted by measuring a DEHS aerosol with an Optical Particle Counting and Sizing System (Palas PCS 2010), using scattered light, and the FID (Fig. 5). The aerosol was generated by a disperser based on the principle of Sinclair LaMer (Palas MAG-3000). It was ensured that all droplets were within the measurement range of the Optical Particle Sizer, and therefore could be detected. The particle size distribution and particle concentration obtained from the PCS can be converted to a mass concentration in mg/m³ with the given density of DEHS. The FID indicates the concentration in the unit ppm propane.

Fig. 6 shows the measured values of both instruments at different aerosol concentrations. Relating the values of these two devices to each other gives a calibration factor that enables the conversion from FID-measured ppm propane to mg/m³ DEHS.

Fig. 7 indicates that a median calibration factor can be calculated and assumed constant for all aerosol concentrations.

4. Fractionated airborne mist measurements

In the following a first application of the new method to the mist of a soluble oil metalworking fluid is shown.

The used MWF is a multi-purpose oil based on synthetic base oils, emulsified in a concentration of 5% (mass) in water. It was applied in a testing facility developed by Neumann et al. [16–18] that simulates the machining process. By spraying the metalworking fluid onto a rotating element, which is in shape

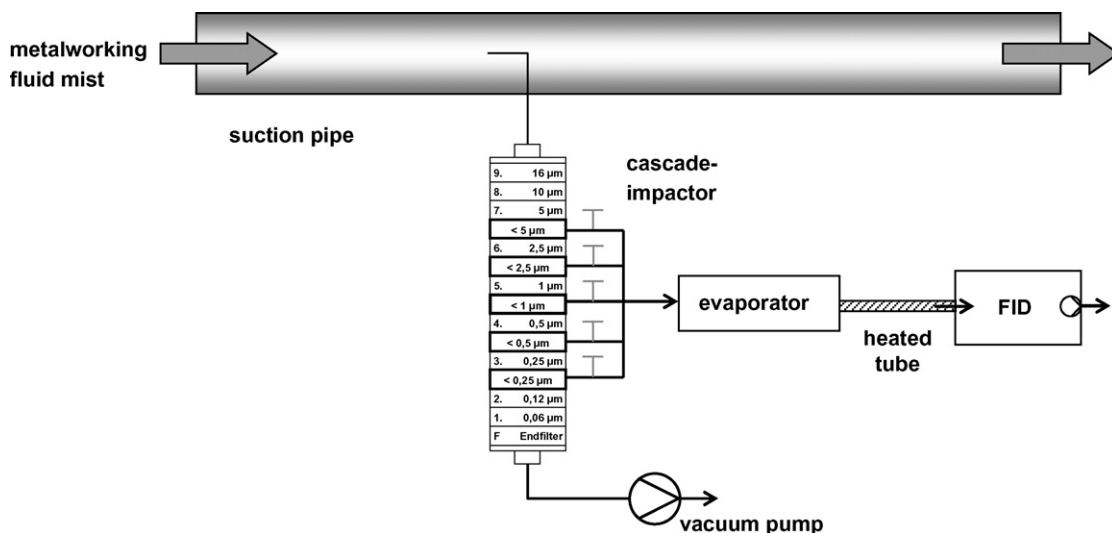


Fig. 4. Experimental setup.

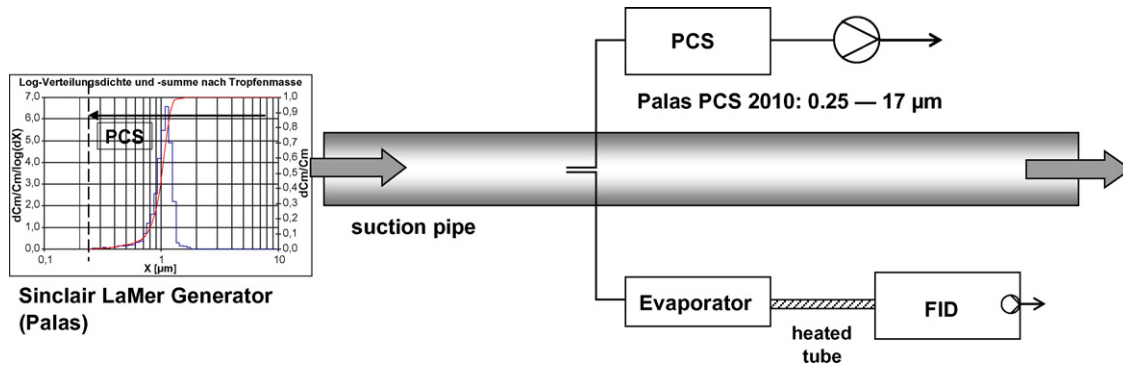


Fig. 5. Experimental setup for the calibration.

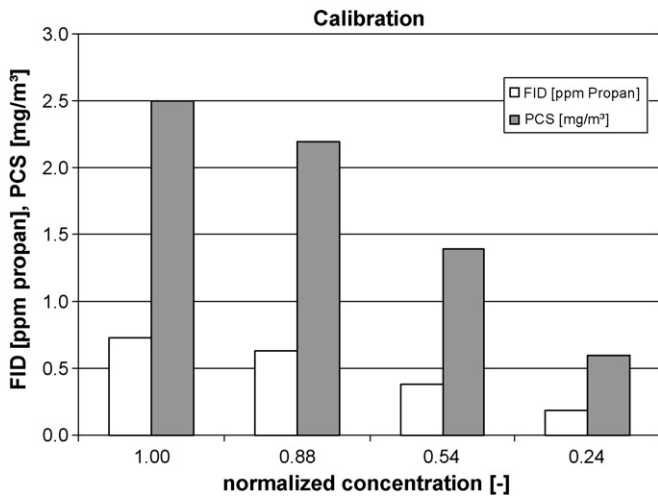


Fig. 6. Values measured by FID and PCS at different DEHS aerosol concentrations.

similar to a milling cutter, mist and vapor are generated in an enclosure very similar to plant practice [19]. From there the emission is exhausted by a suction pipe, from which the air samples are taken. The metalworking fluid was sprayed onto the rotating tool (7000 rpm) by a 8 mm slit nozzle at a flow rate of 1.9 l/min. The air sample was taken out of the suction pipe after a length of 1.8 m.

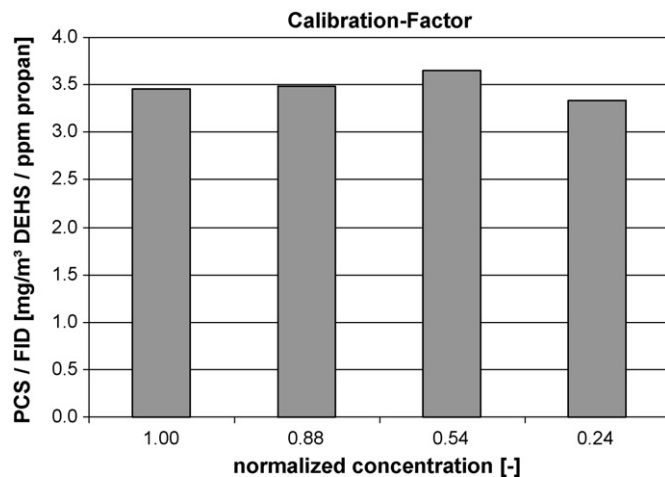


Fig. 7. Calibration factor for the conversion of the FID values to mg/m³ DEHS.

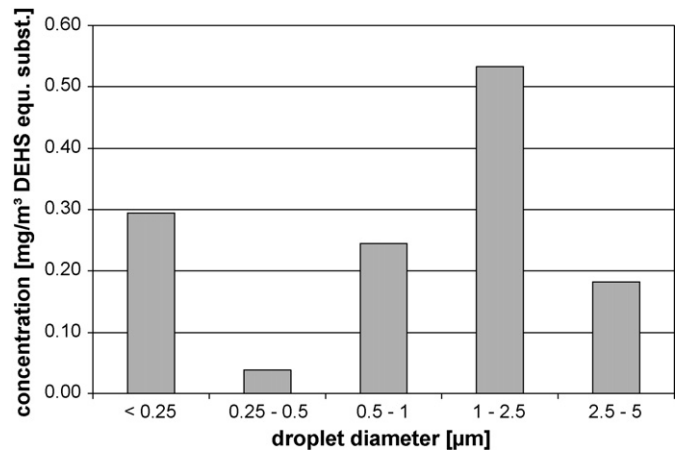


Fig. 8. Distribution of oil concentration vs. droplet diameter.

Fig. 8 shows the mass distribution of oil versus droplet diameter. The droplet diameters to which the mass concentrations are attributed come from the total droplet volume, thus the sum of water and oil content. The mass concentrations indicated on the y-axis however are only given by the oil component in the droplet, as the FID does not detect water. It can be observed that the fraction with the smallest droplets contains considerable amount of oil either in the form of very small droplets or in the form of vapor (Fig. 9).

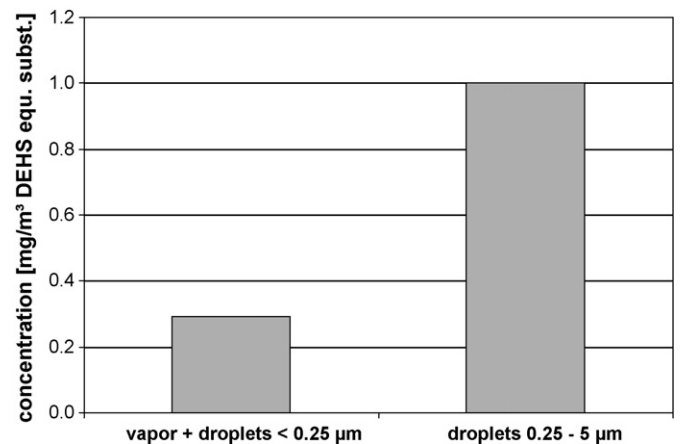


Fig. 9. Oil concentration of vapor and mist.

5. Summary

A new continuous measuring method and procedure has been developed to determine both droplets and vapor of airborne metalworking fluid mist. It provides information about the droplet size distribution of the oil concentration. DEHS has been established as equivalence substance and a calibration factor was determined to allow the conversion from the measured values to mg/m^3 equivalence substance. A first application of this procedure to a soluble oil mist generated by a testing facility has been successfully demonstrated.

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