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Exposure assessment of organic solvents for aircraft paint stripping and spraying workers

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Abstract

The main objective of this study is to investigate the personal or area exposure of organic solvents during paint stripping and paint spraying. Three aircraft paint stripping/spraying workplaces in Taiwan were selected, and the Council of Labor Affairs and NIOSH recommended sampling/analytical methods used in this study. Activated charcoal tubes were used to investigate the personal and area exposure concentration of organic solvents in paint stripping and paint spraying operations.

During aircraft paint stripping, experiment results show that methylene chloride personal exposure concentration at the ground area, 42.01 ± 31.86 ppm, is higher than that at the working platform 4 M high above the ground, 20.41 ± 11.43 ppm. Exposure concentration of methylene chloride in the initial paint stripping operation stage of every workplace is over the PEL (50 ppm) set by the Taiwan Council of Labor Affairs. Corrective actions are needed. During paint spraying, concentrations of all organic solvents were found to be below the PEL of OSHA.

Keywords: Aircraft maintenance; Methylene chloride; Organic solvents; Paint stripping

1. Introduction

Many aircraft maintenance activities involve the use of chemicals among which paint stripping and spraying use the most solvents (Ribak et al., 1995; Puhala et al., 1997; U.S. EPA, 1998; ILO, 1998). In traditional strippers, methylene chloride and phenol are the two main compositions, which consist of 50% and 15% by volume, respectively. In spraying paint,

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major compositions are base resin hardener and thinner, in which many kinds of solvents, including ketones, esters, and aromatic hydrocarbons are used (U.S. EPA, 1994). These solvents are listed as hazard compounds in the regulations of Taiwan Council of Labor Affairs. Excessive exposure to organic solvents may cause irritation of skin, mucous membranes, and eyes, and some may even cause toxication and increase cancer risk. The report on toxicological profile of methylene chloride by US Department of Health and Human Services highlights the physical, chemical properties of methylene chloride, its health affect, toxicity and the mechanism. The expert committee felt the need of adequate database to better access the human health. The study of 14,457 aircraft maintenance workers shows that organic solvents may increase the risk of non-Hodgkin's lymphoma and multiple myeloma (Blair et al., 1998; OSHA, 1998; Dell et al., 1999; ATSDR, 2000). Lemasters et al. (1999) researched on the effect of solvent exposure on the sperm mobility for aircraft assembly workers. Among the workers in sheet metal manufacturing, fueling, painting, and crew workers, the painting workers exposed to the highest VOC (volatile organic compound) concentration with a significant decline of 19.5% in the sperm mobility while other workers remained normal. The exposure of workers to organic compounds was measured in working atmosphere during paint stripping of a Boeing 747 and painting on an Airbus A320 (Vincent et al., 1994). Concentrations of many kinds of solvents were high and a hazard compound, EGEEA (ethylene glycol monoethyl ether acetate), was found in biological samples from the workers.

With the increasing demand of the commercial air flights in Taiwan, demand of aircraft maintenance is also increased each year. Therefore, the occupational hygiene and safety problems of these workers deserve attention. In this study, we focus on the exposure of paint stripping and spraying workers to VOCs. In Taiwan, this is a first attempt to study the solvent exposure of aircraft paint stripping and spraying workers. Our particular interest is to find out whether the PEL (permissible exposure limit) for methylene chloride and phenol set by Taiwan IOSH (Institute for Occupational Safety and Health), 50 ppm and 5 ppm, respectively, or the PEL of other VOCs set by OSHA (Occupational Safety and Health Administration) during spray painting is exceeded. Differences in the exposure concentrations of different aircraft models, different time periods, and different working locations were also investigated.

2. Methods

In order to compare the differences of exposure levels among different aircraft models (Boeing 747-400, Airbus A300, Military Carrier and Fighter Plane) during paint stripping/spraying operations, three hangars were selected: plant A (for Boeing 747-400 and Airbus A300, 80 m in width, 80 m in length, and 40 m in height, mainly for large and medium-sized aircrafts) ; B (for Military Carrier, 30 m in width, 30 m in length, and 20 m in height, mainly for medium- and small-sized aircrafts); C (for Fighter Plane, 20 m in width, 20 m in length, and 8 m in height, mainly for small-sized aircrafts). The size of the large aircraft is >300 seats, 50–300 seats for medium aircraft, and <50 seats for small aircraft. No ventilation system is used in plants B and C, but it is used in plant A. The ventilation system in plant A contains seven fans (20 hp/unit) at the top of the hangar and two exhauster (120 hp/unit, total flow rate = 34,000 m^3/h) under the working areas. The procedure of paint stripping and spraying shown in Figs. 1 and 2 is the same in these three plants.

Number of workers and time required for paint stripping or spray painting operation for each aircraft model differ because of the difference in aircraft size and the thickness of the old paint to be removed. For

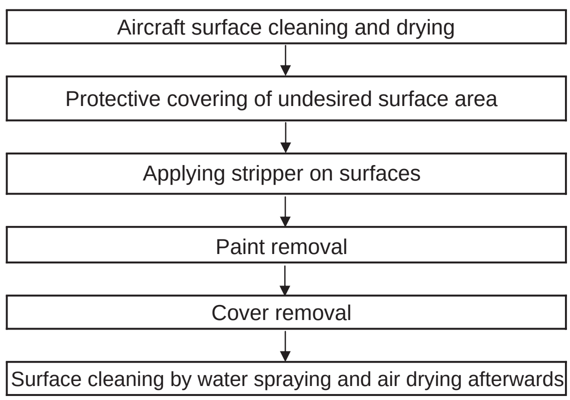

Fig. 1. Procedure of paint stripping.

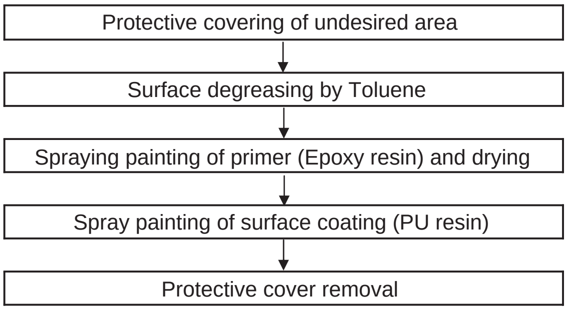

Fig. 2. Procedure of spray painting.

the paint stripping operation, Airbus A300 has the thickest paint to be removed and due to its large aircraft size, it normally takes one to two working days to complete the task. Other models take about half a day to complete the same operation because the layer of paint to be removed is thin (Boeing 747-400, and Military Carrier) and aircraft size is small (Fighter Plane). There are two 12-h shifts, and 6–15 workers per shift involve in the paint stripping of Airbus A300, while other models need only one shift and 5 workers/shift. For spray painting operation, there are two 8-h shifts and 15 workers per shift involve in it for Airbus A300, while other models need only one shift and 5 workers/shift. Normally, two layers of primer and one layer of surface coating are spray painted and each layer takes about half an hour to finish. The waiting time for each layer to dry before the next layer is painted is about 2 h.

During stripping operation workers wore safety helmet, activated-carbon mask, rubber gloves, high rubber overshoes and safety shoes. During spraying operation, workers wore activated-carbon mask, full-face respiratory equipment, whole-body protective garment and safety shoes. Because whole-body garment is heavy and too warm, workers took off the garment and the sampling equipment as well after 1-2 h of painting work, when the sampling also had to be stopped.

2.1. Sample collection during paint stripping operation

In our study, a direct reading instrument (MIRAN SapphIRe® Portable Ambient Air Analyzer, 205A Series) was used to preliminarily survey concentration of methylene chloride in working atmosphere. According to the preliminary test, the sampling flow rate of 30–50 mL/min was set to avoid breakthrough. This test also concluded that the time for area sampling should be limited to 4 h while that for personal sampling should be limited to 2 h to avoid breakthrough.

Based on the Council of Labor Affairs' recommended method, CLA-1210, Charcoal tube (100/50 mg sections, SKC 226.01) was used for sampling methylene chloride (Cassinelli and O'Connor, 1994). During personal sampling, charcoal tube was clipped to the lapel or face masks. During area sampling, the samplers were located at the same height as the worker's breathing zone, or 1.5 m above the ground for the ground level sampling or 1.5 m above the working platform (for the working platform sampling, the platform is about 4 m above the ground). For ground sampling, the samplers were placed on the nose gear and body gear directly. For platform sampling, the distance between the sampler and surface of the aircraft is about 1 m. Sampling lasted for 2 h for person sampling and 4 h for area sampling. Workers normally took a rest after working for 2 h and this tells why the personal sampling time was 2 h.

For sampling phenol, NIOSH recommended method 2546 was followed and XAD-7 (SKC, Cat. No. 226-95) was used and only area sampling was conducted. The flow rate was set at 150 mL/min and sampling lasted for 4 h. The locations of the samplers were the same as those for sampling methylene chloride.

In this study, the statistical tests of the data were based on the one-way ANOVA (analysis of variance) method.

2.2. Sample collection during paint spraying operation

Charcoal tube (100/50 mg sections, SKC 226.01) was used for sampling during spraying and the flow rate was set at 100 mL/min following the CLA-1210 method. During personal sampling, the charcoal tube was clipped to the lapel or face masks. Each personal sampling lasted for 1–2 h only and the number of samplers taken per worker that we chose to conduct sampling was two during the work period. As mentioned before, the reason for choosing 1 to 2-hr sampling time is that each spraying operation lasted

Table 1
Concentration of methylene chloride at different working areas, personal sampling, 2-h per sample, AirBus A300, plant A

	Ground	Platform (right wing)	Platform (left wing)	Platform (nose area)
Average (ppm)	42.01	23.44	20.41	21.60
Standard deviation (ppm)	31.86	12.81	11.43	14.90
# of samples	11	9	13	8
p-value[a]		0.0495		
p-value[b]		0.8625		

[a] Comparison of 4 different sites on ground and working platform.
[b] Comparison of 3 different sites on working platform.

for about 1–2 h. Workers had to remove the protection garment and discontinue the personal sampler after that.

All of the samples during paint spraying and painting operations were analyzed by using gas chromatography by a Taiwan IOSH certified laboratory.

3. Results and discussions

3.1. Exposure of organic solvents during aircraft paint stripping

3.1.1. Personal exposure of methylene chloride at different working areas

Methylene chloride personal exposure concentrations were measured during the total work period from 19:30 of the first day to 23:30 of the second day, for AirBus A300 at plant A. There are four different sampling locations: the ground level, the right wing, the left wing and the nose area on the working platform. Table 1 shows that the average concentration at these four different locations is 42.01, 23.44, 20.41 and 21.60 ppm, respectively, and it also shows statistically significant differences ($p=0.0495$) among these four average values. However, there are no statistically significant differences ($p=0.8625$) in average concentration at three different locations on the platform: right wing, left wing, and the head of the aircraft. Repeated measurements revealed that the deviation of concentrations at the ground area was larger than that on the platform since the working space of the ground area was larger and workers moved more freely on the ground. Also when the workers on the platform removed the paint, the paint settled down to the ground and evaporated. This is the possible cause for higher methylene chloride concentration close to the ground than that at the working platform.

3.1.2. Methylene chloride and phenol concentration at different time periods

Methylene chloride concentrations of area and personal samplings during paint stripping of AirBus A300 at plant A are summarized in Table 2. During personal sampling, the exposure concentration is decreased from 55.69 to 14.82 ppm monotonically during the 2-shift working period (19:30 of the first day, until 23:30 of the next day). Statistically significant differences ($p=0.0001$) are observed among methylene chloride concentrations at different time periods, which is 4.5 h per time period. That is, there is a clear trend of lowering methylene chloride

Table 2
Concentration of methylene chloride at different time periods, personal (2-h/sample) and area sampling (4-h sample), AirBus A300, plant A

Period	Personal sampling			Area sampling		
	Average (ppm)	Standard deviation (ppm)	# of samples	Average (ppm)	Standard deviation (ppm)	# of samples
19:30–00:00[a]	55.69	28.23	8	84.07	64.86	8
00:30–05:00[b]	34.93	14.89	8	74.88	112.93	9
10:00–15:30	19.91	11.71	8	6.67	3.05	6
12:30–17:00	16.23	3.64	8	19.82	16.59	6
20:00–23:30	14.82	7.27	10	13.51	6.05	4
p-value[c]		0.0000			0.1332	

[a] Day 1.
[b] Day 2.
[c] Comparison of 5 different periods.

Table 3
Concentration of phenol at different time periods, area sampling (4-hr/sample), AirBus A300, plant A

Period	Average (ppm)	Standard deviation (ppm)	Minimum (ppm)	Maximum (ppm)	# of samples
19:30[a]–05:10[b]	0.83	0.73	0.23	2.14	7
10:00–17:00[b]	1.06	1.36	0.24	3.81	6
20:00–23:30	1.21	0.96	0.57	2.62	4
p-value[c]			0.8293		

[a] Day 1.
[b] Day 2.
[c] Comparison of different periods.

concentration as more paint was removed and less solvent was applied as paint stripping proceeded. In comparison, during area sampling, exposure concentration at the first time period (84.07 ± 64.86 ppm) was the highest while it was lowered to the minimum at the third time period (6.67 ± 3.05 ppm), 10:00–15:30, when the paint stripping work was discontinued during the afternoon lunch hour while the area sampling still continued. The concentration was increased to the level of personal sampling during the fourth and fifth time periods. Because of the interruption of lunch hour, differences ($p = 0.1332$) in exposure concentrations at different time periods become insignificant.

Phenol concentrations of area sampling during paint stripping of Airbus A300 during different time periods are summarized in Table 3. Average concentrations at three time periods are 0.83 ± 0.73, 1.06 ± 1.36, and 1.21 ± 0.96 ppm, respectively. No significant difference ($p = 0.8293$) is seen among phenol concentrations at three periods. Phenol concentrations are well below the PEL of the Taiwan IOSH, 5 ppm.

3.1.3. Methylene chloride and phenol concentration of different aircraft models

Comparison of different aircraft models at the first 4 h, when the largest amount of solvent is used during paint stripping, is shown in Table 4. Comparison during other time periods is impossible since it takes less than half a day for other models to finish stripping except Airbus A300. It is seen that workers had the highest exposure to methylene chloride during stripping of Boeing 747-400 in plant A (116.09 ± 40.21 ppm), followed by Airbus A300 (80.08 ± 52.58 ppm), Military Carrier (94.57 ± 56.85 ppm) and Fighter Plane (31.48 ± 16.81 ppm). Highest concentration observed for Boeing 747-400 in plant A is due to its largest aircraft size, and more strippers were used than other models. Both AirBus A300 and Military Carrier are smaller in size than Boeing 747, less stripper was used and hence the concentration of methylene chloride is comparatively lower. The Fighter Plane is the smallest and requires the least amount of solvent, which explains its observed lowest methylene chloride concentration, 31.48 ppm.

From this table, it is seen that methylene chloride concentration of the large and medium-sized aircrafts is all higher than the PEL of 50 ppm set by Taiwan Council of Labor Affairs, which needs immediate corrective action. Unfortunately, owing to the large size of the hanger such as plant A (80 m in width, 80 m in length, and 40 m in eight), improving ventilation to reduce methylene chloride concentrations is difficult. Other alternative approach is to replace methylene chloride and phenol with less toxic compounds to lower the exposure risk. The hazard of using strippers can also be reduced by using physical or mechanical stripping process.

Table 4
Comparison of different aircraft models during paint stripping, area sampling at the first 4 h

Plant	Aircraft	Methlyene chloride		Phenol	
		Average (ppm)	Standard deviation (ppm)	Average (ppm)	Standard deviation (ppm)
A	Boeing 747-400	116.09	40.21	0.88	0.38
A	AirBus A300	80.08	52.58	0.83	0.73
B	Military carrier	94.57	56.85	1.99	1.10
C	Fighter plane	31.48	16.81	0.52	0.48
p-value[a]		0.0625		0.0374	

[a] Comparison of 4 different aircrafts.

From Table 4, phenol concentrations are seen to be low for different aircraft models. The concentrations are well below the permissible exposure limit (PEL = 5 ppm). Significant difference ($p = 0.0374$) among concentrations of different models is also observed. During stripping of Military Carrier, phenol concentration is the highest followed by other models.

3.2. Personal exposure of VOCs during paint spraying

Personal sampling concentrations of VOCs during primer and surface paint spraying are listed in Table 5. During primer spraying, the concentrations of toluene (6.55 ± 2.44 ppm) and isobutyl ketone (3.52 ± 0.19 ppm) during spraying on large-sized aircrafts are higher than other chemical compounds. During spraying on medium-sized aircrafts, concentrations of toluene (10.72 ± 8.28 ppm), isobutyl ketone (5.55 ± 4.96 ppm), MIBK (3.73 ± 2.74 ppm) are higher than other compounds. During spraying on small-sized aircrafts, concentrations of acetone (18.85 ± 24.46 ppm), xylene (5.03 ± 2.87 ppm), toluene (3.09 ± 2.13 ppm) are higher than other compounds. However, all concentrations of organic solvents are below the PEL of OSHA, which is also listed in Table 5 for all compounds.

Table 5
Concentration of VOCs during paint spraying, personal sampling, 1–2 h/sample

Work place	Solvent	OSHA PEL (ppm)	Primer			Surface paint		
			Average (ppm)	Standard deviation (ppm)	# of samples	Average (ppm)	Standard deviation (ppm)	# of samples
Plant: A	MIBK	50	1.99	0.81	8	1.65	1.01	6
	n-Butyl Acetate	150	1.29	0.88	8	4.03	2.12	6
Boeing 747-400	Butanone	200	0.76	0.30	8	1.80	1.87	6
	Xylene	100	0.77	0.25	8	0.68	0.21	6
	Acetone	750	1.32	0.48	8	1.90	0.60	6
	Isobutyl ketone	50	3.52	0.19	8	12.77	8.36	6
	Toluene	100	6.55	2.44	8	5.93	7.27	6
	Benzene	5	0.77	0.32	8	0.94	0.30	6
	Cyclohexanone	25	0.66	0.27	8	3.26	2.66	6
Plant: A	MIBK	50	3.73	2.74	9	0.93	0.52	9
AirBus A300	Ethyl acetate	400	2.49	2.15	9	2.54	1.32	9
	n-Butyl Acetate	150	1.79	1.93	9	3.55	1.85	9
	Butanone	200	0.18	0.03	9	0.17	0.04	9
	Xylene	100	0.48	0.38	9	0.18	0.08	9
	Acetone	750	4.28	4.67	9	0.72	0.10	9
	Isobutyl ketone	50	5.55	4.96	9	14.34	8.52	9
	Toluene	100	10.72	8.28	9	5.16	2.81	9
	Benzene	5	0.19	0.04	9	0.15	0.02	9
	Cyclohexanone	25	0.32	0.06	9	2.70	3.01	9
Plant: C	MIBK	50	1.65	1.26	5	1.59	0.43	2
Fight plane	Ethyl benzene	100	1.82	0.92	5	3.03	1.06	2
	Ethyl acetate	400	0.16	0.08	5	0.18	0.02	2
	n-Butyl acetate	150	2.08	0.95	5	4.63	1.60	2
	Xylene	100	5.03	2.87	5	7.31	2.53	2
	Acetone	750	18.85	24.46	5	0.23	0.02	2
	Isobutyl ketone	50	0.10	0.05	5	0.12	0.01	2
	Toluene	100	3.09	2.13	5	9.37	3.73	2
	Benzene	5	0.14	0.07	5	0.19	0.02	2
	Styrene	50	1.25	0.68	5	1.97	0.68	2
	Cyclohexanone	25	0.12	0.06	5	0.17	0.02	2

During surface painting, the concentrations of isobutyl ketone (12.77 ± 8.36 ppm), toluene (5.93 ± 7.23 ppm), and n-Butyl Acetate (4.03 ± 2.12 ppm) for large-sized aircrafts are higher than other chemical compounds. Concentrations of isobutyl ketone (14.34 ± 8.52 ppm), toluene (5.16 ± 2.81 ppm), and n-Butyl Acetate (3.55 ± 1.85 ppm) during spraying on medium-sized aircrafts are higher, and concentrations of toluene (9.37 ± 3.73 ppm), xylene (7.31 ± 2.53 ppm), and n-Butyl Acetate (4.63 ± 1.60 ppm) during spraying on small-sized aircrafts are higher than other chemicals. Again, all concentrations of organic solvents are below the PEL of OSHA.

For environmental and safety considerations, more environmental friendly solvents that contain high solid ingredient are used recently. Paint of high solid ingredient was used in these three plants selected. Therefore, organic solvents, including MIBK, acetone, Methyl Ethyl Ketone, isobutyl ketone, cyclohexanone, ethyl acetate, n-Butyl acetate, benzene, toluene, xylene, ethylbenzene, and styrene are all below the PEL of OSHA.

4. Conclusion

The study suggests that there is maximum concentration of methylene chloride close to the ground as compared that on the working platform. Secondly, the methylene chloride concentration during different work periods and for different aircraft models exceeds the PEL limit set by the Taiwan Council of Labor Affairs. The existing ventilation system in plant A does not help to reduce the concentration of methylene chloride. Immediate corrective actions are needed. One of the technologies such as physical or mechanical stripping process for paint stripping in the aeronautical industry can be used to reduce the exposure to methylene chloride (Robert, 1996; SRRP, 1991).

During spray painting, this study shows that current spray painting practice in Taiwan's aviation industry uses paint which contains high solid ingredient reduces organic solvents concentration in working atmosphere. In this study, personal exposure of VOCs during paint spraying is found to be lower than the standards set by OSHA.

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