

ORGANIC VAPOR CARTRIDGE TESTING, SELECTION AND USE

Ernest S. Moyer and Herbert Linn

Department of Health and Human Services
National Institute for Occupational Safety and Health
Division of Safety Research
Morgantown, West Virginia 26505

Abstract

Numerous diverse factors must be accurately evaluated prior to the proper selection of an organic vapor (OV) air-purifying respirator.

Environmental factors such as oxygen level, contaminant composition, contaminant concentration, temperature and relative humidity must all be considered. Other factors, like the particular **wearer's** workrate and the **contaminant's** warning properties, must be assessed. All of these parameters must be properly evaluated in order to ensure worker safety. The Federal regulations concerning respirators (30 CFR Part 11) has built-in safety precautions as it relates to some of these parameters. For example, the regulations specifically address the issues of warning **properties**, **use concentrations**, and restrictions on use. However, even with these limitations, knowledge of the possible factors which influence performance characteristics of OV cartridges is essential.

The purpose of this paper is to outline the test criteria currently employed for evaluation of OV respirator cartridges, and to discuss the multiple factors which influence the performance and therefore the selection and use of these cartridges.

Introduction

Organic vapor (OV) and gas air-purifying respirators are used to protect their wearers from exposure to toxic vapors and gases in the ambient work environment. Such respirators are used routinely in diverse industrial environments, and the protection they afford is greatly affected by the wide variety of conditions in which they are used. However, the cartridges used in these respirators are currently tested under limited conditions which do not adequately reflect potential applications in the field. Thus, accurate evaluation of the conditions and circumstances of use is essential. Environmental factors such as oxygen level, relative humidity, and temperature must be considered, as well as characteristics of the contaminant(s) such as composition, concentration(s), warning properties, and adsorption characteristics which are reflected in breakthrough time(s). Also, factors such as the wearer's workrate, which determines the flow characteristics and the facepiece fit must be considered in order to properly select and use these devices.

Laboratory Testing

In general, the laboratory test data available on OV respirator cartridges is quite limited. To be "NIOSH/MSHA Approved," these cartridges, as received from the manufacturer, must provide protection for at least 50 minutes against 1000 ppm of carbon tetrachloride when tested at 50 $\pm$ 5 percent relative humidity, 25°C, and a continuous flowrate of 64 l/min. A preconditioned cartridge or pair of cartridges

(conditioned for 6 hours at 25 l/min. and 85 percent or 25 percent relative humidity) must provide the same duration of protection under those identical test conditions with the exception that the flowrate is reduced to 32 l/min. (It should be noted that this reduction in flow may offset the effect of preconditioning; thus, the value of these latter tests is questionable.)

Nelson and Harder (1972) showed that there was little difference between data obtained with a mechanical breathing simulator and steady state flow. Thus, the use of steady state flow for the testing of organic vapor and gas cartridges appears justified for such respirators with an exhalation valve. However, recent data indicates that this may not be the case for all organic substances (Wood et al. Oct. 1978 - Sept. 1982). For methyliodide, the cyclic flow penetration was greater than steady state flow penetration by a factor of 1.2 - 2.4 at a flowrate of 32 l/min. for respirators with exhalation valves. This raises some additional questions concerning an issue that was thought to be resolved.

Little information is obtained from OV cartridge tests that is related to the cartridge's sorbent capacity for organic vapors or gases. In reality the sorbent efficiency of organic vapor cartridges is a weak area in the present NIOSH/MSHA respirator performance standards (30 CFR Part 11)/due to:

- o the use of a single testing agent
- o the reliance on warning properties rather than on an effective end of service life indicator
- o the potential interactions and synergistic effects one might observe in multi-component environments
- o the effects of real world environmental working conditions, which current laboratory tests do not adequately reflect.

Selection and Use Criteria

Fortunately, the NIOSH/MSHA regulations for approval of respirators do include built-in safety precautions. In fact, some of the regulatory constraints imposed on organic vapor cartridge selection and use are quite restrictive. These constraints are justified since so little is known about the effectiveness of these devices under real world environmental conditions. Constraints on the use of organic vapor cartridge respirators are evident upon examination of the criteria for selecting such devices. These criteria can be found in the NIOSH/OSHA Standards Completion Program Respirator Decision Logic. The following basic questions must be answered in order to determine if the selection of an organic vapor respirator is appropriate:

- (1) Is there adequate O_2 present?

Section 11.3(aa) of 30 CFR 11 states that any environment which contains an oxygen partial pressure of less than 148 millimeters of mercury (19.5 percent oxygen by volume at sea level) is oxygen deficient.

- (2) Has the **contaminant(s)** been completely identified?

In order for OV cartridges to be used, the **contaminant(s)** must be accurately **identified** so that the remaining questions can be answered. Unless the **contaminant(s)** has been completely identified, the rule of thumb is to use maximum respiratory protection (positive pressure, atmosphere supplying **respirators**).

- (3) Has the **contaminant's** concentration been determined to be below the maximum use concentration?

It is important to know the expected range of **concentrations**. If OV respirators are employed for routine use, a measure of peak concentrations and representative **8-hour** TWA data collected over a period of time should be obtained. The maximum use concentration, according to 30 CFR 11.150, is 1000 ppm or a lower value **for** organic vapors which produce IDLH atmospheres at concentrations equal to or lower than 1000 ppm. The established ceiling level times the protection factor (C_{out}/C_{in}) could also be considered the maximum use **concentration**. The lowest of these values should be used. The reduced concentrations have been incorporated because air-purifying respirators are not to be used in IDLH environments as defined in 30 CFR 11.3(t). This requirement is intended to ensure that the worker can escape without injury or irreversible health effects should the respirator fail.

- (4) Does the **contaminant(s)** have adequate warning properties?

Warning properties of organic vapors and gases include odor, eye and/or respiratory tract irritation, and taste. According to the established definition, "adequate warning properties" means that a gas or vapor has a reliable and persistent odor or irritation threshold which is less than three times its permissible exposure level (PEL) and, if a ceiling limit is established, less than its ceiling level. The reliance on the adequate warning properties of environmental contaminants is the most significant problem associated with the use of OV respirators. Therefore, a detailed discussion of this critical criterion is warranted (see below under Contaminant Warning Properties).

- (5) Has any hazard due to skin adsorption been ruled out?
- (6) If the contaminant is an eye irritant at the use concentration, is there a full facepiece respirator available?
- (7) Has the generation of high heats of reaction with the sorbent been ruled out?
- (8) Has the potential for shock sensitivity of the substance sorbed on the sorbent been ruled out?

If the answer to of the above questions is yes, then the regulations allow organic vapor cartridge respirators to be used. However, it may be impractical and economically infeasible to use these devices against substances with extremely short breakthrough times (< 3-5 minutes). An extremely dangerous situation would exist if the contaminant, at a low concentration, produced an environment which was immediately dangerous to life and health (IDLH). Further, due to the problem of desorption, cartridges must be replaced after each use, as sitting for a period of time causes redistribution throughout the entire cartridge.

Contaminant Warning Properties

As previously noted, warning properties include odor, eye and/or respiratory tract irritation, and taste. A gas or vapor is said to have "adequate warning properties" if it has a reliable and persistent odor or irritation threshold which is less than three times its permissible exposure level (PEL) and, if a ceiling limit is established, less than its ceiling level. For example, a substance having both an odor and irritation threshold of more than three times the PEL would be considered as having adequate warning properties unless either the odor or irritation threshold was less than the ceiling. However, if in the prior case the substance had a threshold of odor and irritation which was considerably lower than the PEL, then it might be considered as having poor warning properties because at the PEL concentration the wearer would

not be alerted to the odor. Also, substances which have odors which cause olfactory fatigue or which do not have persistent odors are considered to have poor odor warning properties.

The regulations (30 CFR Part 11) prohibit use of OV cartridge respirators against organic vapors with poor warning properties except where MSHA or OSHA standards permit such use for a specific gas or vapor (11.150 footnote 7). Although 30 CFR Part 11 does not specifically prohibit the use of air-purifying pesticide and paint spray respirators against materials which do not have adequate warning properties, their use for such substances should not be allowed. This limitation is implied in the regulations and a statement of this limitation is required on all approved labels for pesticide and paint spray respirators. This is especially important because only carbon tetrachloride is employed for evaluating pesticide respirators. Further paint spray respirators are evaluated against a paint and lacquer mixture (section 11.16276f11: an enamel having a phthalic alkyd resin vehicle and a titanium dioxide pigment) which is not indicative of present day paint compositions. Therefore, the only adequate means for detecting organic vapor breakthrough for pesticide and paint spray respirators rests solely on warning properties.

These regulatory constraints are in place essentially because of the difficulty of predicting breakthrough times for diverse contaminants and environmental conditions of the workplace. Also, an effective

end-of-service-life indicator (**EOSLI**) has yet to be developed, which makes reliance on adequate warning properties the key element in protecting workers wearing OV cartridge respirators from **overexposure** to toxic substances.

Despite the current necessity for reliance on warning properties, such reliance is undesirable. Some of the reasons are:

- o Human senses are not foolproof and, in fact, sensory acuity may vary greatly among individuals, or with changes in an **individual's** medical condition. In fact, certain individuals should be immediately precluded from the use of organic vapor respirators due to physical problems which hamper sensory perception.
- o Research in the area of substance warning properties is sparse, particularly research involving multiple contaminant **environments**. The evaluations of warning properties which are contained within the **NIOSH/OSHA** Occupational Health Guidelines for Chemical Hazards were developed as a stimulus for further discussion and improvement, not as an ultimate list of warning **properties**. In reality, these guidelines are being used for a purpose for which they were not intended. Unfortunately, they probably constitute the best source of obtaining this type of information. Basically, OV cartridge respirators cannot be used

in atmospheres which contain mixtures of contaminants unless all components have been identified and have adequate warning **properties**. Even then, the problem of component interaction **arises**. One substance could interfere with another, for example, affecting the sorbent properties as well as the warning **properties**. This is an area which has not been addressed adequately. Little, if any, testing is performed on organic cartridges with mixed contaminant **environments**.

- o Research results which are available in the literature are inconsistent due to the lack of standard methods of measuring warning properties, in addition to other variables such as chemical purity and human sensitivity (**Amoore** and Huatala, 1983). Amoore and Huatala report that of the 29 threshold values reported for **n-butyl** alcohol which represents the work of 26 principal authors, no more than two of these threshold values were measured by the same exact experimental method. As would be expected, a rather large range exists for the air-dilution threshold (1.45×10^{-7} to 9.23×10^{-5} g/l). Thus, many of the current threshold values for odor, taste and irritation lack a statistically valid scientific basis for their **establishment**.

In order to thoroughly evaluate whether a substance has adequate warning properties, the following questions must be answered:

- (1) What threshold value (absolute or 100 percent recognition threshold) was determined?
- (2) Was a suitable, representative panel of individuals used in determining the threshold and what variations were seen?
- (3) What is the effect of competing substances on the warning properties?
- (4) Do the contaminant's warning properties persist and are they reliable or is olfactory fatigue a problem?
- (5) Has adequate data been collected on the effect of contaminant concentration on individual sensory capabilities?
- (6) Does exposure to other contaminants have a long or short term effect on sensory perception?
- (7) Is there a threshold shift due to chronic exposure?
- (8) What effect do various medical conditions have on sensory perception?
- (9) Basically, what is the distribution of sensory perception among normal individuals?

Although the reliance of warning properties is undesirable, it is the best means of protection currently available, at least until an effective end-of-service-life indicator can be developed. In the meantime, the scientific community must strive to remedy the predicament by:

- o determining if contaminant substances have "reliable and persistent" warning properties based on statistically sound scientific data
- o developing and implementing validated administrative controls based on data generated in the actual environment of use.

Breakthrough Time

One of the environmental factors which affect the use of organic vapor respirators is the breakthrough time. The literature contains data relating charcoal's breakthrough characteristics against classes of compounds (Faust and Hermann, 1969; Freedman et al., 1973; Nelson and Harder, 1974), low boiling compounds (Balieu, 1983), anesthetics (Maggs and Smith, 1976; Enderby et al., 1977; Kim and Sicar, 1977) and specific compounds (Beaumont and Garrido, 1979; Stampfer et al., 1980). Since these data were collected under various test conditions, they are not directly comparable. The most extensive study was that of Nelson and Harder (1974), who tested commercially available organic vapor cartridges against 121 different organic vapors and gases (1000 ppm, 50 percent RH,

53.3 l/min, predried followed by exposure to 50 percent RH at 22°C for > 2 days). Although 51 of the 121 compounds tested had shorter breakthrough times than carbon tetrachloride, which is used for approval testing by NIOSH, only 12 of the 51 would be considered as having adequate warning properties.

Relative Humidity

The effect of relative humidity on the ability of activated charcoal to adsorb gases and vapors has been studied by numerous investigators (Maggs and Smith, 1976; McGinnis and Fawcett, 1976; Nelson, Corrcia, and Harder, 1976; Balieu, 1977; Balieu, 1980; Burrage and Allmand, in press).

Basically, this data indicates that little difference is observed in the service life as long as the relative humidity is below 50 percent.

However, above this value, and in particular above 65 percent RH, the dependence on humidity becomes very significant and is reflected by a large shift to shorter or longer breakthrough time (generally shorter) depending on the contaminant. This phenomenon is also observed when samples are preconditioned at high RH conditions prior to testing.

Although both preconditioning and varying test humidities alter the cartridge service life, it has been postulated that the test humidity has the greater effect, but this is debated.

Temperature

Little data appears in the literature on the effect of temperature on cartridge performance and efficiency. Yet the breakthrough time would be expected to become shorter due to increased desorption if adsorption were the only mechanism involved. Nelson, Corrcia, and Harder (1976) stated that for every 10⁰ C rise in temperature above room temperature (20 - 25⁰ C) the service life would be reduced from 1-10 percent depending on the contaminant. This prediction was based solely on calculations using a selected adsorption isotherm. However, data by Wood et al. (Oct 1978 - Sept 1982) indicates that there may be as much as a twofold reduction in service life for a 5⁰ C temperature rise above room temperature (assuming only an adsorption mechanism exists). Further, one would also expect that the breakthrough time would be reduced as the temperature increases due to increased desorption. This is an area where research efforts could readily supply the needed data to fill an existing void. This would shed light on all types of organic vapor respirators which includes paint spray and pesticide cartridges. Further it would alert us to the need for restrictions, if any, on their use so as to prevent wearer misuse and injury.

Concentration

As noted previously, the contaminant's concentration imposes major restrictions on the use of organic vapor respirators. But here we are

concerned with the effect that concentration has on the breakthrough characteristics of charcoal. Nelson, Harder, and Bigler 1976 and Nelson et al. (1980), showed that a family of straight lines is obtained when one plots the log of the breakthrough time at selected percentages versus the log of the concentration. Further, a similar plot for various flowrates gives a family of straight lines. This relationship was found to hold for numerous organic contaminants over a concentration range of 50-3000 ppm. A study by Smith and Giesler (1975) showed that vinyl chloride gave a linear correlation when the log of the concentration was plotted against the 10 percent breakthrough time over the concentration range from 100 to 5000 ppm. These reported differences (log/log vs. log/linear) raise some questions about concentration effects. Of more importance is the fact that lower percentages of sorbate are absorbed at low contaminant concentrations. However, little work has been done at concentrations below 50 ppm. Thus it is necessary to study low concentrations of vapors and gases which might be routinely found in the workplace, particularly those with extremely low threshold limit values.

CONCLUSIONS

In summary, it is obvious that numerous factors must be accurately assessed in order to ensure the appropriate selection of an organic vapor respirator. Environmental factors can be determined generally by appropriate instrumentation, but the most important factor is the adequacy of warning properties. Warning properties represent a critical

factor since the wearer depends upon them for his safety. Unfortunately, it is the one factor which is most questionable. Thus, certain precautionary steps need to be instituted to ensure worker safety. First, individuals should be carefully screened to make sure they have adequate sensory perception to detect contaminants. Secondly, precautionary administrative controls should be instituted based on workplace measurements of cartridge breakthrough times. In addition, the scientific community should strive to (1) determine statistically sound, scientifically valid warning property evaluations and (2) develop an effective end-of-service-life indicator for organic substances.

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