ABSTRACT

Evaluation of Organic Vapor Adsorption and Filter Performance of Disposable Dust Masks Containing Activated Carbon

Tae-Seob Kim
Department of Environmental Health
Graduate School of Public Health
Seoul National University, Korea

Advisor Chungsik Yoon, Ph.D, CIH

Objective Disposable dust masks containing activated carbon in the filtration material are widely used. However, there have only been a few studies of the adsorption of organic compounds by activated carbon in the masks. This study evaluated the effectiveness of organic vapor adsorption (hereafter, breakthrough time, BT) and the filter performance of disposable dust masks containing activated carbon.

Methods Fourteen types of disposable dust mask containing activated carbon were selected for this study. All masks were certified by the Korea Occupational Health and Safety Agency. Australia and New Zealand standards (AS/NZS 1716, 2003) were applied to determine the BT. The performance of the activated carbon was tested under three different temperature and humidity combinations: room temperature (25±3℃) and no humidity, high temperature (70±3℃) and no humidity, and high temperature (70±3℃) and high humidity (70±10% relative humidity). The masks were assessed against the filter performance safety certification standard for dust masks established by Korean Ministry of Employment and Labor (KMOEL).

Results Only 2 out of 14 (14%) types of mask met the AS/NZ standard. Eight types of mask had a BT of less than 1 min, four of which showed immediate breakthrough. Two types of mask had a BT of over 10 min, and their performance did not change with changes in temperature but decreased drastically with an increase in humidity. When comparing the “quality factors (qF)” used as a benchmark for filter performance, no discernible changes were observed with changes in temperature and humidity. There was no meaningful correlation between BT and qF standards for pressure drop (PD) and penetration (PN) of filter media.

Conclusion Only 2 of 14 (14%) studied types of disposable dust mask containing activated carbon used in the workplace can effectively remove organic vapors. Hence, most of these types of mask are not appropriate for protecting workers from exposure to organic solvents and gaseous substances. Manufacturers of such masks must provide accurate information regarding organic vapor relief, users must acknowledge the limitations of these products,

and the government must establish a precise standard level of organic vapor adsorption for combined dust masks.

Keywords : Activated carbon, Disposable dust mask, Combined dust mask, Organic vapor, Breakthrough time, Quality factor

Student number : 2011-22066

Contents

List of Tables

List of Figures

1. Introduction

According to the American Industrial Hygiene Association (AIHA), industrial hygiene is a science and art devoted to the anticipation, recognition, evaluation, prevention, and control of environmental factors or stresses that arise in or from the workplace, which may cause sickness, impaired health and well-being, and/or significant discomfort among workers and/or citizens of the community and a decrease in work efficiency (AIHA, 1994). Some of the management and improvement methods can be engineering controls such as sealing, substitution, isolation, and ventilation; administrative controls such as work time adjustment and training; and the wearing of personal protective equipment (PPE) such as masks, hard hats, safety glasses, and safety shoes (Cho, 1985).

Traditionally, the wearing of PPE is considered to be the last resort after engineering management and other appropriate management methods (NIOSH, August 19, 2011; NIOSH, July 26, 2012) but in the workplace it is a common practice. Because PPE is the last means to protect workers from hazardous substances its quality is important. The Korea Occupational Safety and Health Agency (KOSHA) provides a safety certification system to control the functionality standards for protective equipment. The safety certification is divided into obligatory safety certification and self-regulated safety confirmation; the categories of PPE are listed in Appendix 1.

Articles 32 and 469 of the Korea Ministry of Employment and Labor's (KMOEL) Regulation of the Occupational Safety & Health standard provides that "the employer must distribute and mandate the wearing of personal dust masks or gas masks to protect the employees' respiratory health when working on manufacturing machinery or using hazardous substances subject to authorization. The employees must wear the distributed dust/gas masks according to the directions given by the employer" (KMOEL, 2013).

In Korea, dust masks and gas masks are differentiated as follows. According to the KMOEL dust mask safety certification standard, a dust mask should be used to prevent dust, mist, or fumes from entering the body through the respiratory system (Pritchard, 1976; KMOEL, 2012). They are classified into three groups (special class, first class, and second class) and each workplace must ensure that the appropriate class of dust mask is worn (Appendix 2). In dust masks, the filter collects particulate matter such as dust, mist, and fumes by capture mechanisms such as interception, inertial impaction, diffusion, and electrostatic attraction. Thus, the weight and velocity of a particle affects the utility of the mask. When the size of the particle is such that mechanical filtration efficiency becomes lower, electrostatic attraction can help improve the efficiency (Davies, 1983; Yang, 2012).

In terms of the gas mask safety certification standard, the mask is categorized according to the target gas, which may be an organic compound, halogen, hydrogen sulfide, hydrogen cyanide, sulfurous acid, or ammonia (Appendix 3). The gas is also categorized according to its density, i.e., high, medium, low, and very low density (Appendix 4). Hazardous gaseous substances are usually eliminated using cartridges consisting of activated carbon. Activated carbon contains numerous macro/micro pores and has a large surface area; hence, it is very effective at absorbing gaseous substances (Wigmans, 1989; Bansal and Goyal, 2010). Consequently, dust masks should be worn to prevent particulate matter from entering the respiratory system, and gas masks should be worn to prevent exposure to gaseous substances.

However, in many workplaces, exposure to particulate matter and gaseous substances can occur at the same time. In such cases, the respiratory system must be protected from both types of hazardous substance by using the masks in parallel or in combination, because a dust mask cannot eliminate gases and a gas mask cannot capture particulate matter (Chen et al., 2013).

Article 34 of Korea’s Industrial Safety and Health Act provides a definition for a combined gas mask, which is essentially a gas mask with the additional functionality of a dust mask. Such combined masks are efficiently used in workplaces in which particles and gaseous substances occur at the same time. However, local laws do not provide any definition of a dust mask with the added functionality of a gas mask, i.e., a combined dusk mask. Such masks already exist in the marketplace, but they have only obtained safety certification for use as a standard dust mask. Hence, workers that use these types of mask may currently be at risk for exposure to gaseous substances.

The ability of activated carbon to absorb gaseous substances has been studied (Karanfil and Kilduff, 1999; Li et. al., 2002). Recently, the National Institute of Occupational Safety & Health (NIOSH) reported preliminary research regarding the performance of combined dust masks sold in the United States for protecting against exposure to gaseous substances (Rozzi et al., 2012). However, the study adopted its own discretionary laboratory standard and did not take into account environmental factors that may affect the performance of activated carbon such as temperature and humidity (Tsai and Chang, 1994; Kaplan et al., 2006; Fletcher et al., 2007). In Korea, there are no reports on the performance of activated carbon in combined dust masks.

This study evaluated the breakthrough time (BT) of organic vapor and the filter performance of disposable combined dust masks. The results should raise awareness of the potential issues facing manufacturers, users, and the government in regard to the use of these types of mask.

2. Materials and Methods

Experiments were conducted using the activated carbon performance test based on AS/NZ standards and a filter performance test based on KOSHA standards. The samples were subjected to three different conditions, described in detail below (Figure 1).

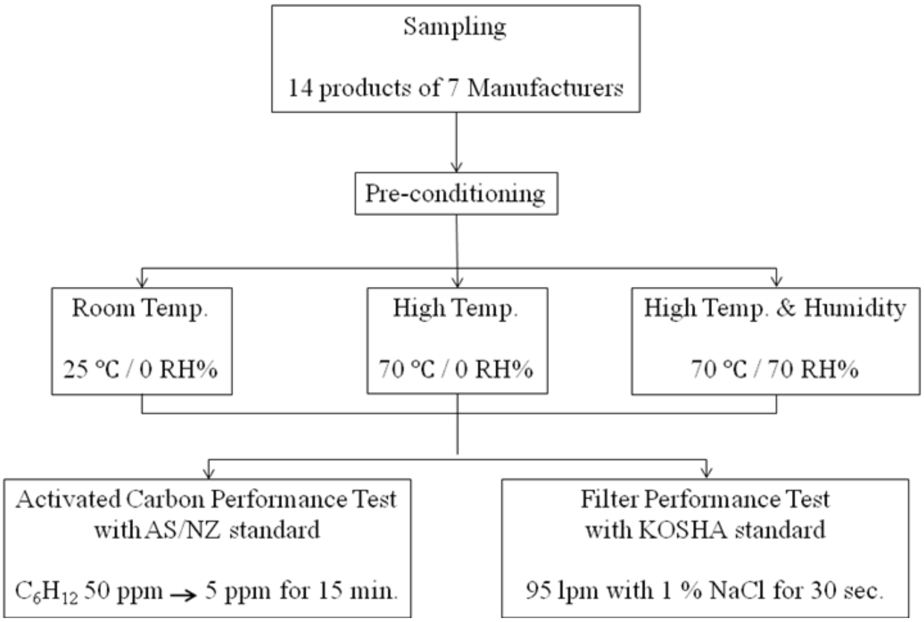


Figure 1. Test procedure for determining organic vapor adsorption and filter performance.

2.1 Sample set and conditions

A total of 14 types of combined dust mask that had obtained the KOSHA Korean Certification and which were easily accessible to workers in Korea were selected for testing. The specimens comprised seven types of first class dust mask and seven types of second class dust mask to compare the function of different classes of activated carbon. To determine the effect of an exhalation valve on the performance of activated carbon eight of thee specimens also has these valves (Table 1). None of these masks had undergone any tests regarding the performance of their activated carbon filters, but rather were merely available products that complied with the regulatory standards for dust masks in each class.

Specimens were tested under three conditions (Table 2): preprocessing at room temperature (25±3℃) and 0% relative humidity (RH) (condition 1), preprocessing at high temperature (70±3℃) and 0% RH (condition 2), and preprocessing at high temperature (70±3℃) and 70±10% RH (condition 3). After preprocessing, each specimen was tested, evaluated, and analyzed regarding two main functionalities: the BT of organic vapor and filter performance.

Table 1. Combined dust masks that meet the KOSHA KCs

Manufacturer	Sample	Class (KMOEL*)	Valve	Shape
# 1	A	1	Yes	Cup
	B	2	Yes	Cup
	C	2	No	Cup
# 2	D	1	Yes	Hybrid**
# 3	E	1	Yes	Cup
	F	2	No	Cup
# 4	G	1	Yes	Cup
	H	2	No	Cup
# 5	I	1	Yes	Cup
	J	2	No	Cup
# 6	K	1	Yes	Cup
	L	2	No	Cup
# 7	M	1	Yes	Hybrid**
	N	2	No	Hybrid**

* Korea Ministry of Employment and Labor

** Cup shape with foldable frame

Table 2. Preconditioning treatments by temperature and relative humidity

Conditions	Temperature (℃)	Humidity (RH%)	Duration (hour)
1	25±3	0	24
2	70±3	0	24
3	70±3	70±10	24

2.2 Activated carbon performance: Breakthrough time

The BT of organic vapor was tested against AS/NZ standards. During tests, the temperature/humidity conditions in the experimental chamber were maintained at 23±3℃ and 70±5% RH. The organic vapor used was 50 ppm cyclohexane, and the time required for breakthrough to reach 5 ppm at 30 L/min (LPM) of continuous flow was checked. The details of the experimental procedure are given in Table 3 (AS/NZS 1716: 2003). A 22 mL syringe and syringe pump were used to maintain a consistent cyclohexane concentration within the chamber, a flowmeter was used to gauge the flow, and a heating plate was used to vaporize the cyclohexane solution that flowed into the chamber. A flame ionization detector (FID; GOW-MAC Instrument Co., Bethlehem, PA, USA) was used to gauge the breakthrough concentration of cyclohexane, and the data were recorded using data acquisition software programmed by LabVIEW™ (NATIONAL INSTRUMENTS CORPORATION, Austin, TX, USA).

Each combined dust mask was situated such that only its exterior was exposed to the cyclohexane; its interior was connected to the FID to measure the cyclohexane concentration upon breakthrough (Figure 2).

Table 3. Test conditions for type G masks in the AS/NZ standard

Type	Class	Test gas or vapor	Test gas concentration (ppm) by volume	Breakthrough conditions	
				Breakthrough concentration (ppm) by volume	Minimum life (Min.)
G	-	Cyclohexane (C_6H_{12})	50	5	15

Note: Type G–for use against certain organic compounds with vapor pressures less than 1.3 Pa (0.01 mmHg) at 25℃ as specified by the manufacturer. These filters shall have an integral particulate filter with efficiency at least equivalent to that of a P1 filter.

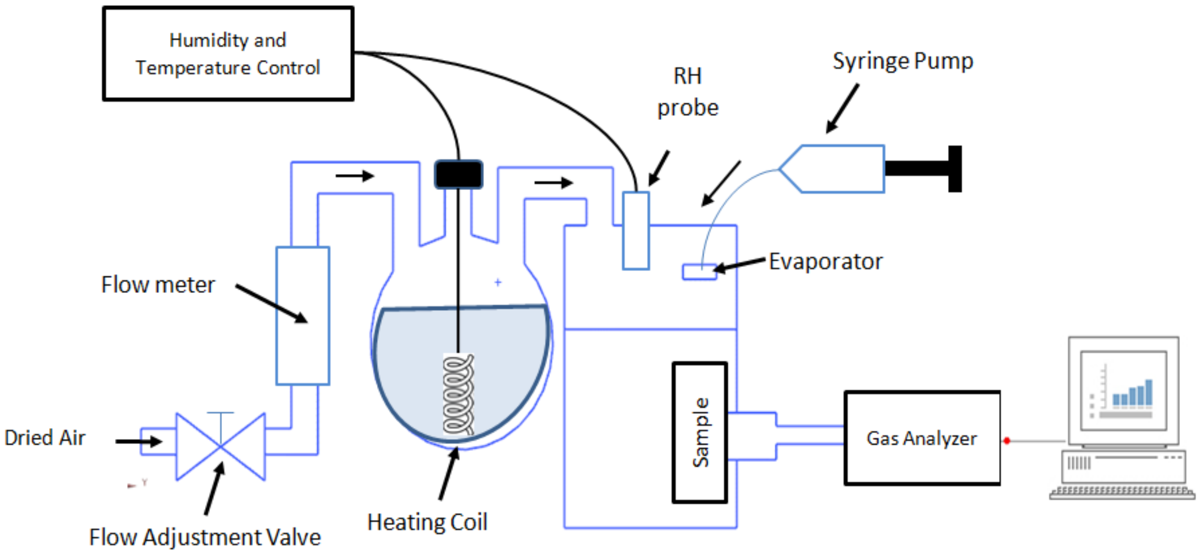


Figure 2. Experimental schematic for the testing of organic vapor (cyclohexane) adsorption capacity of disposable combined dust masks.

2.3 Performance of particulate matter filter: Penetration, pressure drop, and quality factor

Three specimens of each product preprocessed as detailed above were used. To test the filter performance of particulate matter, filtration efficiency against particulates including dust and a breathing resistance test method were selected in accordance with the KOSHA standard. Dust collection efficiency was tested at a flow rate of 95 LPM using 1% sodium chloride with a particle size distribution of 0.04~1.0 μm and an average particle size of approximately 0.6 μm. Breathing resistance was tested by measuring the difference in pressure when the air was transmitted in a continuous flow at a flow rate of 95 LPM (Notice of KMOEL No. 2012-83).

A TSI 8130 AFT particulate generator, as specified by the aforementioned KMOEL standard, was used for the experiment, and the measured value was averaged from results obtained during the first 30±3 s. TSI 8130 AFT uses a light-scattering method and measures the upstream and downstream particle concentrations in the masks (Li et al, 2012). This was used to calculate the aerosol penetration (PN), according to the following formula:

$$\mathrm{P}\ (\%) = \frac{\mathrm{C_{down}}}{\mathrm{C_{up}}} \times 100$$

where P is the PN (%), C_{up} is the concentration of sodium chloride before the passage of aerosol (mg/m^3), and C_{down} is the concentration of sodium chloride after the passage of aerosol (mg/m^3).

However, the filtration efficiency and filter media of a mask cannot be deemed satisfactory simply because the breathing resistance is low. Therefore, the so-called “quality factor (qF)” was also considered, calculated as follows (Hinds and Kadrichu, 1997; Han, 2000; Eninger et al., 2008; Cho et al., 2011):

$$qF = \frac{\ln\frac{1}{P}}{\Delta P}$$

where is P is the PN at a given time and ΔP is the pressure drop (PD) at the corresponding PN point. According to this formula, a good filter medium has low breathing resistance and high filtration efficiency (Chen et al., 1992). The higher the qF, the better the filter performance.

3. Results and Discussion

3.1 Activated carbon performance: Breakthrough time

The experiment was conducted as described in section 2.2 using three replicates of each mask that were preprocessed under the three different conditions, and the mean and standard deviation values are shown in Table 4.

Table 4. Breakthrough time of activated carbon by product and preconditioning treatment

Manufacturer	Product	Test condition	Sample (n)	Breakthrough Time (Min.) Mean (SD)
# 1	A	1	3	1.48 (0.18)
		2	3	1.49 (0.12)
		3	3	1.25 (0.48)
	B	1	3	0.86 (0.44)
		2	3	0.96 (0.20)
		3	3	1.42 (0.88)
	C	1	3	1.19 (0.59)
		2	3	0.84 (0.30)
		3	3	0.72 (0.30)
# 2	D	1	3	0.61 (0.57)
		2	3	0.95 (0.53)
		3	3	0.95 (0.62)
# 3	E	1	3	7.37 (3.79)
		2	3	4.68 (0.42)
		3	3	4.91 (0.44)
	F	1	3	6.76 (0.60)
		2	3	6.86 (0.70)
		3	3	6.91 (1.25)
# 4	G	1	3	16.81 (1.23)
		2	3	14.99 (1.89)
		3	3	6.82 (1.51)
	H	1	3	15.26 (3.39)
		2	3	17.40 (1.96)
		3	3	6.76 (0.60)
# 5	I	1	3	0.01 (0.00)
		2	3	0.01 (0.00)
		3	3	0.01 (0.00)
	J	1	3	0.01 (0.01)
		2	3	0.01 (0.01)
		3	3	0.02 (0.00)
# 6	K	1	3	0.01 (0.00)
		2	3	0.03 (0.00)
		3	3	0.02 (0.00)
	L	1	3	0.01 (0.00)
		2	3	0.01 (0.00)
		3	3	0.01 (0.01)
# 7	M	1	3	3.61 (0.53)
		2	3	3.21 (0.40)
		3	3	2.78 (0.35)
	N	1	3	3.78 (0.25)
		2	3	4.28 (0.62)
		3	3	3.8 (0.67)
Total		1	42	4.13 (5.60)
		2	42	3.98 (5.50)
		3	42	2.60 (2.72)

To determine whether there was a difference in BT depending on condition or product, a two-way ANOVA was conducted. The results indicated that both factors affected BT (condition: $p = 0.000$, product: $p = 0.000$).

Therefore, a one-way ANOVA was conducted as described below to determine what differences existed for each factor, and a comparison was made using the Tukey method.

There was a difference in BT depending on the product irrespective of preconditioning ($p = 0.000$). Figure 3 shows a boxplot of the BT value depending on product, which shows that a very high BT value was observed for products G and H, whereas products A, B, C, D, I, J, K, and L had extremely low values less than 1 min. A more precise grouping was obtained using the Tukey method (Table 5). Five groups were identified.

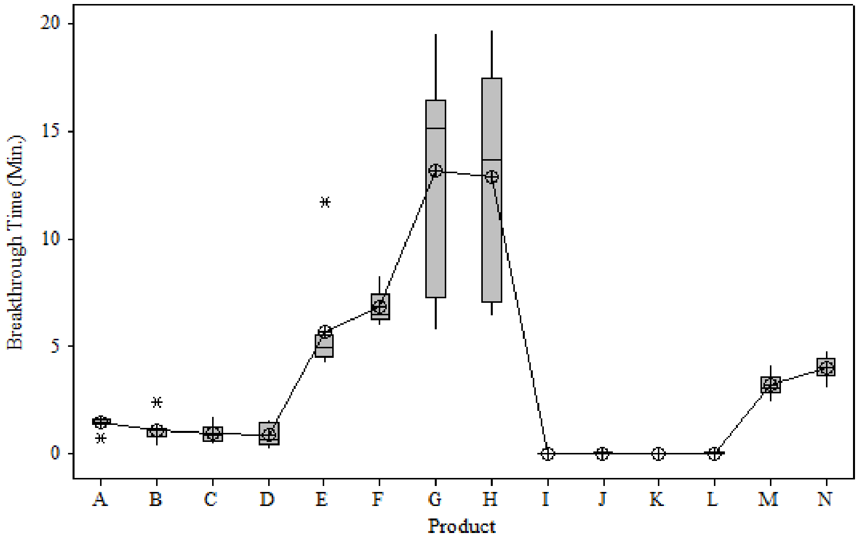


Figure 3. Breakthrough time of activated carbon for different products.

Table 5. Grouping of products using the Tukey method

Product	Sample (n)	BT (Min.) Mean (SD)	Grouping				
G	9	13.14 (5.06)	I				
H	9	12.87 (5.02)	I				
F	9	6.84 (0.78)		II			
E	9	5.65 (2.32)		II	III		
N	9	3.95 (0.53)		II	III	IV	
M	9	3.20 (0.52)			III	IV	V
A	9	1.41 (0.29)				IV	V
B	9	1.08 (0.57)				IV	V
C	9	0.92 (0.42)				IV	V
D	9	0.84 (0.53)				IV	V
L	9	0.02 (0.01)					V
J	9	0.01 (0.01)					V
K	9	0.01 (0.00)					V
I	9	0.01 (0.00)					V

The difference in BT value depending on the type of preconditioning (irrespective of product type) was not meaningful at a confidence level of 95% (p = 0.2777). This is a statistical phenomenon caused by large discrepancies in the BT value depending on product type, but the BT values under condition 3 were very different from those under conditions 1 and 2 as can be seen in Figure 4. Therefore, it is clear that high humidity affects the BT value.

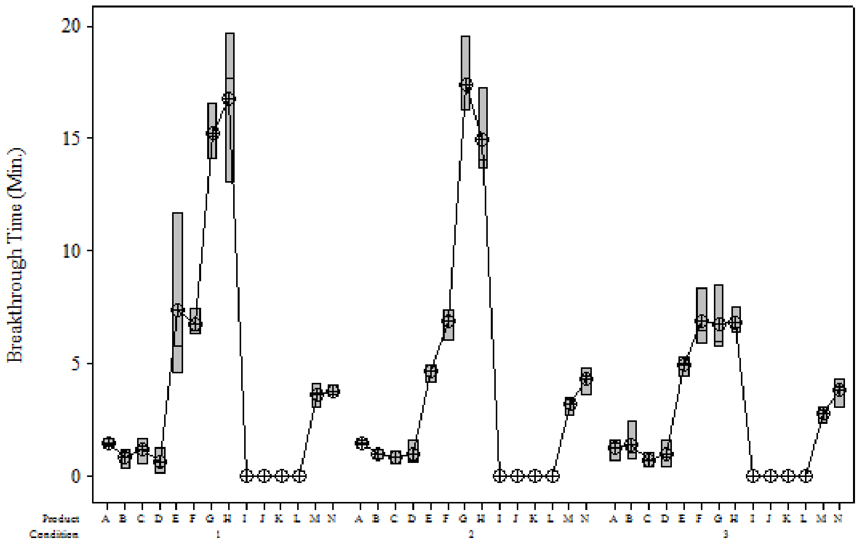


Figure 4. Breakthrough time of all products according to preconditioning treatment and product type.

In four types of mask (I, J, K, L) the BT was almost zero, and in another four types of mask (A, B, C, D) it was under 1 min. Consequently, the activated carbon performance of 8 of the 14 masks (57%) did not meet the basic function of a combined dust mask.

In four other types of mask (E, F, M, N) the activated carbon showed a slightly improved performance compared to the eight aforementioned masks, but these also failed to meet AS/NZ standards. Thus, overall, only 2 of the 14 mask types (14%: G and H) met the standards under conditions 1 and 2; none met the standards under condition 3, in which the environment was hot and humid.

3.1.1 Organic vapor adsorption capabilities depending on temperature and RH conditions

Considering that 9 (except upper group I and II in Table 5) out of 14 masks (64%) had very low BT values, it would be meaningless to compare the results for each condition across all masks. However, it is possible to compare the performance of the activated carbon under high temperature and humidity conditions for five masks (E, F, G, H, N), in which the carbon maintained a sufficient level of performance, i.e., the specimens categorized as group I and II in Table 5 (Figure 5).

A one-way ANOVA analysis was conducted for these five specimens and it was confirmed that there was a difference in the BT value depending on preconditioning ($p = 0.038$). There was no difference in performance with changes in temperature but there was a large reduction in performance as the humidity increased. This is probably because, at high humidity, vapor droplets began occupying holes in the carbon matrix before cyclohexane molecules could be trapped (Nelson et al., 1976; Moyer, 1983; Tsai and Chang, 1994).

These results indicate that a combined dust mask should not be stored or distributed in locations with high humidity. Where possible, as with the cartridges used in gas masks, the mask should be sealed so as to reduce exposure to humidity when it is stored or distributed.

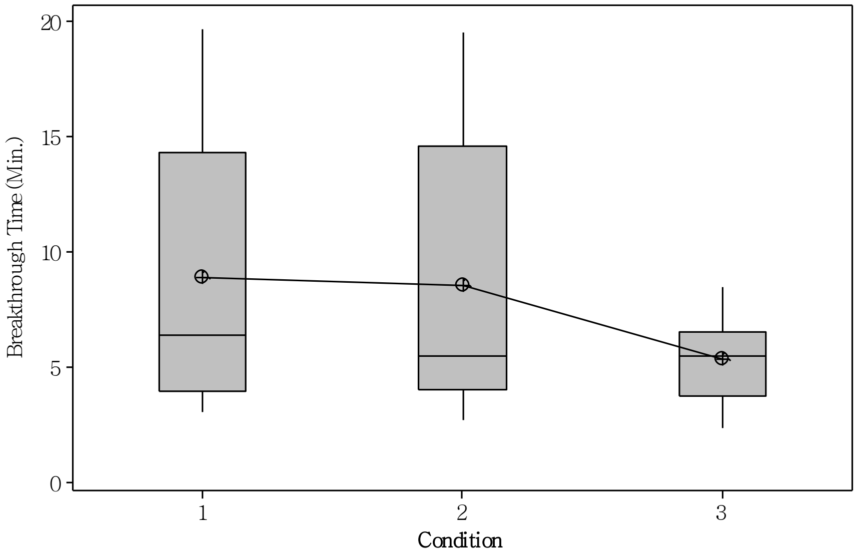


Figure 5. Breakthrough time according to preconditioning for five products (E, F, G, H, N) of groups I & II.

3.1.2 Organic vapor adsorption capacity in relation to the exhalation valve on the mask and the mask class

According to PPE regulation Notice No. 2012-83, a disposable dust mask without an exhalation valve should not be used in venues classified as special class and first class (KMOEL, 2012). In most cases, an exhalation valve is attached to the face piece of the mask, and upon breathing it allows high-temperature exhalations to be immediately emitted out of the mask so that it does not remain in the filter (Japuntich, 1993). The first-class combined dust masks used in this study all contained exhalation valves. The second-class masks did not, except for mask B (Table 1).

When comparing combined dust masks with and without an exhalation valve, those with a valve would contain less activated carbon because of the area taken up by the valve and therefore should have a worse organic vapor adsorption performance.

For this reason, a one-way ANOVA analysis was conducted between masks B/C, E/F, G/H, and M/N to compare the BT value depending on the type of preconditioning (I/J and K/L were excluded from the comparison because they had a BT value of almost zero). As shown in Figure 6, in three out of the four groups tested, masks without an exhalation valve had longer BTs than those with a valve. However, for all test groups, the differences were negligible (B/C: $p = 0.48$, E/F: $p = 0.80$, G/H: $p = 0.50$, M/N: $p = 0.64$). Therefore, it can be seen that the existence of the valve does not significantly affect the performance of the activated carbon.

There are many other complicating factors that may explain the differences. First, the density of the activated carbon was not consistent among masks, and it was difficult to determine which mask contained more activated carbon. Second, the existence of the valve does not affect the BT according to the AS/NZ standard because the difference in the amount of activated carbon to the extent of the area of the valve is negligible.

The existence of an exhalation valve in a mask also depends on the class of the mask (a mask with an exhalation valve is first class, whereas one without it is considered second class), therefore a comparison between first class and second class masks in accordance with the regulation was performed, but this did not indicate a strong correlation. The difference in the first and second class masks can be attributed to differences in filter performance such as filtration efficiency and breathing resistance, and therefore provides evidence that the filter media by itself without activated carbon do not affect the BT of organic vapor.

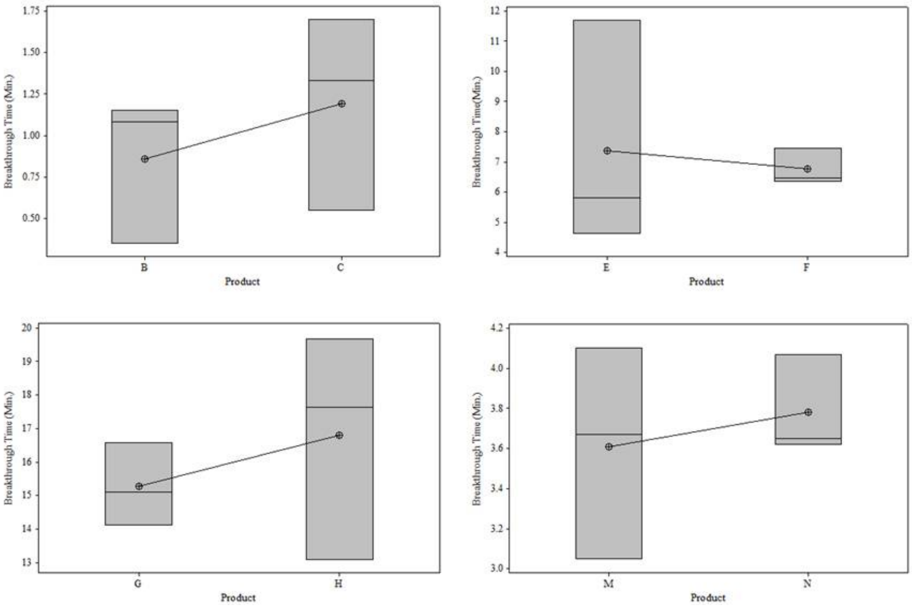


Figure 6. Comparison of breakthrough time for masks with and without an exhalation valve

3.2 Filter performance: Pressure drop, penetration, and quality factor

The data are shown in Table 6. A two-way ANOVA was conducted to determine if there was a difference in PD, PN, and/or qF in relation to conditions and product types. There was little difference in PD, PN, and qF in relation to precondition values (PD: $p = 0.413$, PN: $p = 0.657$, qF: $p = 0.343$), but each variable differed significantly according to the type of mask (all factors: $p = 0.000$) but not according to temperature and humidity. Unlike the activated carbon, the filter media were not affected by temperature and humidity conditions and maintained their performance levels under all conditions.

A one-way ANOVA was conducted to assess differences according to type of mask irrespective of preconditioning. There were significant differences in the qF value only ($p = 0.000$). As explained previously, the qF uses PD and PN to establish a benchmark for the performance level of filter media, and this was used here to confirm differences between different types of mask. Figure 7 shows the qF value of each mask; it was high for masks A, D, I, and J and low for masks E, F, K, and L.

Table 6. Filter performance based on penetration, pressure drop, and quality factor

Manufacturer	Product	Condition	Sample (n)	Pressure drop (mmH_2O) Mean (SD)	Penetration (%) Mean (SD)	Quality factor ($1/mmH_2O$) Mean (SD)	Manufacturer	Product	Condition	Sample (n)	Pressure drop (mmH_2O) Mean (SD)	Penetration (%) Mean (SD)	Quality factor ($1/mmH_2O$) Mean (SD)
# 1	A	1	3	12.43 (0.68)	0.12 (0.02)	0.54 (0.04)	# 4	H	1	3	11.63 (0.25)	1.39 (0.13)	0.37 (0.01)
		2	3	12.53 (0.35)	0.21 (0.06)	0.49 (0.03)			2	3	11.13 (0.25)	1.48 (0.03)	0.38 (0.01)
		3	3	12.50 (0.85)	0.25 (0.07)	0.48 (0.02)			3	3	10.73 (0.15)	1.53 (0.10)	0.39 (0.01)
	B	1	3	9.43 (0.25)	2.65 (1.91)	0.39 (0.08)	# 5	I	1	3	14.87 (1.59)	0.04 (0.03)	0.53 (0.02)
		2	3	10.47 (0.86)	1.67 (1.67)	0.39 (0.08)			2	3	16.20 (0.60)	0.07 (0.02)	0.45 (0.01)
		3	3	10.60 (1.79)	2.00 (1.45)	0.37 (0.01)			3	3	16.37 (0.76)	0.08 (0.02)	0.44 (0.02)
	C	1	3	13.57 (0.93)	0.50 (0.07)	0.39 (0.03)		J	1	3	12.67 (0.67)	0.41 (0.19)	0.43 (0.01)
		2	3	14.77 (1.29)	0.66 (0.21)	0.34 (0.05)			2	3	12.10 (0.53)	0.28 (0.06)	0.49 (0.04)
		3	3	13.67 (0.95)	0.89 (0.09)	0.35 (0.02)			3	3	12.30 (1.10)	0.34 (0.04)	0.46 (0.04)
# 2	D	1	3	13.37 (3.07)	0.41 (0.45)	0.41 (0.10)	# 6	K	1	3	16.16 (0.67)	0.56 (0.30)	0.32 (0.03)
		2	3	10.83 (1.31)	0.26 (0.19)	0.55 (0.05)			2	3	22.10 (0.85)	0.32 (0.24)	0.26 (0.03)
		3	3	11.90 (0.26)	0.35 (0.13)	0.48 (0.04)			3	3	20.63 (0.75)	0.30 (0.18)	0.28 (0.02)
# 3	E	1	3	22.20 (0.70)	1.64 (0.54)	0.19 (0.01)		L	1	3	21.20 (1.65)	0.07 (0.02)	0.34 (0.03)
		2	3	23.07 (0.12)	2.46 (0.23)	0.16 (0.00)			2	3	21.27 (1.63)	0.08 (0.01)	0.34 (0.03)
		3	3	22.53 (1.25)	4.34 (4.33)	0.14 (0.04)			3	3	21.20 (1.15)	0.08 (0.01)	0.34 (0.02)
	F	1	3	16.17 (0.61)	1.57 (0.65)	0.26 (0.02)	# 7	M	1	3	13.50 (0.20)	0.98 (0.45)	0.34 (0.03)
		2	3	15.73 (0.47)	1.42 (0.40)	0.27 (0.01)			2	3	13.37 (0.23)	1.05 (0.17)	0.34 (0.02)
		3	3	15.37 (0.35)	0.66 (0.13)	0.33 (0.01)			3	3	12.93 (0.31)	1.07 (0.10)	0.35 (0.01)
# 4	G	1	3	14.50 (0.36)	0.21 (0.05)	0.42 (0.01)		N	1	3	12.07 (0.21)	0.46 (0.04)	0.45 (0.01)
		2	3	13.73 (0.50)	0.19 (0.01)	0.46 (0.02)			2	3	11.97 (0.21)	0.48 (0.05)	0.45 (0.00)
		3	3	13.63 (0.06)	0.29 (0.08)	0.43 (0.02)			3	3	12.33 (0.42)	0.65 (0.06)	0.41 (0.01)
							Total		1	42	15.03 (4.15)	0.79 (0.89)	0.38 (0.11)
									2	42	14.95 (4.22)	0.76 (0.82)	0.39 (0.11)
									3	42	14.76 (3.92)	0.92 (1.50)	0.37 (0.09)

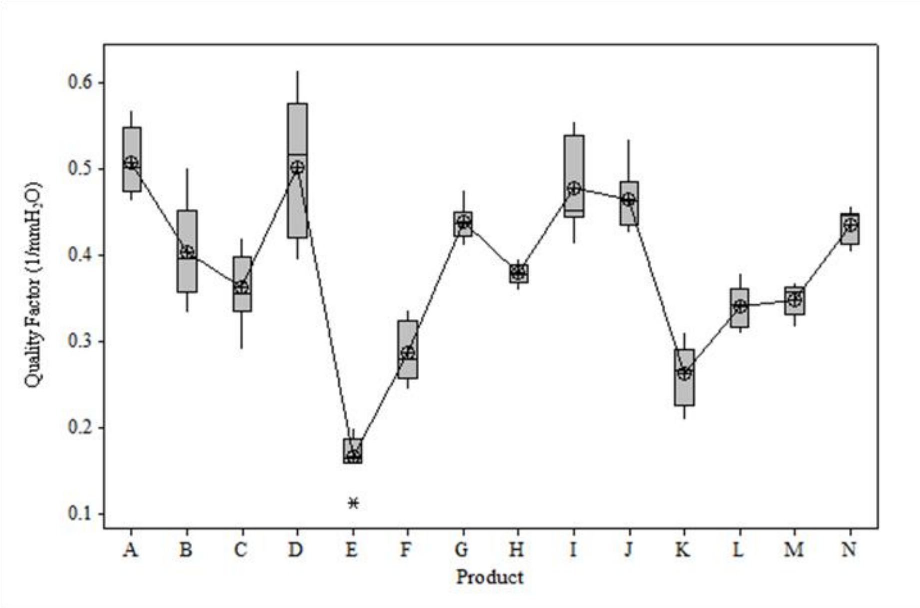


Figure 7. Comparative analysis of the quality factor by product.

3.2.1 Analysis of filter performance by mask class

To determine differences in the values of PD, PN, and qF among mask classes, a two sample T-test was conducted. Generally it is obvious that PD and PN clearly differ by mask class whereas qF does not change much depending on the class. However the analysis shows that PD was lower for second-class masks than for most first-class masks (Figure 8a, $p = 0.002$) and PN was almost the same for the two groups (Figure 8b, $p = 0.328$). It should be noted that the reason for the lack of discrepancies in the PN value between the two groups is because filter media manufacturing in Korea has improved as manufacturers have stopped over-engineering second-class disposable dust masks.

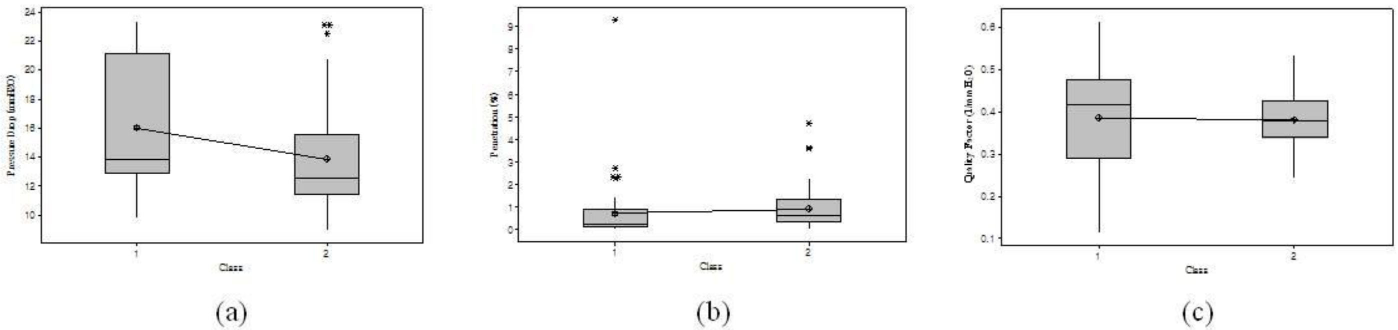


Figure 8. Comparative analysis of (a) pressure drop, (b) penetration, and (c) quality factor between first-class and second-class masks.

3.2.2 Correlation between activated carbon and filter performance

A regression analysis was conducted to determine if there was a correlation between organic vapor adsorption of activated carbon and the performance of filter media in combined dust masks. No discernible correlation was found (Figure 9). This confirms that a product with good filter performance does not necessarily imply that it will also have activated carbon that performs well.

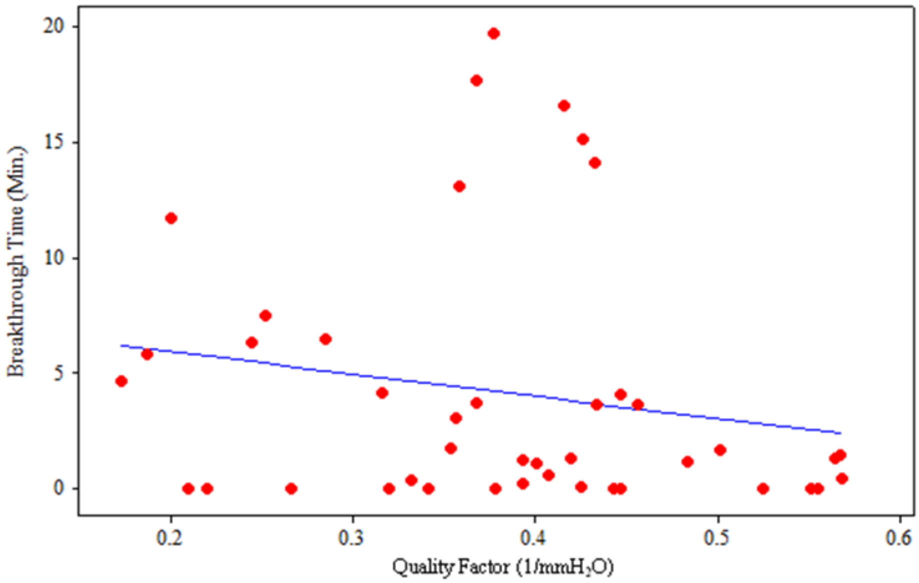


Figure 9. Correlation between breakthrough time and the quality factor.

4. Conclusion

The BT of organic vapor is not affected by high temperatures but is substantially reduced by high humidity. The performance of activated carbon differs substantially depending on the type of product. More specifically, of the 14 types of combined dust mask currently used in Korea, only 2 manufactured by the same company meet AS/NZ standards. Thus, the performance of activated carbon in combined dust masks currently on the market differs greatly between products, mainly due to the lack of any clear standard in Korea that allows for their proper evaluation. The fact that these masks are on the market means that workers are using these masks for the prevention of exposure to both particulate matter and gaseous substances, and for this reason these masks should have an appropriate level of activated carbon and filter performance, and should meet a minimum standard to ensure the health and safety of the workers. Ultimately, this study provides a basis for the enactment of local regulations and the establishment of an appropriate standard for combined dust masks so as to protect workers who are exposed to particulate matter and gaseous substances.

The AS/NZ standards used in this study target harsher conditions (50 ppm, cyclohexane) than likely occur in the actual workplace. Further studies with a lower test gas concentration are needed for more practical application.

5. References

American Industrial Hygiene Association (AIHA): What is an Industrial Hygienist? 1994-1995 Membership Directory of the American Industrial Hygiene Association. 1994

AS / NZS 1716. Respiratory protective devices: SECTION 5 GAS AND VAPOUR FILTER RESPIRATORS. 2003

Bansal RC, Goyal M. Activated carbon adsorption: CRC press. 2010

Chen C, Lehtimäki M, Willeke K. Aerosol penetration through filtering facepieces and respirator cartridges. The American Industrial Hygiene Association Journal. 1992;53(9):566-74

Chen HL, Chung SH, Jhuo ML. Efficiency of different respiratory protective devices for removal of particulate and gaseous reactive oxygen species from welding fumes. Archives of environmental & occupational health. 2013;68(2):101-6

Cho GS. Particulate measurement and counter step, Pneumoconiosis. The Catholic Industrial Medical Center. 1985:122-145

Cho HW, Yoon CS, Lee JH, Lee SJ, Viner A, Johnson EW. Comparison of pressure drop and filtration efficiency of particulate respirators using welding fumes and sodium chloride. Annals of occupational hygiene. 2011;55(6):666-80

Davies C. Filtration of aerosols. Journal of Aerosol Science. 1983;14(2):147-61

Eninger RM, Honda T, Adhikari A, Heinonen-Tanski H, Reponen T, Grinshpun SA. Filter performance of N99 and N95 facepiece respirators against viruses and ultrafine particles. Annals of occupational hygiene. 2008;52(5):385-96

Fletcher AJ, Uygur Y, Thomas KM. Role of surface functional groups in the adsorption kinetics of water vapor on microporous activated carbons. The Journal of Physical Chemistry C. 2007;111(23):8349-59

Han DH. Performance of respirator filters using quality factor in Korea. Industrial health. 2000;38:380-384

Hinds WC, Kadrichu NP. The effect of dust loading on penetration and resistance of glass fiber filters. Aerosol science and technology. 1997;27(2):162-73

Japuntich DA. One way exhalation valve with filtering facepiece respiratiory. International Patent PCT/US 93/03797. 1993

Kaplan D, Nir I, Shmueli L. Effects of high relative humidity on the dynamic adsorption of dimethyl methylphosphonate (DMMP) on activated carbon. Carbon. 2006;44(15):3247-54

Karanfil T, Kilduff JE. Role of granular activated carbon surface chemistry on the adsorption of organic compounds. 1. Priority pollutants. Environmental science & technology. 1999;33(18):3217-24

Korean Ministry of Employment and Labor (KMOEL). Regulation of the Occupational Safety & Health standard (Article 32 and 469 of the KMOEL Decree 77). 2013

Korean Ministry of Employment and Labor (KMOEL). Notification of personal protective equipment obligatory safety certification (Notice No. 2012-83). 2012

Li L, Quinlivan PA, Knappe DR. Effects of activated carbon surface chemistry and pore structure on the adsorption of organic contaminants from aqueous solution. Carbon. 2002;40(12):2085-100

Li L, Zuo Z, Japuntich DA, Pui DY. Evaluation of filter media for particle number, surface area and mass penetrations. Annals of occupational hygiene. 2012;56(5):581-94

Moyer ES. Review of influential factors affecting the performance of organic vapor air-purifying respirator cartridges. The American Industrial Hygiene Association Journal. 1983;44(1):46-51

National Institute for Occupational Safety and Health (NIOSH). Respirator trusted-source, information section 3: Ancillary respirator information. Available from http://cdc.gov/niosh/npptl/topics/respirators/disp-part/RespSource3.html#d. 2011

National Institute for Occupational Safety and Health (NIOSH). Control of Smoke from Laser/Electric Surgical Procedures. Available from http://cdc.gov/niosh/docs/hazardcontrol/hc11.html. 2012

Nelson GO, Correia AN, Harder CA. Respirator cartridge efficiency studies: VII. Effect of relative humidity and temperature. The American Industrial Hygiene Association Journal. 1976;37(5):280-8

Pritchard JA. A guide to industrial respiratory protection. 1976

Rozzi T, Snyder J, Novak D. Pilot study of aromatic hydrocarbon adsorption characteristics of disposable filtering facepiece respirators that contain activated carbon. Journal of Occupational and Environmental Hygiene. 2012;9(11):624-9

Tsai W, Chang C. Surface chemistry of activated carbons and its relevance for effects of relative humidity on adsorption of chlorinated organic vapors. Chemosphere. 1994;29(12):2507-15

Wigmans T. Industrial aspects of production and use of activated carbons. Carbon. 1989;27(1):13-22

Yang C. Aerosol filtration application using fibrous media - An industrial perspective. Chinese Journal of Chemical Engineering. 2012;20(1):1-9

6. Appendix

Appendix 1. Personal protective equipments by KMOEL standard

Classification	Obligatory safety certification	Self-regulated safety confirmation
Personal Protective Equipment	1. Industrial safety helmet 2. Safety shoes 3. Protective gloves 4. Dust mask 5. Gas mask 6. Air-line mask 7. Power assisted filtering devices 8. Protective clothing 9. Industrial safety belts & harnesses 10. Eye-protectors (Filters for welding) 11. Welding face-shield 12. Hearing protectors	1. Industrial safety helmet (except items for obligatory safety certification) 2. Eye-protectors (except items for obligatory safety certification) 3. Face-shield (except items for obligatory safety certification) 4. Diving apparatus

Appendix 2. Classes of dust masks

Class	Application
Special	-Places with dusts containing toxic substances such as beryllium -Places that treat asbestos
First	-Places with dust except for place subject to the special class -Places with dusts caused thermally such as metal fumes. -Places with dusts caused mechanically (except for dusts such as silicon where it is safe to wear a second class dust mask)
Second	Other places with dusts except for place required special or first class
Filtering Facepiece Respirator without the exhalation valve should not be used in special and first class places.	

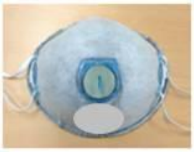
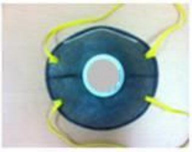
Appendix 3. Types of gas masks by test gas

Type	Test Gas
Organic Compounds	Cyclohexane (C_6H_{12})
Halogen	Chlorine (Cl_2)
Hydrogen Sulfide	Hydrogen Sulfide (H_2S)
Hydrogen Cyanide	Hydrogen Cyanide (HCN)
Sulfur Dioxide	Sulfur Dioxide (SO_2)
Ammonia	Ammonia (NH_3)

Appendix 4. Classes of gas mask by challenge concentration

Class	Application
High Concentration	Place with gas or vapor concentration of lower than 2/100 (for ammonia 3/100)
Medium Concentration	Place with gas or vapor concentration of lower than 1/100 (for ammonia 1.5/100)
Low Concentration & Very Low Concentration	Place with gas or vapor concentration of lower than 0.1/100 and is not under urgent condition
Note: Gas masks are to be used in places with at least 18% oxygen saturated, and full-facepiece type (isolated type, direct type) gas masks should be used in high and medium concentration places.	

Appendix 5. Products for the study

Manufacturer	Product		
# 1			
	A	B	C
# 2			
	D		
# 3			
	E	F	
# 4			
	G	H	
# 5			
	I	J	
# 6			
	K	L	
# 7			
	M	N	

7. 국문초록

연구목적 : 최근에 방진 마스크에 활성탄을 추가한 일회용 방진 마스크가 많이 사용되고 있으나 이 마스크의 활성탄 흡착 성능에 대한 연구가 없었다. 본 연구의 목적은 흡착제가 추가된 방진 마스크의 방독 성능 및 방진 성능 평가를 하는 것이다.

연구방법 : 연구 대상 마스크는 국내에서 작업자가 쉽게 구입할 수 있는 한국 산업안전보건공단 방진 마스크 안전인증 (KCs)을 받은 겸용 방진 마스크를 대상으로 하였는데 7개 제조회사의 14 종을 선정하였다. 선정된 겸용 방진 마스크의 방독 성능을 평가하기 위하여 호주 / 뉴질랜드의 관련 표준 방법 (AS / NZS 1716 : 2003) 을 이용하여 파과 시간으로 평가하였다. 단, 이 법규에서 명시하고 있지 않았으나 첨가된 활성탄의 온도 및 습도로 인한 성능 변화를 살펴보기 위해 다음과 같이 세 가지 온 / 습도 조건을 설정하여 전처리를 진행한 후 각 표본 당 세 개씩 반복하여 실험을 진행하였다. (1) 상온 조건: 25 ±3 ℃ / 0 RH% 에서 24시간 전처리 (2) 고온 조건 : 70 ±3 ℃ / 0 RH% 에서 24시간 전처리 (3) 고온 다습 조건 : 70 ±3 ℃ / 70 ±10 RH% 에서 24시간전처리. 방진 성능에 대한 시험은 방진 마스크 안전인증 기준 (고용노동부 고시 제 2012-83호) 을 이용하였고, 분진 투과율, 호흡 저항, 그리고 양질 계수의 세 요소로 성능을 평가하였다.

연구결과 : 방독 성능 평가에서는 14 종의 겸용 방진 마스크 중 2 가지 (14 %) 만 호주 / 뉴질랜드의 성능 기준을 만족하였다. 성능 기준을 만족

하지 못한 제품 중 파과 시간이 0 분에 가까운 제품이 4종, 1 분 내외인 것이 4 종으로 총 8 종 (57 %) 은 매우 짧은 파과 시간을 나타냈다. 파과 시간이 15 분 이상 되는 두 종류의 마스크는 온도에 의한 성능 변화는 없었으나 수분에 의한 성능 저하는 현저하였다. 방진 성능의 지표로 사용된 양질 계수 값을 비교했을 때 온도 및 습도의 변화로 인한 방진 성능 변화는 관찰되지 않았다.

결론 : 작업장의 유기용제를 제거할 목적으로 사용되고 있는 활성탄 함유 일회용 방진 마스크 14종을 대상으로 방독 성능을 평가한 결과 2 종 (14 %) 만이 유기용제를 제거할 수 있는 것으로 평가되었다. 겸용 방진 마스크의 방독 성능에 온도는 영향을 주지 않았으나 습도는 제독 능력을 현저히 감소시켰다. 본 연구 결과 대부분의 겸용 방진 마스크는 유기용제 취급 사업장에서 가스 상 물질로부터 근로자를 보호하기 위해 사용하기에 부적절하며 일부 적절한 방독 성능을 지닌 제품이라 하더라도 습도의 영향을 많이 받는 것을 알 수 있었다. 따라서 겸용 방진 마스크를 방독 측면에서 사용할 경우, 제조자는 정확한 정보를 제공하여야 하며, 사용자는 한계점을 인식하여야 하고, 정부는 겸용 방진 마스크의 방독 성능 기준에 대한 정확한 지침을 제공하여야 한다.

주요어 : 활성탄, 안면부 여과식 방진 마스크, 겸용 방진 마스크, 유기 증기 제독, 파과 시간, 양질 계수

학 번: 2011-22066