

REVISING ORGANIC VAPOUR RESPIRATOR CARTRIDGE CHANGE SCHEDULE: A CASE STUDY OF A PAINT PLANT IN IRAN

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After having revised the change schedule for organic vapour respirator cartridges in a paint plant in Iran, we established that it did not provide adequate protection against organic vapours at some workplaces and needed shortening from (48 to 72) h to 4 h. The revision also showed that relying on odour thresholds as the primary means to determine the time to change a chemical cartridge was not effective and that the National Institute for Occupational Safety and Health (NIOSH) MultiVapor service life software program could be applied to develop cartridge change schedules adjusted to specific workplaces.

KEY WORDS: *chemical cartridge, NIOSH, odour threshold, service life*

In the processes involved in paint manufacture (such as mixing, milling, and shearing) workers are exposed to organic solvents that may cause a variety of symptoms, including transient symptoms of the central nervous system such as euphoria, headache, and dizziness at low or moderate concentrations and serious symptoms such as fainting and respiratory and circulatory failure at high concentrations. Some of these solvents such as benzene, toluene, and xylenes (BTXs) are known or suspected carcinogens and need effective control.

In paint manufacture, workers should wear suitable types of respirators throughout the work processes to minimise exposure to organic vapours, especially when work is carried out in poorly ventilated conditions.

Most air-purifying respirator cartridges for organic vapour contain a packed bed of activated carbon granules. The service life (breakthrough time) of cartridges depends on the amount of sorbent in the cartridge, activated carbon properties, or bed geometry

and conditions of use (concentration of indoor organic vapours, relative humidity and temperature, and workers' respiratory rates) (1, 2).

According to the Occupational Safety and Health Administration (OSHA) respiratory protection standard (3), if there is no end-of-service-life indicator (ESLI) for canisters and cartridges, a change schedule should be based on objective information which will ensure that canisters and cartridges are changed before the end of service life. Change schedules will provide workers who are using air-purifying respirators information when cartridges no longer provide adequate protection. OSHA suggests three valid ways to estimate cartridge service life and establish a change schedule for them: experimental tests, manufacturer's recommendation, and a mathematical model (4).

Several studies have evaluated and developed models for the estimation of the service life of organic vapour cartridges. Nelson et al. (5) determined the service life for organic vapour cartridges for a wide variety of air flow concentrations, air flows, humidity

and temperatures (6), and solvent vapour concentrations (7). They also presented an empirical model for estimating cartridge service life (8).

Different models and equations have been proposed for estimating the service life of cartridges, including the D/R, Mecklenburg, Wheeler, Yoon, and Wood equations (9). The most common model used by OSHA and some manufacturers is the Wood math model (12) for estimating the service life of single (11) and multiple organic vapour cartridges (12) at different humidity levels.

However, most of these studies have failed to look at the practical aspects of establishing change schedules at specific workplaces. Furthermore, developing a cartridge change schedule is a new exercise for most respirator users. Because standard approaches to setting a change schedule have neither been developed nor validated, there is uncertainty about their efficacy (13).

Therefore, the aim of our study was 1) to evaluate the efficacy of the current cartridge change schedule in workers using air-purifying respirators against organic vapours and 2) to propose a new cartridge change schedule according to cartridge specifications and workplace conditions.

MATERIALS AND METHODS

Existing change schedule evaluation

The efficacy of the existing change schedule of air-purifying respirator cartridges used in a paint manufacturing plant was investigated using a procedure recommended by OSHA (3). Tanaka et al. (14) found this procedure useful for determining the service life of chemical cartridges and for scheduling cartridge change before workers are exposed to hazardous vapour concentrations.

The apparatus used for this purpose was made of detector tubes (as direct reading instruments), a leak-free cartridge holder, adaptors, inert tubing and Teflon tee, sampling tube, and a sampling pump, as shown in Figure 1. To evaluate the efficacy of the existing change schedule, we tested 10 randomly selected cartridges for benzene breakthrough by passing air through them just before the scheduled replacement. The schedule was considered inefficient if benzene broke through in concentrations above the occupational exposure limit.

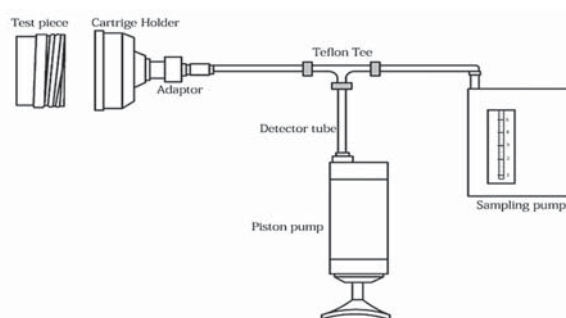


Figure 1 Schematic diagram of a set-up for testing cartridge change schedule

Workplace conditions (cartridge use conditions)

Determination of workplace conditions (cartridge use conditions) included organic vapour concentrations, temperature, relative humidity, and workers' respiratory rate.

We measured the concentrations of benzene, toluene, and xylenes (BTX) both as a representative set of organic vapours and as the most common organic compounds found in paint manufacturing. For this purpose, we collected 32 personal air samples from workers' breathing zones (as a similar exposure group). Samples were collected with SKC model 224-44EX pumps, flowing air at approximately 50 mL min⁻¹ on charcoal tubes (coconut charcoal 20/40 mesh, 50/100 mg, SKC, USA) with a 100-mg sampling section and 50-mg back-up section. Before each use all pumps were calibrated using a calibrated rotameter. Sampled air and contaminant vapour volumes were corrected for density variation to ambient temperature of 25 °C and pressure of 101.33 kPa.

We also calculated cumulative exposure over the eight-hour work shift based on the frequency and duration of exposure of employees wearing respirators, excluding the time for lunch breaks.

A standard OSHA analytical procedure (No. 12) was used to analyse air samples (15). Briefly, organic chemicals were desorbed from charcoal using CS₂ and analysed by gas chromatography (Shimadzu 175A series with a flame ionisation detector, Shimadzu, Japan) operated in a split mode. Thirty-two major peaks were identified in daily samples based on a comparison of retention times and mass spectra to peaks from a calibration standard.

To estimate the service life of a cartridge we used the worst-case organic vapour concentration, calculated by adding standard deviation to the mean concentration.

We also measured other workplace conditions that could influence the service life of a cartridge, including indoor relative humidity and temperature at the workplace using a digital humidity/temperature meter (model MTH-1361, Thaimeter, Thailand) and took maximum values for cartridge service life estimation.

Workers' respiratory rates were estimated based on the type of work (mixing, milling, or shearing) and this amount was used as total airflow passed through the respirator cartridge.

Estimation of service life based on NIOSH MultiVapor software

To estimate cartridge change schedule based on the measured data we used NIOSH MultiVapor software (16), which is based on a model designed by Gerry O. Wood (10). A number of software has been developed for the estimation of cartridge service life. OSHA has developed one (Advisor Genius) to predict the service life of organic vapour respirator cartridges when used as protection against single contaminants (17). In fact, most available programs to calculate breakthrough time are based on exposure to a single contaminant and are strongly influenced by high humidity. However, NIOSH has recently developed the MultiVapor program, which can be used for both single and multi-vapour contaminants, and we found it to suit our needs best.

Evaluation of the efficacy of the developed change schedules (field testing)

If organic vapours were not detected in the used cartridges, it meant that no significant breakthrough had occurred, and the cartridge change schedule was considered valid. However, if breakthrough had occurred, the schedule was shortened (usually by one hour) and the test was repeated.

RESULTS AND DISCUSSION

The paint plant employed 15 operators (five in each shift), who worked 10 hours a day, six days a week. Workers wore half-face respirators to protect themselves against organic vapours for eight hours. The usual period for changing the cartridges was weekly (48 h to 60 h). All processes including mixing, milling, and shearing (canning) were carried out in one hall and natural ventilation was the only means

of handling air pollutants in the absence of ventilation systems. Partitioning the process was not feasible because of transportation and technical problems. The lids of paint tanks, which influence the ventilation capacity, could not close properly.

Each cartridge contained 46.39 g of sorbent. According to the manufacturer carbon micro-pore volume was $0.533 \text{ m}^3 \text{ g}^{-1}$, average carbon granule diameter 0.15 cm, carbon bed diameter 8 cm, and depth 2.2 cm.

The existing schedule for changing the cartridges in the plant ranged from two to three working days (48 h to 72 h). In fact, workers themselves decided when to change it, depending how well they tolerated odour or whether they had difficulty breathing. To evaluate the efficacy of this cartridge change schedule a breakthrough of benzene was tested in the workplace, just before the usual cartridge change. This was done for 10 cartridges using the method described above.

A benzene breakthrough was observed in five cartridges, suggesting that the existing cartridge change schedule in the workplace was not efficient and that workers could be exposed to organic vapours, especially as there was no engineering control (exhaust ventilation) in the studied workplace.

Workplace air monitoring and characteristics

Table 1 shows the results of air monitoring and other workplace characteristics which are required for developing a cartridge change schedule, including air humidity and temperature. Concentrations of organic solvent vapours were significantly higher than the American Conference of Industrial Hygienists ACGIH threshold limit value (TLV) for the eight-hour time weighted average (TWA) (Table 1, $P < 0.05$).

To estimate cartridge service life, we used the worst-case concentrations of organic solvent vapours in the spraying booth, calculated by adding the mean measured concentration to its standard deviation. These concentrations were 115.5, nine, and three times higher than their ACGIH TLV for benzene, toluene and xylenes, respectively.

Air temperature and relative humidity in the spraying booths were $(20.83 \pm 0.68) ^\circ\text{C}$ and $(54.5 \pm 0.5) \%$, respectively, which are the worst-case conditions of the workplace.

Air was passed through the respirator cartridge at a flow rate of 37 L min^{-1} , which was the average respiratory rate for operators wearing respirators and doing moderate to heavy work in the paint plant.

Table 1 Workplace air and other characteristics

Parameter	n	M±SD	TLV	MD	t	Significance (2-tailed)*	Worst case condition**
Concentration / ppm	Benzene	31.98 ±26.08	36.05	0.114	5.09	0.001	58
	Toluene	105.82±74.88	91.44	0.344	4.42	0.002	181
	Xylenes	231.76±68.53	212.92	0.945	6.99	0.000	300
Temperature / °C	6	20.83±0.68	-	-	-	-	22
Relative humidity / %	6	54.5±0.5	-	-	-	-	55

M±SD: mean ± standard deviation; MD: mean difference; TLV: threshold limit value (ACGIH eight-hour TWA).

*One-sample test

**Worst-case conditions were calculated by adding standard deviation to the mean

Table 2 Estimation of cartridge service life with the NIOSH MultiVapor software

Test agent	Test conditions	Challenge concentration / ppm	Breakthrough criteria / ppm (50 % TLV)	Breakthrough time / min
Single vapours	Benzene	58	0.25	1437
	Toluene	181	10	839
	Xylenes*	291	50	616
Mixtures	Benzene, toluene and xylenes		0.25	276

* Estimation for xylenes was based on the primary component of *m*-xylene;

Cartridge testing and service life estimation

Table 2 shows the estimation of cartridge service life using the NIOSH MultiVapor software. In the extreme conditions, we estimated that the cartridges would resist the breakthrough of single contaminants benzene, toluene, and *m*-xylene for no longer than 23.95 h, 13.98 h, and 10.26 h, respectively. However, in the real-life situation with a mixture of these contaminants, the cartridges' maximum breakthrough time was 4.6 h. This breakthrough time was taken as a rough benchmark for setting the change schedule to four hours, following the procedure recommended by OSHA (3).

Although there are uncertainties associated with cartridge change schedules, it is believed that they present less of a public health problem than would relying on odour as a warning sign (18). Relying on odour thresholds alone is not effective because it involves human senses, which are fallible. Moreover, odour detection thresholds vary substantially in the general population and may shift due to extended low exposure and illnesses such as simple cold (13).

When the odour threshold of a compound is greater than its TLV, overexposure is quite likely. For benzene, the odour threshold is about 4.7 ppm (15015 µg m⁻³) (19) or about ten times its occupational exposure limit in Iran (0.5 ppm or 1597 µg m⁻³). In contrast, the odour threshold of xylene is 1 ppm (4342 µg m⁻³) while the

current ACGIH TLV-TWA is 20 ppm (86847 µg m⁻³) (20) and is considered reliable enough. While the case may be similar with toluene, with its odour threshold being well below the permissible exposure limit (PEL) (2.49 ppm vs. 100 ppm or 9383 µg m⁻³ vs. 376851 µg m⁻³), individual variations are so large that it cannot be relied on (22).

OSHA's revised respiratory protection code has therefore abandoned using odour threshold. Instead, OSHA requires that an effective cartridge change schedule should identify the service life of a chemical cartridge at a particular workplace. This ensures that chemical cartridges could be used even for chemicals with poor warning properties.

To verify whether our own four-hour change schedule estimate really worked, we tested ten cartridges and found no benzene breakthrough in any of them. Even so, we believe that change schedules should be re-evaluated regularly and every time workplace conditions change.

Ideally, the best change schedules are based on cartridge breakthrough tests under worst-case conditions of contaminant concentration, humidity, temperature, and air flow (5), but in practice this method is difficult and time-consuming. Therefore, the NIOSH's service life software program provides a feasible alternative.

CONCLUSION

Needless to say, the best way to control exposure to organic vapours at the studied workplace would be to use a ventilation system that would provide a continuous flow of air of acceptable quality and velocity at all points in the operators' breathing zone. Air purifying respirators are generally considered a supplemental control measure and can hardly replace ventilation systems. In addition, a comprehensive respiratory protection program with all the elements including medical monitoring and fit testing should be implemented.

For the time being however even proper cartridge change scheduling can provide some degree of protection to the workers.

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Sažetak**REVIZIJA RASPOREDA ZAMJENE FILTARA RESPIRATORA ZA ZAŠTITU OD ORGANSKIH PARA U POGONU ZA PROIZVODNJU BOJA**

Nakon revizije rasporeda zamjene filtera respiratora u pogonu za proizvodnju boja u Iranu utvrđeno je da postojeći raspored ne pruža odgovarajuću zaštitu od organskih para na pojedinim radnim mjestima te da ga treba skratiti s postojećih 48 h do 72 h na 4 h. Revizijom je također utvrđeno da vrijeme zamjene filtera na temelju osjeta mirisa nije djelotvorno te da se za utvrđivanje rasporeda zamjene filtera i njegovu prilagodbu pojedinomu radnomu mjestu može primijeniti računalni program za određivanje vijeka trajanja filtera MultiVapor koji je osmislio američki Nacionalni institut za sigurnost na radu i medicinu rada (National Institute for Occupational Safety and Health, krat. NIOSH).

KLJUČNE RIJEČI: *kemijski filter, prag mirisa, vijek trajanja filtera*

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