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REVIEW ARTICLE

Exposure to aerosols during high-pressure cleaning and relationship with health effects

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Abstract

In different occupations cleaning has been identified as the work task causing the highest exposure to aerosol components. High pressure cleaning (hpc) is a cleaning method used in many environments and seems to be considered as a cleaning method causing high exposure. In the presented study, the literature concerning exposure to aerosols during hpc is reviewed. Only a few studies have been published about exposure to aerosols during hpc. Exposure during hpc has been measured on farms, at waste water treatment plants, at a chemical factory and for graffiti removers. High exposures to bacterial endotoxin or chemical components were found in these environments during hpc. Few cases have been published documenting acute health effects caused by exposure to microorganisms and endotoxin during hpc. High pressure cleaners are also used in private settings but no papers have been found about exposure or related health effects during work in private settings. The use of clean water during hpc is important since effluent water or roof-collected rain water can cause a higher exposure to bioaerosols and related health effects. However, tap water in some areas also seems to have a high content of endotoxin, and this too should be considered when deliberating the protection of the airways of workers. Different attempts have been made to reduce workers' exposure and the health effects of exposure during hpc, among them the use of respiratory protection, ventilation and automation of work processes have been used with some degree of success. However, some of these studies only show tendencies. A high number of repeats seem to be necessary in order to obtain conclusive results. The material to be cleaned, as well as the degree of dirtiness, highly influences the exposure level; therefore, in comparative studies it is important also to consider these parameters. No study has been found which compares exposure during the use of different high pressure cleaners. The comparison of exposure levels during the use of different equipment for hpc and other cleaning methods are necessary steps for developing hygienic recommendations.

Key words

aerosol, bioaerosol, endotoxin, high pressure cleaning, occupational health, power washing

Background. In different occupations, cleaning is identified as a work task causing the highest exposure to aerosol components [1, 2, 3, 4]. Therefore, it is relevant to focus on cleaning when planning interventions to reduce exposure. In many papers, the cleaning methods causing exposure are not specified, but sweeping with a broom and emptying of a vacuum cleaner are work tasks shown to increase the exposure to particles and bioaerosol components [5]. High pressure cleaning (hpc) is a cleaning procedure used in many environments, including in occupational settings, e.g. in stables on farms, in food production and in private premises. Several papers describe exposure problems from the use of hpc [6, 7, 8, 9, 10, 11] but exposure results are not presented. Thus, it seems to be assumed that hpc causes high exposure. To check whether documentation exists for this assumption and to ascertain which factors affect the exposure, a reviewed of the literature concerning exposure to aerosols during hpc was undertaken. It is important to know whether the protection of workers or bystanders is needed when hpc is performed. In the presented study, papers with 'observed exposure' have not been included, but only papers where exposure or health effects have been measured in relation to hpc. The exposure levels are compared to exposure during other work tasks, including while using other cleaning methods in the studied environments. In some papers, hpc is also called power washing, water blasting and high pressure spray washing, and these terms have also been used in the search for literature for the presented paper.

In the food industry, hpc has been shown to be more effective for the removal of a biofilm of bacteria than low pressure rinsing, followed by disinfection plus low pressure rinse [12]. Hpc is used for removing different substances, for example, for cleaning a farm with a high prevalence of *Mycobacterium avium* [13], and for cleaning a chemical factory [14]. Consequently, the exposure composition and level during hpc is expected to depend on what is cleaned. Also, the water used for hpc may affect the exposure level. In some environments, the dirty area to be cleaned by hpc is pretreated by a cleaning agent, which can be hazardous [15], and the subsequent hpc may cause exposure to cleaning agents. These subjects have also been included in the presented study.

EXPOSUSE IN OCCUPATIONAL SETTINGS DURING HPC

Exposure to dust, endotoxin and bacteria. Exposure to dust and endotoxins during cleaning using high pressure has been measured in farm environments and in a sewage treatment plant (Tab. 1). If reported in the studied papers, exposure during other work tasks or other cleaning methods is mentioned in Table 1 under the heading 'Exposure in a related environment'.

The hpc of pig farrowing house floors contributes significantly to the decontamination process [16] and the amount of airborne dust particles are seen in pig barns to

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Table 1. Exposure of workers and bystanders to inhalable dust and endotoxin during hpc.

Environ-ment	Specifi-cation	High pressure cleaner	Sampling method	Personal/ stationary sampling	Exposure to dust mg/m^3 Median (Min-max) n	Exposure to endotoxin EU/m^3 Median or mean (Min-max) n	Exposure in related environment Unit/m^3 n	Study
Farm	Hpc	Nm	IOM	Personal	0.54 - n=3	20.20 - n=3	Scraping poultry houses 6.67 mg dust 1861EU n=5	[2]
Pig farm	Bystanders to hpc	Nm	IOM+ splashguard	Personal	0.94 (0.74–1.55) n=16	*830 (410–1170) n=16	-	[25]
Pig farm	Bystanders to hpc	Nm	IOM	Personal	≈2.1 (1.4–2.6) n=6	≈*3000 (2100–5600) n=6	Pre-cleaned by robot ≈1.4 mg dust ≈*500 EU n=5	[31]
Pig farm	Hpc	Nm 3500 psi	Impinger (SKC)	Stationary	-	9378 (1913–32422) n=5	-	[42]
			Impinger (SKC)	Stationary	-	88112 (25545–340846) n=17	Hog load-out 7996 EU (2771–19280) n=5	
			Impinger (SKC)	Personal	-	40353 (5401–180864) n=13	Hog load-out 12150 EU (3497–84357) n=19	
Sewage treatment plant	Hpc, belt press, effluent water	Fire hose with blocked nozzle causing high pressure	GSP	Personal	-	Ventilation 59 (6–379) n=8	Ventilation, Low pressure 165 EU (43–601) n=8	[23]
				Stationary	-	Ventilation 78 10–363 n=6	Ventilation, Low pressure 187 EU (45–8683) n=6	
	Hpc, filter press, tap water		GSP	Personal	-	804 (729–887) n=2	Low pressure 140 EU (132–149) n=2	
				Stationary	-	583 (513–662) n=2	Low pressure 72 EU (60–88) n=2	
	Hpc, sludge buffer tank, tap water		GSP	Personal	-	107 (105–108) n=2	Low pressure 28 EU (4–71) n=6	
				Stationary	-	91 (78–107) n=2	Low pressure 38 EU/m^3 (38–38) n=2	

* Converted from ng to EU by a conversion factor 10EU≈1ng; Nm – not mentioned.

increase over a 3-week period after hpc [17]. The generation of dust is affected by the activity, number and weight of the pigs [18], therefore the increase in particle generation may be due not only to the increasing size of pigs, but also to the accumulation of dirt. Exposure to dust and endotoxins has been measured during the hpc of stables; in one study a low exposure to endotoxin and dust was found during hpc, and the exposure was lower than during scraping of poultry houses [2]. In a study performed among Danish pig farmers, hpc was the most influential task for exposure to endotoxin, but not for exposure to dust [19]. In the other studies on farms, high exposures to endotoxin were found during hpc of stables and the exposures were often higher than during other activities (Tab. 1). Outdoor background exposures to inhalable endotoxin are around 0.5–4 EU/m^3 [20], although there is no internationally accepted occupational exposure limit for endotoxin, but no effect levels around 90 EU/m^3 have been found [21, 22]. Thus, exposures during the hpc of farms and on sewage treatment plants can indeed be high. In a study of a sewage treatment plant, exposure during high and low pressure cleaning have been compared. In some areas at the plant, the exposure to endotoxin was highest during hpc, but this was not consistently observed (Tab. 1). The object to be cleaned significantly affects the exposure level [23]. At another sewage treatment plant, stationary measurements showed significantly higher concentrations of coliform bacteria (1×10^3 cfu/m^3) and mesophilic bacteria (4×10^4 cfu/m^3) in an area with hpc than in any other areas at the plant [24].

Different devices have been used for measuring exposure during hpc (Tab. 1). In one study, a splashguard was used together with an IOM sampler because hpc generates a lot of water splashing [25], but in other studies protection against splash is not described.

Exposure to chemical compounds. Three studies have been published about exposure to chemical compounds during hpc, two about graffiti removal and one about cleaning-up chemical pollutions. In a study from 1993, during graffiti removal, the workers using hpc were exposed to the solvent dichloromethane (DCM). The exposure level exceeded the Swedish short-term exposure limit by up to 17 times [26]. Since December 2010, the use of DCM in paint-strippers has been banned for consumers and many professionals in the European Union. In a study published in 2001, the removal of graffiti using hpc caused exposure to pseudocumene (1,2,4-trimethylbenzene) (Tab. 2). The exposure level occasionally exceeded the exposure limit, but only when working in poorly ventilated spaces, such as in lifts [27]. Furthermore, the 8-hour time-weighted average exposures were below 20% of the Swedish permissible exposure limit for all solvents. Even though the exposures were below exposure limits, the workers displayed more unspecific health symptoms, such as irritative symptoms of the respiratory tract, compared to controls [27]. Hpc methods are still used for the removal of graffiti [28, 29], although there is awareness of the environmental consequences of graffiti removal [29].

During maintenance of a chemical plant producing Toluene 2,4-diisocyanate (TDI), hpc of objects was carried out without using respiratory protection. The exposure to TDI could be much higher than exposure limits [14] (Tab. 2).

Exposure of bystanders. Two cases of Legionnaire's disease seem to be associated with exercise walking through a marina where boats were being cleaned by hpc using water containing *Legionella pneumophila* [30]. Also, bystanders (2–5 m away) of farmer who was cleaning a pig stable were exposed (Tab. 1) and showed health effects of exposure [25, 31], but symptoms were not compared to symptoms when other work tasks were performed in the stable.

To obtain an impression of how distance from an active hpc influences exposure, Visser et al. used stationary samplers to measure exposure at different distances (<1, 1–2 and >2 m) from the high pressure cleaner. A significant concentration gradient could not be found, although the expected trend with decreasing concentration with distance was seen in some areas of hpc [23].

Aerosolisation in experimental settings. Aerosolisation of particles of different sizes during the cleaning of a car door has been measured in an experimental setting. For the car washing experiment, a high pressure spray unit using 7.3 litres water/min was compared with a hand spay nozzle operated between 11.8–15.4 litres water/min. During the experiment, when using hpc, a visible fog formed which persisted for several minutes after the high pressure hose was turned off. A high variability in aerosol emissions was observed, although the detection of statistically significant differences in emissions associated with the type of device was not possible. The use of a water-efficient device tended to generate more particles smaller than 2 µm in diameter. Thus, the use of a water-efficient device may cause a higher exposure to these small particles during hpc [32].

In an experimental set up to simulate typical high pressure water cleaning (Kärcher K460, Castorama, Créteil, France) of surfaces in the food industry, the aerosolisation and spread of a bacterium from a biofilm was demonstrated. The study showed that *Pseudomonas putida* was aerosolized during

Table 2. Personal exposure to organic compounds in aerosols during hpc.

Environment	Exposure during hpc Geometric mean or mean (Min-Max)	Relation to exposure limit	Related environment	Study
Graffiti removal workers	N-methylpyrrolidone = 1.97 mg/m^3 (0.01–24.61), n=38 Propyleneglycol monomethyl ether =18.41 mg/m^3 (0.18–215.97), n=38 Toluene =0.13 mg/m^3 (0.05–2.06), n=38 Xylene =1.48 mg/m^3 (0.2–21.92), n=38 Pseudocumene= 11.16 mg/m^3 (1.59–**278.84**), n=38 Hemimellitine= 1.85 mg/m^3 (0.62–39.18), n=38 Ethylbenzene=0.4 mg/m^3 (0.075–4.82), n=38 Nonane=0.67 mg/m^3 (0.23–6.69), n=38 Octane=0.16 mg/m^3 (0.12–0.28), n=38	All under the Swedish short term exposure limit. Only pseudocumene occasionally exceeded an exposure limit of 170 mg m^{-3} when working in poorly ventilated spaces	-	[27]
Graffiti removal workers	DCM long term exposure= **127 mg/m^3** (18–**1188**), n=12 DCM shot term exposure= 400 mg/m^3 (6–**5315**), n=12 Dipropyleneglycol monomethyl ether & Propylene Glycol Butyl Ether = 7.9 mg/m^3 (2–11.8), n=3 N-methylpyrrolidone =9.9 mg/m^3, n=1	DCM long-term exposure limit= 120 mg/m^3 DCM & N-methylpyrrolidone short-term exposure limit= 300 mg/m^3	-	[26]
Maintenance of a chemical plant	TDI (Toluene 2,4-diisocyanate) **0.245**mg/m^3, (0.075–**0.91**), n=6 Monochlorobenzene 7 mg/m^3, n=1 Dichlorobenzene 10 mg/m^3, n=1	Threshold limit value – time weighted average for TDI = 0.036 mg/m^3; short- term exposure limit = s 0.14 mg/m^3.	Dismantling: TDI 0.056mg/m^3, (0.008–**0.129**), n=6 Monochlorobenzene 0.5mg/m^3, n=1 Dichlorobenzene 5mg/m^3, n=1	[14]

Values above exposure limits are in bold. The names of the high pressure cleaners are not mentioned in the papers.

the hpc of an area contaminated with this bacterium. A large number of *P. putida* cells adhered immediately to the outside of the nozzle of the high pressure cleaner, and from there it spread to the water pipe at a mean rate of 4.3 cm/day. This shows that hpc can generate a microbial aerosol from a contaminated surface which can continue its growth in other environments [33]. It also shows that the high pressure cleaner can become contaminated and therefore can be a source of exposure.

Influence of water quality on exposure. Water quality has a significant effect on exposure during hpc [23]. Contaminated water may cause health effects if it is used for hpc [30]. For example, an outbreak of Legionnaires' disease seems to be associated with the hpc of boats using roof-collected rainwater containing *Legionella pneumophila* [30]. *L. pneumophila* is a gram negative bacterium producing endotoxin and it has been found in very high concentrations in a water reservoir used for hpc at a sugar beet factory where 14 persons developed Pontiac fever [34] (Tab. 3). Pontiac fever has also been caused by work at a sewage treatment plant where hpc had been carried out, but it is not known whether hpc was the cause of the outbreak of the fever [35].

Water containing 20,400 EU/ml caused Pontiac fever among workers at a sugar beet factory, but the workers' exposure to endotoxin was not measured [34]. Hpc with effluent water in a sewage treatment plant caused a significantly higher exposure to endotoxin than when using tap water (Tab. 3). Water in a humidifier at a work place with cases of humidifier disease contained endotoxin at a level of about 1,600 EU*/ml, and caused an exposure of 1,300 – 3,900 EU*/m^3 [36]. In other studies, drinking water is described as containing endotoxin levels between <6.2 – 5,000 EU*/ml water [37], 3.2 – 32,000 EU*/ml water [38], and 0.2 – 11.9 EU*/ml water [39]. These very different findings of concentrations of endotoxin show that drinking water as well as effluent water can contain a high concentration of endotoxin which may cause a high exposure if used for hpc.

Hpc and particle size. The size of particles influences where and how large a fraction is deposited in the airways [40]. It also affects the length of time a particle can remain airborne and thus how far away or for how long time people may be exposed. Only few studies have been performed concerning hpc and exposure to particles of different sizes.

During hpc using a commercially available high-pressure cleaner (6-litre per minute, nozzle pressure 500 psi) a larger fraction of the airborne microorganisms were present in smaller aerosols, for example, 13% of the microorganisms were present in the aerosol fraction of 2.0–3.5µm, while during cleaning using a brush, only 7% of the microorganisms were present in this fraction [41]. During hpc of a pig barn the median exposure to inhalable dust and endotoxin were 0.94 mg/m^3 and 830 EU/m^3, while the same values for respirable exposures were 0.56 mg/m^3 and 230 EU/m^3 [25]. This shows that a large fraction of the airborne particles and endotoxin were of respirable size. Also, during hpc of a car door (described above) most aerosol droplets were of respirable size with diameters between 0.2 – 2 µm, but particles with diameters between 3 – 10 µm were also present in aerosols [32].

Attempts to reduce exposure during hpc. Various attempts may be made to reduce workers' exposure during hpc. Among them are ventilation, use of respiratory protection and automation of processes. But prevention of the need to use hpc, e.g. by preventing leakages, use of material that is easy to clean, or timely disinfection before a biofilm develops [7], and graffiti prevention [29], may also be possible solutions. The use of clean water is also important for the prevention of high exposure (Tab. 3). It has also been shown that bacteria can grow in the nozzle of a high pressure cleaner, and disinfection of the nozzles has been suggested to prevent the spread of living bacteria [33].

A study performed at a sewage treatment plant showed that mechanical ventilation during hpc, in most cases reduces the endotoxin concentration in the room (Tab. 4). Even though the two examples in Table 4 reveal the big effect of ventilation, the study concluded that the presence of mechanical ventilation did not have a significant effect on endotoxin exposure [23]. Hpc of a specific object outdoors is expected to cause a faster dilution of the aerosol and a lower

Table 3. Influence of water quality on exposure during hpc.

Environment	Sampling method	Aim	High pressure cleaner	Concentrations	Concentration in tap water	study
Outbreak of Legionnaires disease	Water sampling from high pressure cleaner	Investigate the cause of Legionnaires' disease	Nm	6*10^5 CFU *Legionella* /l rainwater	Below detection level	[30]
Pontiac fever at a sugar beet factory	Water sampling from water reservoir	Investigated cause of Pontiac fever developed during hpc	Nm 20000 psi	20,400 EU/ml water and 10^5 CFU *Legionella*/ml water.	-	[34]
	Swabs of evaporator vessel tubes			*Legionella* positive	-	
Sewage treatment plant	GSP personal	Find the cleaning method causing lowest exposure	Fire hose with blocked nozzle causing high pressure	Effluent water 363 EU m^{-3} (337–416) n=4	209 EU m^{-3} (135–290) n=3	
	GSP stationary			Effluent water 380 EU m^{-3} (327–508) n=3	144 EU m^{-3} (102–248) n=3	[23]
	Water sample			Effluent water 900–40000EU/ml n=2	-	

Nm – not mentioned.

Table 4. Exposure to inhalable endotoxin with and without ventilation during high pressure cleaning at a sewage treatment plant.

Environment	Personal/ stationary	Exposure to endotoxin EU/m³ Median (Min-Max) n	
		No ventilation	Ventilation
Belt press, tap, water	Personal	209 (135–290) n=3	37 (26–45) n=4
	Stationary	144 (102–248) n=3	29 (26–34) n=3
Belt press, effluent water	Personal	363 (337–416) n=4	59 (6–379) n=8
	Stationary	380 (327–508) n=3	78 (10–363) n=6

Reference [23].

exposure than if performed indoors: however, this has not been verified in an experiment.

Robots for cleaning stables are used as an alternative to hpc; the robots do not make hpc redundant but reduce the amount of dirt and the time needed for hpc. Pre-cleaning of a piggery using a robot compared to no pre-cleaning has been shown to reduce the exposure to dust and endotoxin during the following high pressure cleaning of the piggery (Tab. 1). Pre-cleaning using a robot compared to no pre-cleaning also resulted in an attenuation in the increase in bronchial responsiveness and airway inflammatory response of people present in the piggery during hpc [31].

Studies with volunteers present in a stable during hpc showed acute inflammatory responses in the upper airways. When the volunteers used half-masks (Sundströms, p3 filter) the inflammatory responses were weaker [25]. Graffiti removers are exposed to organic solvents during hpc, and while using half-mask respirators workers have reported reduced irritative symptoms in the upper respiratory tract [26].

CONCLUSIONS

Only few studies have been published about exposure to aerosols during hpc, and exposure has only been measured in some environments. Several papers have concluded that cleaning is a work process causing high exposure, but the cleaning procedure is not further described. Measuring exposure during hpc in such diverse environments as agriculture and graffiti removal has been performed, and high exposures to aerosol components were found in both environments. A few cases about outbreaks of diseases caused by exposure to microorganisms and endotoxin during hpc have also been published which showed that exposure levels can cause acute health effects. The use of clean water during hpc is also emphasized since effluent water or roof-collected rain water can cause a higher exposure to bioaerosols and related health effects. However, tap water in some areas also seems to have a high content of endotoxin, and this should be considered when deliberating the protection of the workers'airways. High pressure cleaners are also used in private settings, but no papers have been found about, e.g. exposure to bioaerosols during hpc of garden furniture or tiles. However, under experimental conditions, particle generation during car washing has been measured. Potential health effects of these particles have not been measured but may be of high relevance as they may contain traffic-generated particles, including combustion particles, as well as microorganisms and pollen.

Different attempts have been made to reduce workers' exposure and the health effects of exposure during hpc. Among them, the use of respiratory protection, ventilation and automation of work processes have been used with some degree of success. However, in general, the few studies performed concerning the factors affecting the exposure, or health effects of exposure, during hpc have difficulties in showing significant effects. This seems to be caused mainly by very high variations in aerosol generation between repeats of the same task, both in a work place and in an experimental setting. This may partly be because the objects to be cleaned may be dirty in varying degrees, and this will affect the exposure. In order to obtain conclusive results a high number of repeats seem to be necessary, but it may also be relevant in an experimental setting to control other factors, such as the degree of dirtiness of the object to be cleaned.

The presented study shows that both the material to be cleaned and the water used highly influence the exposure to aerosol components. Exposures during high and low pressure cleaning have been compared. A single study has shown that use of a water-efficient device during hpc seems to generate more small particles (smaller than 2 µm), but no study has been found comparing exposure during the use of different high pressure cleaners. The comparison of exposure levels during the use of commercially available equipment for hpc and other cleaning methods are necessary steps for developing hygienic recommendations.

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