

Ventilation and organic solvent exposure during car washing

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NIEMELÄ R, PFÄFFLI P, HÄRKÖNEN H. Ventilation and organic solvent exposure during car washing. *Scand J Work Environ Health* 13 (1987) 424–430. Spray finishing operations often involve cleaning with solvents. White spirit is widely used as a solvent in car washes in Finland. The purpose of the present study was to determine the levels of solvent exposure of car washers and to evaluate the effectiveness of ventilation systems in car washing facilities. The study covered 11 car washes. Airborne solvent concentrations were measured both in workers' breathing zones and at stationary sampling sites. The solvent concentration in the breathing zones ranged from 5 to 465 mg/m³ during the washing of automobiles and from 45 to 685 mg/m³ during the washing of heavy vehicles. Brief concentration peaks up to 4 500 mg/m³ were detected. The flow rate of ventilation air ranged from 0.3 to 3.9 m³/s. The greatest reduction in solvent concentration in the workers' breathing zones was attained with a ventilation design where the supply air jets blew directly into the work zone.

Key terms: airflow rate, spray finishing, white spirit.

Spray finishing is widely used in a number of industries. Spray painting has received more attention in the literature (12) than other spray finishing operations. Spray finishing operations often involve cleaning with solvents. The spray cleaning of vehicles, eg, automobiles and trucks, may expose workers to high atmospheric concentrations of organic solvent vapor.

Solvent-based cleaning agents are commonly used in the spray washing of cars in Nordic countries. The cleaning agent used depends on the model and dirtiness of the car. Solvent-based material is useful for washing new car bodies to remove the protective layer of wax and for removing old wax and bitum-containing dirt from used cars. The agents are usually hydrocarbon solvents (Stoddard solvent, white spirit) containing aliphatic hydrocarbons and smaller amounts of aromatic hydrocarbons. The same solvents are also used in paints, varnishes, and glues and as thinners.

The odor threshold for Stoddard solvent is about 5 mg/m³. Acute exposure to high concentrations of Stoddard solvent causes irritation and central nervous effects. One of six human volunteers exposed to the solvent at an atmospheric concentration of 850 mg/m³ had transient eye irritation. At 2 700 mg/m³ all six volunteers experienced eye irritation and three had lacrimation (4).

Long-term exposure to organic solvents may affect the central and peripheral nervous systems. Solvent-exposed workers suffer from nausea, dizziness, drunkenness, concentration difficulties, and lassitude significantly more often than unexposed workers (6, 7). A

neuropsychological examination of car painters revealed slight differences in visuomotor and psychomotor performance when the painters were compared with an unexposed reference group (6). In another study, painters, varnishers, and carpet layers showed an increased risk of 1.8 for nonspecific neuropsychiatric disorders in comparison with workers not exposed to solvents (3).

Excluding data on spray painting, little information is available about the levels of organic solvent exposure in spraying operations, and data on adequate control measures are scarce. Manual car washing is a typical spray finishing operation in which solvents are sprayed onto large surfaces. From the standpoint of ventilation design, the car washing operation is very complicated because of the washers' movements, back-scattering of solvent jets, convection currents caused by warm motors or hot water flushing, and the different sizes of the vehicles.

The purpose of the present study was twofold: (i) to determine car washers' level of exposure to solvents and (ii) to evaluate the effectiveness of ventilation systems used in car washes. This information was used to determine which ventilation design is most suitable for restricting solvent exposure.

Materials and methods

Car washes, washing agents and washing operations

The investigation covered 11 car washes for automobiles and heavy vehicles. The facilities were built or renovated in the 1970s, and they had different ventilation systems. In all except two of the washes the measurements were carried out at zero or subzero outdoor temperatures.

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Solvent-based car cleaning agents contain some 95 % hydrocarbons and 3–5 % detergents. During the investigation, four plants used a Stoddard solvent and seven a “high flash” Stoddard solvent. The boiling range of the Stoddard solvent was 145–200°C. The solvent was said to contain 15 % aromatic hydrocarbons. The boiling range of the high flash solvent was 185–220°C. At three plants the latter contained 15 % aromatic hydrocarbons, whereas the rest were “dearomatic high flash” Stoddard solvents with an aromatic hydrocarbon content of only 0.5 %.

Cars generally undergo both an automatic and a manual washing phase. In the present study emphasis was placed on the manual washing operations supposedly involving high exposure to solvent vapors. Atmospheric solvent sampling was conducted during the spraying of the solvent, hand washing with a soft sponge, flushing with warm water, and drying. The solvent was applied with a hand sprayer at a pressure of 150–400 kPa. Normal network pressure was used in water flushing. The engines were first sprayed with solvent and then with warm or hot water. Ladders and brushes with long handles were also needed to wash heavy vehicles.

Air sampling and analysis

The air samples collected were personal samples from the worker's breathing zone and stationary samples at 1.5 m above the floor and 1.0 m below the ceiling. The samples were collected in laboratory-made charcoal tubes (200 + 50 mg charcoal) (8), and the sampling covered the entire active washing time, ranging from 3 to 7 h. Personal pumps (Sipin SP15, by AJ Sipin) were used to pump air through the tubes at a flow rate of 0.2 l/min. The sampling period for each tube was 60–90 min. The concentrations were expressed as time-weighted averages for the active washing time. The vertical concentration gradient was determined by dividing the difference between the concentration in the upper part of the shop and that at the height of 1.5 m by the corresponding distance.

Samples were eluted from the charcoal tubes (separate charcoal layers) with 1 ml of carbon disulfide or dimethylformamide and analyzed by gas chromatography (Perkin-Elmer F 17) in a “tris”-column (1 % 1,2,3-tris-cyanoethoxypropane on Chromosorb W, 4 m, inner diameter 4 mm) at 140°C. Detection was made by a flame ionization detector. White spirit (Shell Corp) was used for calibration. The calculations were based on peak areas derived from the chromatograms by integration (Hewlett-Packard 3386A electronic integrator).

The air in the car washes contained mist from the hot water used during the washing. We therefore investigated whether the moisture caused a breakthrough of the solvent in the charcoal tubes. Various amounts of distilled water (10, 25 and 50 mg) were added to the tubes, which were then capped with plastic stop-

pers and allowed to equilibrate at room temperature overnight. The next day, white spirit vapor (1 000 mg/m³) was sampled into the tubes from a dynamic vapor/air stream (0.2 l/min, 30 min) (10). On analysis no breakthrough of the solvent vapor was detected, and therefore it was concluded that the moisture added did not affect the sampling capacity of the tubes. The coefficient of variation of the method of sampling and analysis was 0.08 (N = 10).

A portable gas chromatograph (AID model 511, Analytical Instrument Development, Inc) was used to measure variations in the total hydrocarbon concentration during individual work periods in seven car washes. The instrument sampled the ambient air every or every second minute in the breathing zone of the workers. The samples were taken via a gas sampling loop (1 ml) connected by a stainless steel tube to a flame ionization detector. The hydrocarbons present were thus detected as a single peak.

Measurement of ventilation and air temperature

Simultaneous measurement of solvent exposure and ventilation was performed in each car wash. The airflow in the ventilation ducts was measured with a standard Pitot tube and an electrical micromanometer (Furness Control Ltd) according to the multipoint traversing method (1). The air velocity at the makeup air and exhaust air openings was measured with a vane anemometer (Airflow Developments Ltd). The air exchange rate was determined as usual, by dividing the airflow rate by the volume of the car wash. However, this method was not used in car washes 6, 9, and 10 because the air velocity profiles in the exhaust ducts and supply air openings were very disturbed. In these workplaces the air exchange rate was measured with the tracer gas technique (11).

The tracer gas was nitrous oxide, the concentration of which was measured with an infrared spectrophotometer (Miran 1A, Foxboro Analytical). Tracer gas was released into the workroom air and dispersed with a propeller fan to make the concentration as uniform as possible. When the release of tracer gas had stopped, the decay of the tracer gas concentration was recorded continuously with the infrared analyzer. The air exchange rate was then calculated from the exponential part of the decay curve.

The temperature of the air in the work zone and near the ceiling, as well as of the supply air, and the outdoor temperature were measured three times during the washing period with an electrical thermometer (YSI model 42SC). The average of the observations is given in table 2 in the Results section.

Estimation of solvent consumption

In most of the washing facilities solvent was fed into the spray guns from large reservoirs, and this process precluded the determination of solvent consumption

during the measurements. Furthermore, no adequate records on average daily solvent consumption were systematically available. Thus another approach had to be used to assess the solvent consumption. The number of cars washed during the measurement period was recorded for each plant. The average number of vehicles washed per hour was used as a parameter of the rate of solvent consumption. This technique did not, however, allow comparison between the washing of automobiles and the washing of heavy vehicles because of the basically higher solvent consumption during the cleaning of heavy vehicles. The volume of dilution air per vehicle washed was obtained by dividing the ventilation airflow rate by the average number of vehicles washed per hour.

Table 1. Solvent concentration in personal sampling.

Car wash number	Number of workers	Solvents ^a	Number of samples	Time-weighted average (mg/m ³)	Range (mg/m ³)
<i>Automobiles</i>					
1 ^b	4	WS	14	150	60–285
	2	WS	4	125	110–150
2	1	WS	2	120	40–195
3	5	HF	20	160	90–235
4	2	DAHF	8	20	5–40
5	1	DAHF	4	95	55–140
6	1	DAHF	4	145	95–170
7 ^b	2	HF	6	245	170–270
	2	HF	9	370	240–465
<i>Heavy vehicles</i>					
8	2	DAHF	8	105	45–230
9	1	HF	3	145	115–160
10	2	WS	7	370	225–505
11	2	WS	8	460	210–805

^a WS = white spirit, HF = high flash, DAHF = dearomatic high flash.

^b Measured on two days.

Results

Solvent concentrations and air temperatures

During automobile washing, the time-weighted average concentration of the solvent ranged from 5 to 465 mg/m³ for personal samples (table 1) and from 15 to 390 mg/m³ for stationary samples (table 2). For heavy vehicles, the corresponding figures were 45–805 mg/m³ for personal samples (table 1) and 40–685 mg/m³ for stationary samples (table 2). During various work phases, there occurred brief concentration peaks as high as 4 570 mg/m³ (table 3 and figures 1 and 2).

The absolute value of the concentration gradient was usually less than 10 mg · m⁻³ · m⁻¹. A negative concentration gradient denotes lower solvent content near the ceiling than in the work area (table 2).

The air temperature in the work zone varied between 18 and 24°C (table 2). Because the measurements were carried out during the heating period in all the car washes except number 4, the supply air temperatures were higher than those in the work zone. The vertical temperature gradient was usually less than 0.7°C/m.

Ventilation parameters

All 11 car washes had mechanical general ventilation. The design of the ventilation system in the shops varied widely. Two car washes had exhaust fans only. Seven were provided with downdraft ventilation. In two cases, supply air was introduced from the floor level. The physical dimensions of the washes, airflow rates, air exchange rates, and ventilation schemes are given in table 4.

For automobile washing, the air exchange rate ranged from 2.0 to 19.5 h⁻¹ and airflow rate from 0.3

Table 2. Solvent concentrations at stationary sampling sites and the ambient air temperatures in the car washes.

Car wash number	Solvent concentration in stationary sampling			Vertical concentration gradient (mg·m ⁻³ ·m ⁻¹)	Washing rate (vehicle/h)	Indoor air temperature (°C)	Vertical temperature gradient (°C/m)	Supply air temperature (°C)	Outdoor air temperature (°C)
	Number of samples	Mean (mg/m ³)	Range (mg/m ³)						
<i>Automobiles</i>									
1	12	80	35—120	+ 35	1.8	24	1.4	30	0
2	4	45	35— 60	— 8	1.0	20	0.3	26	— 14
3 ^a	3	85	60—125	+ 2	5.0	20	0.7	33	— 10
3 ^b	2	145	90—200	+ 8	5.0				
4	8	50	15—100	— 5	1.5	24	0.3	—	+ 15
5	8	80	30—135	— 12	1.0	20	0.6	29	— 2
6	4	100	60—115	— 6	0.8	19	0.3	—	— 10
7 ^c	8	205	150—290	— 70	2.0	24	2.2	29	— 5
	3	360	135—390	— 80	2.5	24	2.8	28	— 1
<i>Heavy vehicles</i>									
8	8	75	45—100	— 14	1.0	18	0.3	24	— 2
9	13	125	40—280	— 6	1.0	18	0.3	34	— 5
10	15	265	110—490	— 9	1.0	18	0.4	—	— 5
11	9	465	290—685	— 8	1.0	21	0.5	29	+ 8

^a Maximum fan speed.

^b Half-fan speed.

^c Measured on two days.

to 3.9 m³/s. In car washes where heavy vehicles were being washed, the air exchange rate ranged from 3.5 to 9.5 h⁻¹, and the airflow rate from 0.7 to 2.1 m³/s.

Figure 3 presents the relationship between the time-weighted average solvent concentration in stationary sampling and the volume of dilution air per car washed. The lines were calculated by the method of least squares.

Discussion

All the time-weighted average concentrations for the active washing time were below the accepted occupational exposure limit for Stoddard solvent (525 mg/m³).

The short-term concentrations were much higher than the 15-min exposure limit for Stoddard solvent (1 050 mg/m³) (2). Although the concentration peaks lasted only a few minutes at a time, they occurred throughout the workday when very dirty cars or warm engines were washed. During the concentration peaks workers experienced eye irritation and lacrimation.

The airflow rates measured were approximately the same during the washing of automobiles and heavy vehicles, but the observed solvent concentrations were higher for heavy vehicles. This difference was due to the higher solvent consumption rate during the washing of heavy vehicles. It is apparent from figure 3 that an average solvent concentration of less than, eg, 100 mg/m³ can be obtained by dilution air volumes of ap-

proximately 2 500 m³ per automobile washed or 6 500 m³ per heavy vehicle washed. It is obvious that the flow rates measured in car washes 6 and 7, as well as in washes 10 and 11, may be too low to control solvent exposure at higher washing activities than during measurements. Even at higher flow rates the concentration peaks may still present a problem, and therefore an adequate system of supply air distribution is important.

There was much variation in the way fresh supply air was introduced and contaminated air exhausted in the different car washes, the result being different air-

Table 3. Solvent concentrations measured by the portable gas chromatograph during solvent spraying and hot water washing.

Car wash number ^a	Number of samples	Mean (mg/m ³)	Median (mg/m ³)	Maximum (mg/m ³)	Percentage of samples with values higher than 1 050 mg/m ³
<i>Automobiles</i>					
1					
2	20	155	115	800	0
3	102	420	200	3 000	9
4					
5	37	1 090	780	4 570	33
6					
7	79	880	650	3 630	32
<i>Heavy vehicles</i>					
8	49	820	600	3 250	21
9	57	420	350	1 000	0
10	31	855	900	1 520	33
11					

^a Measurements not made in shops 1, 4, 6 and 11.

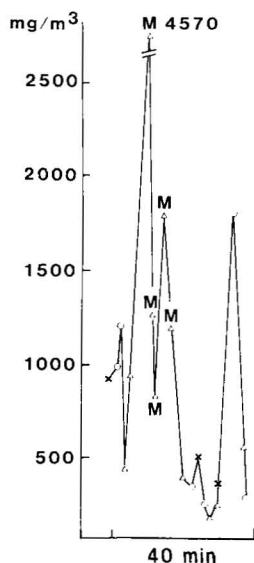


Figure 1. Example of a variation profile of airborne solvent concentration in the workers' breathing zones during automobile washing. (x = spraying with solvent, Δ = flushing with hot water, o = washing with a sponge, M = engine wash)

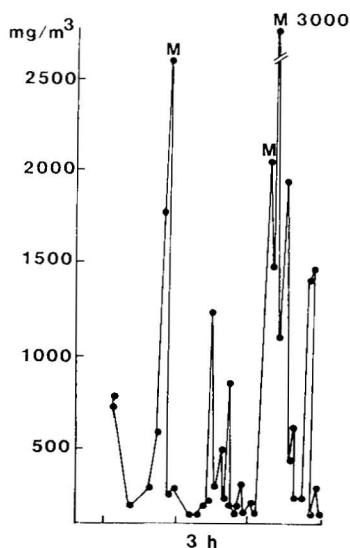
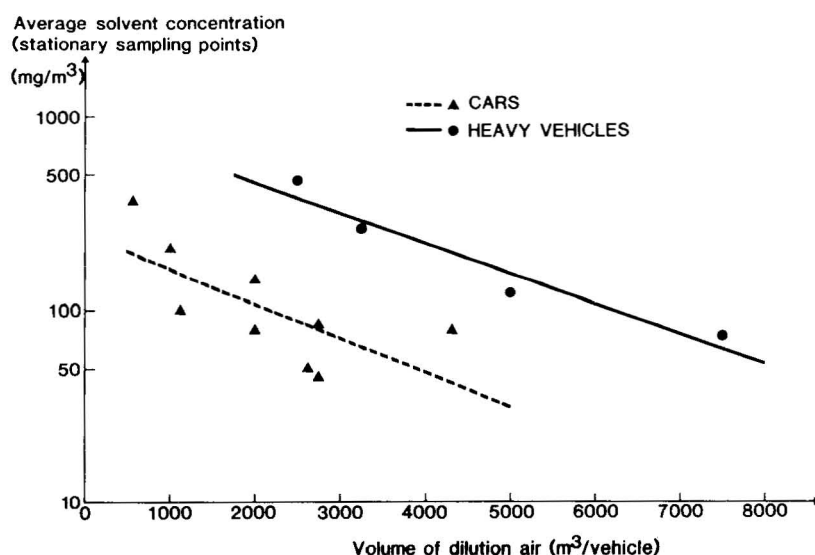


Figure 2. Example of a variation profile of airborne solvent concentration in the workers' breathing zones in a large car wash (M = engine wash)

Table 4. Ventilation parameters of the car washes.

Car wash number	Volume of car wash (m ³)	Height of car wash (m)	Airflow rate (m ³ /s)	Air exchange rate (h ⁻¹)	Ventilation schemes
<i>Automobiles</i>					
1	460	5.5	2.2	17.5	Supply air from two ducts at the long walls at 3.8 m above the floor; the exhaust air terminals near the floor and the ceiling
2	430	6.0	0.8	6.5	Supply air from one grille near the ceiling; exhaust air through the floor
3 ^a	730	5.0	3.9	19.5	Supply air upwards from the floor
3 ^b	730	5.0	2.7	13.5	grilles at the doors; the exhaust air terminals near the ceiling and the floor
4	280	5.8	1.1	15.0	No mechanical supply air system, clean air through door opening from an adjoining repair shop; the exhaust air terminals near the ceiling and the floor
5	210	5.5	0.6	9.5	Supply air from three grilles at one long wall at 4.0 m above the floor; exhaust air through the floor
6	470	5.0	0.3	2.0	No mechanical supply air system; an exhaust grille in the back wall
7 ^c	260	4.2	0.6	7.5	Supply air from four grilles at the long wall near the ceiling; the exhaust air terminals near the ceiling and floor
			0.4	5.5	
<i>Heavy vehicles</i>					
8	780	8.0	2.1	9.5	Supply air from two ducts at the long walls at 6.5 m above the floor; exhaust air through the floor
9	1100	6.5	1.4	4.5	Supply air from two diffusers located at opposite ends of the room near the ceiling; the exhaust air terminals near the ceiling
10	570	4.8	0.9	5.5	Supply air from one grille at the long wall; most exhaust air terminals near the ceiling, one near the floor
11	760	5.5	0.7	3.5	Supply air horizontally from the sides of the doors; the exhaust air terminals near the ceiling

^a Maximum fan speed.^b Half-fan speed.^c Measured on two days.**Figure 3.** Correlation of average solvent concentration in stationary sampling and the volume of supply air per vehicle.

flow patterns and concentration distributions. In nine car washes the vertical concentration gradient was negative and therefore indicated that the air in the work area was more contaminated than that in the upper part of the room.

The highest negative concentration gradient, $-80 \text{ mg} \cdot \text{m}^{-3} \cdot \text{m}^{-1}$, was observed in car wash 7, which was fitted with downdraft ventilation (table 3). In this workplace the warm supply air became stratified in the upper part of the work space, and the contaminated air remained mainly in the work area. This occurrence was also confirmed by the exceptionally high temperature gradient, from 2.2 to 2.8°C/m. The same phenomenon was observed on a smaller scale in car washes 5 and 8, which were also fitted with downdraft ventilation. In these three washes, as well as in car wash 10, the occurrence of high concentration spikes was a notable problem. However, the time-weighted average concentrations in car washes 5 and 8 were relatively low. It is therefore obvious that, when the supply air is poorly distributed to the breathing zone, high concentration peaks occur. This finding is in agreement with that of West (13), who showed, under controlled laboratory conditions, that, when a gas source is located in a stagnant region of the occupied zone, high concentration spikes are detected throughout the ventilated space.

In car washes 1 and 3 the vertical concentration gradient was positive. In the former, where the supply air was discharged from two ducts mounted on the long walls at 3.8 m above the floor, the relatively high gradient value of $+35 \text{ mg} \cdot \text{m}^{-3} \cdot \text{m}^{-1}$ was detected. This value indicated that the supply air flushed the work zone efficiently. In car wash 3, where the highest airflow rates were measured, the supply air was introduced into the work area from the floor level. Only a few high concentration spikes were observed in this workplace. In car wash 2, fitted with downdraft ventilation, and in car wash 9, where the supply air was introduced from the ceiling level and extracted through the ceiling, no concentration peaks higher than 1 050 mg/m³ were observed.

The findings of this study emphasize the adequate distribution of the supply air for controlling localized short-term solvent concentrations. When the downdraft ventilation principle is applied, it is essential that the supplied air be directed very carefully to the work area and that the buoyancy forces of the jets be taken into account. Furthermore, in order to lower concentration peaks, the ventilation rate should be higher during times of high emission. Therefore, ventilation fans should be provided with two-speed motors, the lower speed for continuous drive, the higher one for use during solvent spraying and hot water flushing.

Theoretically, high flash solvent vaporizes less readily than solvent with a lower boiling point. Therefore, one would have expected the airborne solvent concentrations to have been lower during washing with high flash solvents. No such difference between the two

types of solvent was observed, however. The obvious explanation is that the droplets of the spraying mists vaporize. It has been shown (5, 9) that the lifetime of droplets of a solvent with a boiling point of about 175°C is on the order of 10 ms at room temperature. In addition, the lifetime decreases rapidly with rising temperature. In practice mist droplets of high flash solvents vaporize almost as rapidly as those of lower boiling Stoddard solvent. Therefore there is little difference in airborne vapor concentration.

Insufficient work experience may cause high solvent concentrations in the workers' breathing zone. When two or more operators are working on the same car, they should be careful to avoid spraying each other. During spraying the operator should position himself between the supply air inlet and the surface being washed. The distance between the operator and the vehicle should be long enough to prevent exposure to solvent spatter. Access platforms or stepladders are often required to allow the operator to place himself correctly with respect to the supply airflow.

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