Recommendation no. 7

of the BPC Ad hoc Working Group on Human Exposure

Professional exposure assessment to biocidal products used in metalworking fluids (PT 13)

(Agreed at the Human Health Working Group III on 2 June 2015)

1. Background

The HEEG Opinion No. 5 on "Human exposure assessment to biocidal products used in metalworking fluids (PT13)"* was agreed at the TM III 2008. In this paper the professional exposure assessment was discussed and recommendations were given to assess inhalation and dermal exposure during the different steps of handling metalworking fluids (MWF) treated with biocides. Since potential hand exposure to biocides in metalworking fluids was based on a worst case assumption (generic spill model), Member States identified a need to find more appropriate assumptions based on recently published data. The HEEG Opinion No. 5 is therefore revised.

2. Aim of the recommendation

The aim of this recommendation is to propose appropriate models for assessing professional exposure during handling of biocides in metalworking fluids at turning machines.

3. Discussion and proposal for harmonisation

Description of the handling of metalworking fluids

MWF are used in a wide range of manufacturing industries where metal machining, grinding or cutting operations are carried out. MWF are typically used for cooling and lubrication at the tool-metal interface. Four classes of MWF are used: straight oil; soluble oil; semi-synthetics; and synthetics. Straight oils are highly refined mineral oils that are used without any dilution. The soluble oil, semi-synthetics and synthetics classes are all mixed with water. The metalworking fluids diluted with water are treated with biocides to prevent bacterial growth[1)].

The biocidal products on the market are either ready-to-use mixtures of MWF treated with the biocidal active substance or biocidal products (concentrate) intended for the direct treatment of large MWF machine systems. The ready-to-use MWF already treated with biocides seems to be used in small systems.

Mixing and Loading

For mixing and loading no current data were found in the literature. Therefore, the recommendation in the HEEG Opinion 5 is still valid.

Metalworking concentrate containing a biocidal product/active substance is diluted and added to the sump or the biocidal product is added directly as a tank-side additive to the sump at the metalworking plant. Mixing and loading is generally done automatically (connecting of transfer lines is necessary), but may also be done by manual pouring.

The following exposure determinants should be considered:

* The HEEG Opinion 5 is available at http://echa.europa.eu/view-article/-/journal_content/title/support-biocides-heeg-opinions

- Product specific variables to be provided by the applicant:
  - Volume of poured biocidal product dependent on its concentration (in fluids and in the sump or blend tank)
  - Volume of the sumps: variable, up to 100 m^3
  - Concentration of active substance in: concentrate biocidal product, MWF, ready-to-use MWF
- Defaults for duration and frequency: 10 minutes per day or per month (depending on the applicant's description)
- Exposure routes: dermal (mainly hands), inhalation exposure to vapour in case of volatile substances

In carrying out exposure assessment, the assessor should decide if manual and/or automatic mixing and loading is reasonable. based on the proposed package sizes of the applicant. For containers up to 25 L, a manual handling is reasonable. Above 25 L unit, an automatic mixing and loading step could be assumed. However, if the applicant provides the necessary information on the automation degree, this specific information can be used. The dermal assessment of the mixing and loading procedure should be based on HEEG opinion 1 models. Aerosol formation is not expected. For volatile substances inhalation exposure to vapour can occur. Inhalation exposure to vapour can be assessed using the HEEG opinion 13 based on the saturated vapour concentration as a worst case assumption. For a refinement ConsExpo or ART (Advanced REACH Tool) models can be used.

Application

A good description of the metalworkers job is found in Semple et. al. (2007)[2)] and summarised by Cherrie et. al. (2009)[3)]. The authors determined dermal exposure and identified the following working steps where exposure occurs:

1. Machine set-up: This step often involves handling of drill bits and other tools for the cutting machine. This is frequently carried out with items that are covered in MWF from previous use.
2. Machine operation: Often this is completely automated and consequently there is little direct contact with the MWF. However, in many manual and semi-automated machines the worker moves the MWF nozzle direct it accurately to the cutting edge. This frequently results in short whole hand exposure events. For open and manual systems, the machinist's hands become covered with MWF during the turning (cutting/shaping) of the metal components.
3. Work piece removal: After completion of the task the cut item is removed manually from the tool. This item is coated with MWF and handling is usually done without gloves or without any attempt to remove excess fluid.
4. Machine/sump maintenance: The inspection of the sump fluid, removal of excess swarf and general machine maintenance gives rise to dermal exposure to MWF.

In the HEEG Opinion 5 the application phase is divided into two working steps: a) metalworking on turning machine and b) other tasks in the workshop. Taking into account the above description of the different working steps, it is assumed that working step 2 is the metalworking on the turning machine and steps 1 (mainly at the beginning of the shift) and 3 are working steps next to the machine.

Step 4 is a step of ancillary work. According to Semple et. al.[2)], a single worker could have the responsibility for the sump maintenance for all machines. Therefore, it is proposed to assess the metalworker at the turning machine for the application phase and the worker doing the maintenance work for the post-application phase. In small companies a single person would undertake the metalworking (step 1-3) and the maintenance work (step 4) during one shift. Maintenance work is not a daily task and might be performed once a week or month.

The application phase includes working on or next to the turning machine (described in steps 1)-3)). The turning machine could be an open system (manually controlled machines) or a closed chamber so called computer numerically controlled machines (CNC) machine[5)]. Van Wendel de Joode et al. (2005)[5)] described that a worker operates a group of metalworking machines during a working day. For all these different types of machines, the manual changing of work pieces is required.

With regards to the working on turning machines, four studies[2), 4)-6)] were found which determined dermal hand exposure at workshops handling MWF. In addition, the publication of Cherrie (2009)[3)] reviewed three of them[2),4),5)]. Different types of turning machines (open system, CNC machine) are only distinguished in one publication of Van Wendel de Joode et al. (2005)[5)]. Here it is described that in one company open and closed machines can be found. In the publication only graphs of exposure (distinguishing between open and closed systems) are given and no figures are presented. However, based on the graphs it seems that higher dermal exposure levels for open system are observed than for the closed system. Exact data are missing to differentiate between the open and closed system.

The derivation of a distinct value for a potential hand exposure value from the data of the reviewed studies is difficult, because in the studies a mixture of actual and potential hand exposure for different exposure durations is determined.

The data from Roff et.al.[4)] and van Wendel de Joode et al.[5)] describe working situations where protective gloves were worn and therefore represent actual hand exposure values[3)]. The review of these studies by Cherry et al.[3)] stated that gloves are not commonly worn and are also not consistently worn throughout a work shift. Therefore, the data found by Roff and van Wendel de Joode might be a mixture of actual and potential hand exposure. For Henriks-Ekerman et al [6)] it is not reported if gloves are worn or not. Only Semple et al.[2)] provides data for potential hand exposure.

Henriks-Ekerman[6)] measured hand exposure for around 2 hours during working on turning machines. Only the dominant hand was included. For Roff et al.[4)] Cherry assumed that the estimated exposure lasted for 6h. van Wendel de Joode et al.[5)] presented dermal measurements of one shift (411 min). The data from Semple et. al.[2)] assess also a work shift. No data were found to assess the separate working steps 1 to 3.

The following data for hand exposure are based on the publication of Cherry for the studies of Semple et al.[2)], Roff et al.[4)] and van Wendel de Joode et al.[5)]. These values are estimated for one shift. For the study of Henriks-Ekerman[6)], it was necessary to extrapolate the measured data to both hands for a 6 hours exposure duration since the determined values are only given for one hand and for 2 hours of exposure.

Table 1: Overview about estimated exposure of hands and forearms in-use MWF formulation per shift

Study	N	MWF [mg/shift] Median/GM	90th percentile	Comments
Semple et al.[2)]	112	5200 (median)	36 000	Water and oil based. **No protective gloves**. Estimated are both hands.
Roff et al.[4)]	7	16 000 (median)	28 000	Sampling gloves under protective gloves. Both hands
van Wendel de Joode et al.[5)]	51	3700 (GM)	12 000	Hands and forearms by pads, protective gloves are worn
	38	1400 (GM)	12 000	Hands and forearms by fluorescent tracer, protective gloves are worn
Henriks-Ekerman et al.[6)]	32	1820 (median)	6542	Wearing or not wearing of gloves is not reported

It is proposed to use the 90th percentile value of 36 000/6h equivalent to **100 mg biocidal product (b.p.)/min** from the Semple study[2)] to assess the **potential hand exposure** during metalworking on turning machine and ancillary work (working step 1-3). This assumption is valid for the assessment of biocides in soluble oil; semi-synthetics and synthetics metalworking fluids diluted with water. According to the experience of Cherry et al., the exposure lasts for 6 h at turning machines.

For **potential body exposure,** no current data were found and the value of **92 mg b.p./min** (according to User Guidance 75th percentile) based on a publication of Roff et. al.[4)] should be used to assess the body exposure, as already proposed in the HEEG Opinion 5.

According to Semple et. al.[2)] and Roff et al.[4)], wearing of gloves near the turning machine is not a common practice, due to dexterity and safety reasons (gloves could be caught in the turning machines). However, van Wendel de Joode et al.[5)] observed the use of protective gloves.

Based on the HEEG Opinion 5, it is assumed that **one hour** of dermal exposure is reasonable due to direct contact to the MFW at the turning machine (equivalent to working step 2). For this time period, the wearing of protective gloves is not appropriate due to safety reasons. In a second working period of **5 hours** of dermal contact in the same shift the workers performed working steps next to the turning machine like handling and cleaning of work pieces or tools (step 3 and at the beginning of the shift step 1). For this time period the use of protective gloves could be recommended.

For the assessment of actual hand and body exposure, it is recommended to use the recommended protection factors of the HEEG Opinion 9 (e.g. 90% protection for protective gloves). Actual hand exposure should no longer be based on Roff et al. as proposed in the HEEG Opinion 5, since the value of 46 mg/min is only based on 7 data.

For **inhalation exposure** several publications were found describing inhalation exposure to aerosols during metalworking. The workers are exposed to the mist of aerosol when working at the open system. When the closed system (CNC machine) is opened after the machine has stopped turning, the worker is also exposed to aerosol. There was no difference in inhalation exposure levels found for these different types of machine (see e.g. 5)).

The literature values are mainly based on the geometric mean/arithmetic mean (GM/AM). Similar mean values (GM/AM) in the range of 0.17 to 0.78 mg/m^3 were found (see Table 6.3).

The value proposed by the BEAT model of 0.33 µl/m^3 seems to be based also on GM values published in Simpson et. al. (2003)[7)].

Since the use of a mean value is not supported it is recommended to use the 75th percentile of **0.7 mg/m^3** (density 1 for water based MWF) recalculated from GM and GSD.

Based on the measurement data, it is assumed that the worker is exposed to aerosol during the whole working shift, since during the whole shift the worker is next to the turning machine.

For volatile substances inhalation to vapour has to be assumed. In the literature exposure to volatile organic compounds (VOC), alkanolamines and aldehydes can be found[17)-19)]. The assessor should decide on the analogy of the vapour pressure and if these values can be used for the assessment of inhalation exposure to vapour. Some measurements for formaldehyde are presented in the Annex.

Maintenance work

In the literature only the maintenance work of the turning machine is described (see step 4 above). This step could be done as a minor part of work by the worker who performs the metal work or, as described by Semple et. al.[2)], it is done by one worker for all turning machines in the company. As worst case it is assumed that one worker undertakes the maintenance work during one shift. A standard post-application phase does not exist; an additional job is described and assessed instead of this.

It is assumed that the worker is potentially exposed to the hands and body due to contact with contaminated surfaces. During sump maintenance dermal exposure to the MWF occurs directly. The values determined by Roff et. al.[4)] include this maintenance task according to Cherry et al.[3)]. Unfortunately, no measurement data determining the maintenance task only are available.

It is assumed that the maintenance work is often the dirtiest job. Therefore, dermal exposure during this phase is assessed to be higher than for the application phase. It is recommended to use the value of **200 mg b.p./min** based on HEEG opinion 5 (6 ml spill model) to assess potential hand exposure and **92 mg b.p./min** to assess potential body exposure. The use of protective gloves and coverall can be assumed for this maintenance work. The duration of dermal contact to MWF is assumed to be 4 hours during a shift (frequency: monthly) according to the HEEG Opinion 5.

Inhalation exposure of the maintenance worker is in the same order of magnitude (0.7 mg/m^3) as for the operator, since the maintenance worker is next to the turning machine and exposed to aerosol and/or vapour from volatile substances as it is also assumed for application.

4. Recommendation

Based on the HEEG Opinion 5 and the current literature research, the following exposure assessment is proposed:

No.	Description of task	Recommended values	Basis	Defaults
	Mixing & Loading Phase			
1	**Manual** pouring of biocidal Product or MWF treated with biocides (e.g. < 25 L packaging or information from applicant)	**Dermal:** Potential hand exposure: see the HEEG Opinion 1[†] Potential body exposure: see the HEEG Opinion 1 **Inhalation:** – No aerosol formation – Exposure to vapour for volatiles (assessment with ConsExpo or ART)	The HEEG Opinion 1 recommends appropriate models depending on size of container and handled amounts.	10 minutes, daily to monthly (HEEG Opinion 5) The amount of the active substance depends on the volume of the sumps (variable, up to 100 m^3).
2	**Automatic** loading. Worker connects transfer lines. Assessed (e.g.> 25 L packaging or information from applicant)	**Dermal:** Potential hand exposure: 0.92 mg/min. **Inhalation:** – No aerosol formation – Exposure to vapour for volatiles (assessment with ConsExpo or ART)	HEEG Opinion 1 – connecting transfer lines	10 minutes, daily to monthly (HEEG Opinion 5)

[†] "HEEG Opinion on the use of available data and models for the assessment of the exposure of operators during the loading of products into vessels or systems in industrial scale" available at http://echa.europa.eu/view-article/-/journal_content/title/support-biocides-heeg-opinions

	Application phase			
3	Metalworking on turning machine	**Dermal:** Potential hand exposure: 100 mg biocidal product/min Potential body exposure: 92 mg biocidal product/min **No use of gloves can be assumed for this task.** **Inhalation:** – Exposure to aerosols: 0.7 mg/m^3 – Exposure to vapour for volatiles (assessment based on literature values published for substances with analogues vapour pressure)	**Dermal:** Semple et al.[2)]; 90^{th} percentile Roff et.al.[4)]; 75^{th} percentile (HEEG Opinion 5) **Inhalation:** BEAT Worked example PT13 (HEEG Opinion 5, recalculated 75^{th} percentile)	**Dermal:** 1 hour of dermal contact (HEEG Opinion 5), daily **Inhalation:** Inhalation exposure is for one shift (8 h) since the worker is always present next to the turning machine (HEEG Opinion 5), daily

4	Handling of work pieces, tools outside the turning machine	**Dermal:** Potential hand exposure: 100 mg b.p./min Potential body exposure: 92 mg b.p./min. **Use of gloves can be assumed, if necessary, to control the risk.** **Inhalation:** – Exposure to aerosols: 0.7 mg/m^3 – Exposure to vapour for volatiles (assessment based on literature values published for substances with analogues vapour pressure)	**Dermal:** Semple et al.[2)]; 90^{th} percentile Roff et.al.[4)]; 75^{th} percentile (HEEG Opinion 5) **Inhalation:** BEAT Worked example PT13 (HEEG Opinion 5, recalculated 75^{th} percentile)	**Dermal:** 5 hours of dermal contact (HEEG Opinion 5), daily **Inhalation:** Inhalation exposure is for one shift (8 h) since the worker is always present next to the turning machine (HEEG Opinion 5), daily

	Maintenance phase			
5	No classical post-application phase exists. Maintenance work is assumed to be done by one worker the whole shift on a daily basis for all turning machine in the company	**Dermal:** Potential hand exposure: 200 mg biocidal product/min Potential body exposure: 92 mg biocidal product/min **Use of gloves can be assumed, if necessary, to control the risk.** **Inhalation:** – Exposure to aerosols: 0.7 mg/m^3 – Exposure to vapour for volatiles (assessment based on literature values published for substances with analogues vapour pressure)	**Dermal:** 6 spill model (HEEG Opinion 5) Roff et.al.[4)]; 75th percentile (HEEG Opinion 5) **Inhalation:** BEAT Worked example PT13 (HEEG Opinion 5, recalculated 75th percentile)	**Dermal:** 4 hours of dermal contact (HEEG Opinion 5), monthly **Inhalation:** Inhalation exposure is for one shift (8 h) since the worker is always present next to the turning machine (HEEG Opinion 5), monthly

5. References

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6. Annexes

6.1 Overview of literature research

Relevant only for soluble, semisynthetic und synthetic MWF (solutions in water)

Grouped into four major categories: straight MWF, which are undiluted mineral and fatty oils; soluble MWF, which are water emulsions of mineral and fatty oils and other additives; synthetic MWF, which are chemical solutions of organic compounds and inorganic salts in water; and semi-synthetic MWF, which are emulsions of mineral oil with water and the chemicals found in synthetics.

6.1.1 Overview of dermal hand exposure

– Assumption of density of 1.0 g/ml
– Potential hand exposure on bare hands
– Actual hand exposure measured inside gloves

Study	Description/Method	Results	Remarks from the author
HEEG Opinion 5	Spill model: 6 ml of fluid adhering to a bare hand (one) for a one-hour cycle BEAT worked example for PT13 Machining of metal parts	**Potential:** 6 ml on one hand= 6000 mg/820cm^2/60 min = 0.12 mg/cm^2/h; 6000 mg/60 min = 100 mg/min one hand = **200 mg/min both hands** **Actual:** **46 mg/min**	None
Roff et al. (2004)[4)]	– Sampling beneath gloves – Sampling time: 18-90 min – N = 7	**Actual:** – Range: 1.4 - 5.4 mg/cm^2/h – GM of MWF: 2.9 mg/cm^2/h	Approx. 0.5 – 1.4 ml fluid retained in glove samples per pair Sampling gloves were highly contaminated (up to

Study	Description/Method	Results	Remarks from the author
	– PPE – Three sites – Different types of machining – Mineral oil and Water oil mix MWF	– Median: 3.2 $mg/cm^2/h$ – 75th percentile: 4.7 $mg/cm^2/h$	1.4 ml fluid per pair) • calculation based on hand area 820 cm^2 • hand washing method should be used instead of sampling with gloves • gloves were either saturated themselves
Van Wendel de Joode et al. (2005)[5)]	– Hand/forearm: • VITAE, pad – One hand? – Full shift (median 411 min) – N = 51 – PPE unknown – Semi-synthetic MWF	**Potential:** VITAE – GM: 1354 mg Pad – GM: 3706 mg	Surrogate skin sampling overestimates the exposure.
Semple et al. (2007)[2)]	– Hand: • wipes – Whole shift (6 hour) – N = 37 – PPE unknown	**Potential:** GM (GSD) of MWF – Baseline: 4.03(5.58) ml/hand – 1 month: 0.77(5.77) ml/hand – 6-12 month:3.92(3.26) ml/hand	None
Henriks-Eckerman et al. (2007)[6)] (Orginal data)	– Hand: • rinse-off dominant hand (alkanolamines) – 2 hour working time – N = 34 – PPE unknown	**Potential:** Range: 53 – 27981 mg/one hand/2h Median: 859.8 mg/one hand/2h	From the dominant hand a retainment of 1-2 ml of diluted MWF during 2 h work.

Study	Description/Method	Results	Remarks from the author
	– Different types of machining – Water miscible MWF (mineral oil based (70%), synthetic (20%))	75th percentile: 2255.9 mg/one hand/2h	
Cherrie et al. (2009)[3)]	REVIEW of 2) 4) 5)	– Oil-based MWF: 100-28000 mg/hand – Water-based MWF: 100 – 170000 mg/hand – Median both: 2600 mg/hand	-

6.1.2 Overview of dermal body exposure and results of studies

Study	Description/Method	Results	Recommendation
– HEEG Opinion 5 – BEAT - worked example for PT13	– Body – N = 31 – Potential body exposure 75th percentile from HSL study (Roff et al. 2004)		92 mg/min
Roff et al. (2004)[4)]	– Body – N = 31 – Tyvek coverall sampling	– Range: 13 – 1300 µg/cm^2/h – Median: 120 µg/cm^2/h – GM (GSD):62 (4.6) µg/cm^2/h – 75th percentile:176 µg/cm^2/h – 90th percentile:730 µg/cm^2/h	-

6.1.3 Overview of inhalation aerosol exposure and results of studies

Study	Description	Method	Results
– HEEG Opinion 5 – BEAT - Worked example PT13		Inhalation exposure is the 75^{th} percentile of the data set presented in Annex 1 of TNsG v2 (HSE report EH74/4).	**0.33 mg/m³** **0.33 µl/m³**
Simpson et al. (**2003**)[7)] Based on HSE Book EH74/4	Exposure by process (turning, grinding, drilling, grinding, sawing, other), personal exposure by engineering controls	– Personal sampler – N=296 – Water mix concentrate – Differences in exposure levels by machining operation	Total inhalable particle – **GM: 0.33 (GSD 3.05) mg/m³** – Median: 0.32 (0.02-23.1) mg/m³ – Mean: 0.67 mg/m³ – 90^{th} percentile: 1.4 mg/m³
Breuer (2006)[17]	MEGA data	– Personal and area sampler – N=5437 – 8 h TWA – 2000-2005	Aerosol – **50^{th} perc.: 0.6 mg/m³** – 90^{th} perc.: 1.7 mg/m³
BGFE (2005)[18]		– Area sampler – N=60	Aerosol – Median: 0.5 (< 0.49–2.0) mg/m³ (40 of 60 <NWG) – **75^{th} percentile: 0.6 mg/m³**
Park et al. (2009)[8)] REVIEW	Grinding, machining	– Personal and area sampler – N=1107 – (gravimetic determination) – database – data used only for the 2000s year	– Total aerosol • **AM: 0.55 (SD 0.19) mg/m³** – Soluble MWF: N=246 • AM: 0.5 mg/m³ – Synthetic MWF: N=107 • AM: 0.59 mg/m³ – Semisynthetic MWF: N=159

Study	Description	Method	Results
			• AM: 0.48 mg/m^3
Suuronen et al. (2008)[9)]	10 companies	– Personal sampler – N=42 – (gravimetic determination) Duration 6 h	Inhalable dust – **Mean: 0.78 (<0.14-2.0) mg/m^3**
Lillienberg et al. (2008)[10)]	– 3 companies – Turning, Grinding – Most machines were highly automated and almost fully enclosed), enclosed or almost enclosed (partly) or open, general ventilation: Ventilation rate: 2.5-5.2 1/hour	– Personal sampler – N=17-52 – (6-8 h) TWA	Inhalable aerosol 1) N=17 – **GM: 0.2 (GSD 1.79) mg/m^3** – AM: 0.23 (0.04-0.53) mg/m^3 – (Worst case recirculating air) 2) N=26 – **GM: 0.17 (GSD 1.56) mg/m^3** – AM: 0.19 (0.08-0.57) mg/m^3 3) N=52 – **GM: 0.21 (GSD 1.77) mg/m^3** – AM: 0.25 (0.08-1.3) mg/m^3
Verma et al. (2006)[11)]	– 4 companies – Good description of plant and processes, results of all types of MWF incl. “straight”	– Personal sampler – N=5 – 61-320 min – (BGI GK cyclone) – N=168 – Area sample – 100-400 min	Total aerosol – **GM: 0.59 (GSD 2.84) mg/m^3** – AM: 0.99 (0.25-3.28) mg/m^3 Total aerosol – **GM: 0.39 (GSD 2.15) mg/m^3** – AM: 0.52 (0.04-3.84) mg/m^3
Verma (2007)[12)]		Personal and area sampler N=37	Inhalable aerosol – **GM: 0.42 (GSD 1.99) mg/m^3**

Study	Description	Method	Results
		61-400 min (sampler Respicon)	– AM: 0.52 (0.06-1.81) mg/m^3
Ross et al. (2004)[13)]	– 20 companies – Very small machine shops – Machining, Enclosed CNC – Local exhaust 0-541 ft^3/min	– Personal sampler – N=16 – 6-8 h – (gravimetic determination)	Total aerosol – **GM: 0.22 (GSD 2.31) mg/m^3** – AM: 0.32 mg/m^3 (0.04-2.19 mg/m^3)
Piacitelli et al. (2001)[14)]	– 79 small machine shops – Results by type of machining operation, personal exposure by engineering controls (enclosure, LEV)	– Personal sampler – N=106-242 – full shift – (gravimetric determination) – Particle Size Distribution – Differentiation of type of machining operation	Total particles (dust) – Soluble MWF • N=242, Range: 0.07–2.41 mg/m^3 • **GM: 0.34 (GSD 2.08) mg/m^3** – Synthetic MWF • N=106, Range: 0.09-3.76 mg/m^3 • **GM: 0.45 (GSD 2.05) mg/m^3** – Semisynthetic MWF • N=158, Range: 0.05–7.12 mg/m^3 • **GM: 0.33 (GSD 2.07) mg/m^3**

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6.1.4 Overview of formaldehyde and results of studies

Study	Description	Method	Results
Lillienberg et al. (2008)[10)]	– 3 companies – Turning, Grinding – Most machines were highly automated and almost fully enclosed), enclosed or almost enclosed (partly) or open, general ventilation: ventilation rate: 2.5-5.2 1/hour	– Personal sampler – N=4-33 – Full shift (6-8 h TWA)	1) N=4 – GM: 0.125 (GSD 1.29) mg/m^3 – AM: 0.128 (0.087-0.154) mg/m^3 – (worst case: recirculating air in enclosed system) 2) N=16 – **GM: 0.003 (GSD 1.57) mg/m^3** – AM: 0.003 (0.001-0.007) mg/m^3 3) N=33 – **GM: 0.009 (GSD 2.24) mg/m^3** – AM: 0.012 (0.002-0.042) mg/m^3
Suuronen (2008)[9)]	– Water miscible MWF – Manual and CNC, Turning – Grinding, Milling	– Personal sampler – N=42 – 2 h	**Mean: 0.04 (0.011-0.15) mg/m^3** Total aldehyde: Mean: 0.095 (0.026-0.38) mg/m^3
Linnainmaa (2003)[15)]	– Formaldehyde originating from triazine (biocide) – Grinding - enclosed	– Personal sampler – N=21 – Area sampler – N=27 – 2-3 h	Mean: 0.052 (0.01-0.22) mg/m^3 **Median: 0.024 mg/m^3** Mean: 0.055 (0.008-0.24) mg/m^3 **Median: 0.021 mg/m^3**
Steinhausen (2014)[19)]	Milling, drilling, CNC	– Personal sampler – N=402 – 8 h TWA	**Median: 0,02 mg/m^3** 75th percentile: 0,05 mg/m^3
Godderies (2007)[16)]		N=6	**0.02-0.03 mg/m^3**

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