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Selection Guide to Wearing Respirators According to Work Situations and On-site Applicability

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ABSTRACT

Background: This study aims to introduce the formulation of the regulation for the selection of respirators for accident preparedness chemicals (APCs) according to chemical workplace situations and to determine on-site applicability.

Methods: Workplaces were grouped into seven work categories, and APCs were classified into six groups to select adequate respirators. A survey was conducted to enhance the understanding of work situations and adequate respirators. The total number of subjects surveyed in 2018 was 201 managers and handlers, and that in 2019 was 91 handlers and 204 managers.

Results: Adequate respirators were allocated to each cell using the matrix method. The study observed an overall lack of understanding of work situations, especially in the operation of open devices, which was the highest at 32.7%. Despite its implementation in 2015, 17.6% and 25.0% of the managers and APCs handlers, respectively, were unaware of the regulations for selecting respirators. Only 70.4% of the APCs handler wore respirators in compliance with regulations.

Conclusion: The method for selecting respirators according to work situations using the matrix method is considered reasonable. Thus, this study suggests that the development of educational contents and reinforcing education should be essential steps to increasing awareness of regulations.

1. Introduction

According to the white book *Hydrofluoric acid has changed Gumi 2013*, the leakage accident of hydrofluoric acid in Gumi, South Korea, occurred in September 27, 2012, and resulted in 23 casualties (five deaths and 18 injuries), whereas 12,000 residents received hospital treatment. Furthermore, an area near the accident was declared a special disaster area, which led to immense social repercussions [1]. In the wake of the accident, the Korea Ministry of Environment (KME) designated accident preparedness chemicals (APCs) for places with high possibilities of chemical accidents due to acute toxicity or explosion, and whose damage may be exacerbated in the case of accidents. APCs are substances (1) with high physical and chemical risks, such as inflammability and explosion; (2) that are highly, acutely toxic; and (3) proven harmful to human health and the environment and other substances deemed necessary to undergo special management owing to the high risk of chemical accidents [2]. At the time of the enactment of the regulation, the KME recognized 69 APCs; currently, this number has increased to 97 [3].

The white book pointed out that one of the causes of human casualties in the Gumi hydrogen fluoride leakage in 2012 was caused by an accident, in which workers handling chemicals (hereafter referred to as chemical handlers) worked without appropriate respirators, which led to their deaths.

In 2014, governmental authorities urgently issued a regulation entitled "*regulation on wearing personal protective equipment (PPE) for handlers of hazardous chemicals*" (hereafter referred to as the regulation) and required all APCs handlers to wear PPE [4]. However, complaints emerged that working for prolonged periods with PPE (up to 8 h) became extremely difficult. In 2015, when the regulation was implemented, many handlers reported that wearing a full-face mask in handling all APCs was practically impossible. They complained that wearing the mask, an air-line respirator, or a self-contained breathing apparatus (SCBA) may lead to increased risk of accidents or heat disorders during summer more than it can prevent chemical contamination.

Therefore, the National Institute of Chemical Safety (NICS) [5] conducted a two-year study in 2016–2017 to produce a guide in selecting *adequate* respirators for various chemical substances and

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work situations, and revised the regulations. In this context, "*adequate*" indicates that the type of respirator is appropriate for certain hazardous materials and reduces chemical exposure to the level required to protect the health of the wearer [6].

Despite the revision of the regulation, considerable complaints remained about working in respirators as prescribed in the regulation. Therefore, evaluating the on-site applicability of wearing respirators with corresponding work situations is necessary.

The study aims to introduce the formulation of the regulation for selecting adequate respirators for APCs according to work situations and to determine the on-site applicability of wearing respirators as specified by the regulation.

2. Materials and methods

Fig. 1 presents the schematics of this study.

2.1. Hazard ranks and six groups of APCs

The hazard ranks of APCs were grouped into five classifications based on hazardous characteristics, such as LC_{50} and vapor pressure, using matrix analysis. Relevant information was essentially cited in data from the National Fire Protection Association [7] and, if missing, then data from SAX's Dangerous Properties of Industrial Materials [8]. LC_{50} (1 h) <100 ppm chemicals were nearly consistent with chemicals less than 0.1 ppm under the Korea Occupational Exposure Limit [9]. Non-volatile chemicals were classified as *Class 1* because they do not evaporate, and, therefore, can lead to less exposure among humans through inhalation. The chemicals included in this class are those in solid-phase, where protection using a particulate respirator is sufficient. Vapor pressure more than 10 mm Hg can easily vaporize, which could result in high levels of exposure among humans. The higher the vapor pressure and the more toxic APCs are, the classes of these substances are classified as *Class 1* to *Class 5*. Some chemicals can be easily adsorbed and removed using a gas/vapor chemical cartridge respirator, whereas others are not. Several APCs could not be eliminated using the current adsorbent removal techniques. For example, phosgene requires only an air-line respirator or SCBA. Considering the limitations of the current respirators, APCs were again divided into six groups.

2.2. Work situations and work types

In 2016, workplaces that handle APCs were first divided into eight work processes and classified into 55 work types under these processes based on the opinions of a chemical process expert and 18 APCs managers. This workplace classification was monitored to ensure the understanding of APCs handlers in actual workplaces. Contrary to expectations, it was pointed out that this classification did not reflect actual situations in workplaces, which hindered the understanding of APCs handlers regarding the classification. Referring to previous studies [10,11], the current study changed the eight work processes to seven work situations and the 55 work types to 27 to facilitate understanding among APCs handlers as much as possible.

The study presents the determining factors for risk of exposure according to work type with a consideration of the levels of the manual demand of work types, frequency of leakage accidents, and severity of damage in the case of accidents in Korea [12,13].

Notably, two studies on hazard ranks of APCs and exposure risk by work type were previously published [14,15].

2.3. Selection guide for respirators according to work situations

The six APC groups and seven work situations were classified as an exposure risk matrix of 42 ($6 \times 7 = 42$) using the matrix method, which is a risk assessment method [16]. *Levels A*, *B*, *C*, and *D* as specified in OSHA/EPA were placed within these cells because the regulation should include not only respirators but also PPE [17,18]. Although the classification of PPE was similar to that of OSHA/EPA, not everyone was the same. For example, *Level D* in OSHA/EPA requires no respirator. In this study, however, although *Level D* does not require a respirator or needs a particulate mask, it particularly suggests the use of a filtering facepiece respirator. In the case of *Level C*, it was decided whether to use a half- or a full-face mask dependent on the work situation. Moreover, the regulation was revised on the basis of the abovementioned research process, which is undergoing enforcement [5].

2.4. Survey

A survey was conducted from June 1 to July 30, 2018, mainly to gage understanding regarding work situations and wearing of respirators. The researchers visited 30 small- and medium-sized companies that handle APCs to observe work situations and types. At the same time, the study interviewed 30 APCs managers in-depth. During this period, another survey was conducted on 201 chemical managers and handlers who came to NICS to receive education. The main questionnaire aimed to assess understanding about work situations described by the regulation and whether respirators were worn in compliance with the regulation. In

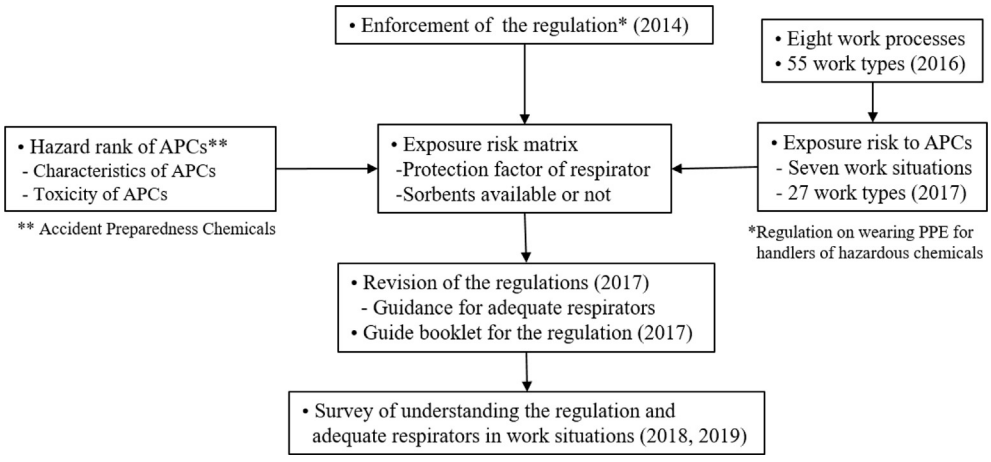

Fig. 1. Schematics of the study.

addition, another questionnaire survey was disseminated from August 1 to September 30, 2019, to 91 APCs handlers and 204 managers to determine their level of understanding about the guide brochure based on the regulation.

3. Results and discussion

3.1. Six groups of APCs

Table 1 depicts that 97 APCs were divided into hazard ranks according to physical–chemical characteristics and toxicities of chemicals. Finally, they were classified under six groups according to the type of respirator currently available. For hazard rank, *Classes 1* and *2* were considered low, *Classes 3* and *4* as medium, and *Class 5* as high. Many previous studies were used as reference during the selection of an adequate respirator for each APC [6,19–21].

A total of 24 APCs, such as phosgene and nitric acid, are classified as *Group A*, since the current technology lacks adsorbents for the removal of these chemicals. Therefore, to protect workers from APCs under *Group A*, air-line respirators or SCBA should be worn.

Groups B and *C* are gas- or vapor-phase APCs. The hazard ranks of chemicals in *Group B* are high, whereas those of chemicals in *Group C* are medium. Therefore, the facial type of respirator should be different. If APCs under *Group C* require the use of a half-face mask, then substances under *Group B* require the use of a full-face mask. Evidently, exposure risk by work situations and type should be considered when making the final decision on whether to use a half- or a full-face mask.

Groups D and *E* denote liquid substances. The hazard rank of substances under *Group D* is "high," whereas that of *Group E* is medium or low. Many substances under these groups simultaneously generate vapor and particulate matter dependent on the process, such that a combination of a gas/vapor and particle respirator is required in certain cases.

Chemicals under *Group F* are not vaporized as solids. Thus, their hazard rank is low and leads to less exposure through inhalation. These substances can be removed sufficiently using a particulate respirator.

According to the hazard assessment of the ISO for the selection of respiratory protection devices (RPDs) [22], the first classification intends to classify chemicals, such as gas, vapor, or particulate matter. In the second adequacy assessment, control banding methods are used to combine chemicals into metrics between health hazard group and protection level (PL) for the selection of respirators. The present study similarly applied the ISO method, but not the same method. Meanwhile, prior to this study, Korea has no regulation that classifies the hazard ranks of chemicals for selecting respirators. At the time of the study, however, only guidelines for classifying chemicals according to available adsorbents were formulated, which was referred [23].

Therefore, this classification is considered extremely reasonable for selecting the appropriate respirator if the health manager lacks an understanding of the respirator and is reliant on the judgment of the manufacturer in selecting the respirator.

3.2. Seven work situations and 27 work types

Table 2 presents the seven work situations and 27 work types. Making clear distinctions was difficult because of the numerous work types. First, the study classified work situations, and the following was divided into representative work types to rate the exposure risk to chemicals. The work types were derived from small- or medium-sized batch processes that may be more dangerous owing to exposure to chemicals instead of the large-scale sequencing batch process of chemical facilities, such as petrochemical plants. This classification was considered reasonable because chemical leakage or spillage accidents occur more in small- and medium-sized companies than in large companies. Thus, this classification may not apply to all workplaces that handle chemicals. Nevertheless, the classification was considered very reasonable because it fully reflected the opinions of chemical managers in workplaces for two years.

Although workplaces that handle chemicals have been classified according to work process [10,11], studies that classified work situations and work types through direct site observations and interviews with personnel that handle chemicals have been lacking. Therefore, this classification is expected to be extremely useful for risk assessment or investigation in workplaces.

3.3. Respirator types by work situations

The types of respirators by work situations in Table 3 were determined according to the classification of APCs with hazard ranks in Table 1 and seven work situations in Table 2 using the matrix [16].

Workers handling APCs in *Group A* should wear air-line or SCBA while working in all work situations except others. If a worker performs a job, such as transportation of a vehicle, which is one of the others, then the worker only needs *basic* despite handling APCs in *Group A*. In this context, basic pertains to at least a PPE, which can be determined by APCs managers according to the work situations. Solid-phase APCs in *Group F* may not be a risk for exposure through inhalation. Thus, wearing a half-mask in many workplaces is appropriate despite the high levels of toxicity of solid-phase APCs. In the event of accidents during open-device, leakage, and waste disposal operations, APCs handlers are more exposed to chemicals.

Table 1
Group of APCs with hazard rank and recommended respirator

Group	Hazard rank*	Recommended respirator	Phase of APCs	No. of APCs	Examples
A	High or medium	Air-line or SCBA	Gas Liquid	16 8	Phosgene Nitric acid
B	High	Gas/vapor cartridge	Gas Liquid	7 8	Formaldehyde Isoprene
C	Medium	Gas/vapor cartridge	Gas Liquid	7 2	Methyl amine Tetra methyl silane
D	High	Gas/vapor cartridge Combination gas/vapor and particulate	Liquid	10 5	Carbon disulfide TDI
E	Medium or low	Gas/vapor cartridge Combination gas/vapor and particulate	Liquid	16 7	Formic acid Phenol
F	Low	Particulate	Solid	11	Sodium cyanide

Note. SCBA: self-contained breathing apparatus, APC: accident preparedness chemicals.
* High: Class 5, Medium: Classes 3 or 4, Low: Classes 2 or 1.

Table 2
Classification of work situations and work types for workplaces

Work situations	Work types	Examples	Illustration
Open-device operation	Cleaning the container Others: 6	Manual cleaning of storage containers or appliances as a process step (IV)* Others: 19	
Closed-device operation	Injection, reaction, mixing, and discharging of raw materials under normal operation Others: 1	Injection, transport, reaction, mixing, and discharging raw materials in a closed state (I)* Others: 2	
Loading or unloading of raw materials	Tank truck loading or unloading Others: 2	Loading or unloading of tankers fixed to a carrying vehicle (by pressurization from tankers or vehicle attached pumps) (III)* Others: 6	
Repair	In-device repair operations Others: 2	Maintenance conducted in the equipment in a situation where several APCs are present or can be introduced through pipes (IV)* Others: 5	
Leak and waste disposal	Leaks or spillage response operations Others: 4	Emergency response work around the equipment in the presence of gas or liquid effluents from external equipment, pipes, and pumps (III)* Others: 9	

(*continued on next page*)

Table 2 (*continued*)

Work situations	Work types	Examples	Illustration
Sampling and testing	Tests conducted within the facility Others: 2	Simple inspection on-site without any test space indoors or outdoors (II)* Others: 3	
Others	Daily inspection Others: 3	Daily inspection around a device (I)* Others: 7	

* Exposure risk to chemicals by work type. The larger the number, the higher the risk.

Thus, they should wear full-face masks in all APCs except for those under *Group F*.

The work situations with the lowest risk is closed-device operations; therefore, workers should be protected from all chemicals (except from those under *Group A*) and wearing a half-mask or basic PPE. Exposure to chemicals is extremely rare in this work situation owing to the process in which chemicals are automatically transported, mixed, or reacted in enclosed facilities. It would be, of course, an exception if work facilities were damaged or if joints were disconnected.

Several cases require the designation of a specific respirator when interacting with certain chemicals. In workplaces that generate formaldehyde or benzene, a full-face mask or SCBA should be worn for escape [24,25]. When handling methyl chloride or ethylene oxide, half-masks must not be used because the chemicals may cause eye irritation or injury [26,27]. However, this study may be the first to group various chemicals according to their hazards and designate adequate respirators by work situations.

3.4. Understanding the regulation and use of appropriate respirators

3.4.1. General characteristics of the respondents

The majority of workers that handle chemicals were male (n = 177; 88.1%). By age, 70 workers (34.8%) were aged 30–39 years, followed by 55 workers (27.4%) aged 50 years and above. In the business sector, 54 (26.9%), 39 (19.4%), and 22 (10.9%) companies belong to the plating, chemical manufacturing, and steel industries, respectively. According to the number of regular workers, 70 (34.8%), 64 (31.8%), and 28 (13.9%) companies employed more than 100, 10–49, and less than five employees, respectively.

Regarding their current main duties, 121 (60.2%), 30 (14.9%), 28 (13.9%), and 11 (5.5%) respondents reported themselves as managers or handlers of hazardous chemicals, general affairs officers, field managers, and health and safety managers, respectively. The difference in their duties is due to the fact that individuals should be legally appointed in all workplaces that handle chemicals.

Only 132 employees (65.7%), which include managers of hazardous chemicals and health/safety managers, were suitable for managing APCs. The remaining respondents whose main duties do not include managing APCs were considered unfit for these jobs. In other words, small- and medium-sized enterprises are limited in terms of managing APCs (Table 4).

3.4.2. Lack of understanding of work situations

Fig. 2 indicates that only 113 out of 201 respondents (56.2%) answered the question “Which of the seven work conditions are not understood or are absent from your work facility?”

Contrary to expectations, the understanding of the managers and handlers regarding their respective work situations was very low. Open-device operation had the highest response rate with a total of 37 (32.7%), followed by leak and waste disposal with 13 (11.5%). Similar proportions were observed for the five other work situations.

Undoubtedly, one may easily be exposed to the dangers of work owing to unawareness of specific work situations. Thus, sufficient education and promotion of work situations are crucial to ensure the safety of employees handling hazardous chemicals.

3.4.3. Understanding of the regulation and wearing of respirators

The respondents were asked to indicate their recognition of the types of respirators for each work situations. Two respondents did not answer this question, whereas 170 (85.4%) were aware that the type of respirator used varies according to work situations and chemicals specified in the regulation (Fig. 3). Moreover, 140 (70.4%) reported wearing respirators according to the work situations and chemicals handled. In other words, approximately 15% of the respondents are unaware that their respirators require changing, whereas another 15% were aware but did not practice it. Thus, the study infers that the best method of resolving these issues is through continued and efficient education and publicity.

3.4.4. Reasons for the non-use of respirators according to work situations and handled chemicals

A total of 59 respondents who responded with “no” or “don’t know” to the previous question “do you think you wear respirators properly depending on the work situations and chemicals?” in Fig. 4, were asked the follow-up question “What is your main reason

Table 3
Types of respirators by work situations

Work scenario	Group of APCs and total numbers					
	A (24)	B (15)	C (9)	D (15)	E (23)	F (11)
Open-device operation	Air-line or SCBA	Full-mask	Full-mask	Full-mask	Full-mask	Half-mask*
Closed-device operation	Air-line or SCBA	Half-mask*	Basic†	Half-mask*	Basic†	Basic†
Loading or unloading	Air-line or SCBA	Full-mask	Half-mask*	Full-mask	Half-mask*	Half-mask*
Repair	Air-line or SCBA	Full-mask	Half-mask*	Full-mask	Half-mask*	Basic†
Leak and waste disposal	Air-line or SCBA	Full-mask	Full-mask	Full-mask	Full-mask	Half-mask*
Sampling and testing	Air-line or SCBA	Half-mask*	Half-mask*	Half-mask*	Half-mask*	Half-mask*
Others	Basic†	Basic†	Basic†	Basic†	Basic†	Basic†

Note. SCBA: self-contained breathing apparatus; APCs: accident preparedness chemicals.
‡ Others include transportation of vehicles, piling up of sealed containers in warehouses, daily inspections, and security and guarding.
* Safety glasses should also be worn when wearing half-masks.
† Basic denotes minimum PPE according to work situation, which is determined by APCs managers.

Table 4
General characteristics of the respondents

Classification		No. of respondents (%)
Gender	Male	177 (88.1)
	Female	24 (11.9)
Age	20s	25 (12.4)
	30s	70 (34.8)
	40s	51 (25.4)
	≥50s	55 (27.4)
Type of business	Plating	54 (26.9)
	Manufacture of chemicals	39 (19.4)
	Steel	22 (10.9)
	Synthetic resins	13 (6.5)
	Electronic	9 (4.5)
	Waste disposal	6 (3.0)
	Textile (including dyeing)	5 (2.5)
	Medicines	5 (2.5)
	Paint manufacturing or use	4 (2.0)
	Others	42 (20.9)
	No response	2 (1.0)
Size of company (No. of employees)	<5	28 (13.9)
	5–9	21 (10.4)
	10–49	64 (31.8)
	50–99	17 (8.5)
	≥100	70 (34.8)
	No response	1 (0.5)
Current main duty	Manager or handler of hazardous chemicals	121 (60.2)
	General affairs (e.g., quality control and purchase)	30 (14.9)
	Field manager (management supervisor)	28 (13.9)
	Health and safety manager	11 (5.5)
	Others	9 (4.5)
	No response	2 (1.0)

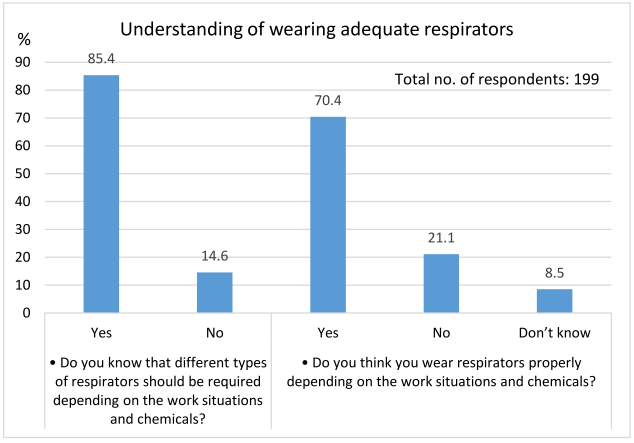

Fig. 3. Understanding of the regulation and wearing of adequate respirators. *Two respondents provided no responses.

for not wearing respirators?" Out of 59, 30 (50.8%), 20 (42.4%), and 1 (1.7%) responded that they were uncomfortable in wearing respirators while working, and that they did not need to wear respirators due to the low concentration of chemicals, and that the employer did not provide sufficient respirators, respectively.

In a previous study [28], 75% of respondents reported the non-use of respirators due to discomfort, such as sweat, difficulty with breathing, and pain, whereas only 1% pointed to the low concentrations exposed to chemicals. The difference in the results between this previous study and the present study is substantial (n = 25; 42.4%).

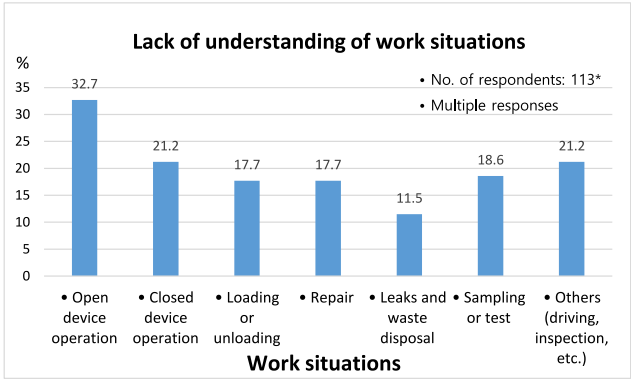

Fig. 2. Percentage of lack of understanding of work situations. *113 respondents (56.2% of the total).

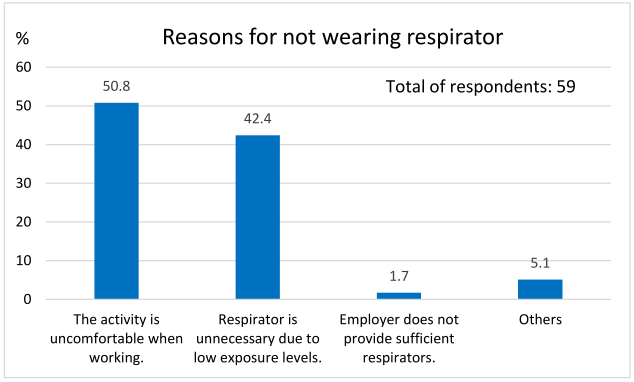

Fig. 4. Main reasons for the non-use of respirators according to work situations and chemicals handled.

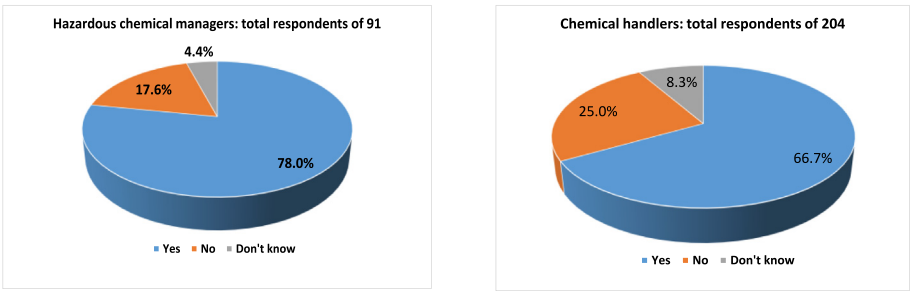

Fig. 5. Comparison of awareness of the regulation between managers of hazardous chemicals and handlers, which was statistically significant between the two groups ($p < 0.05$).

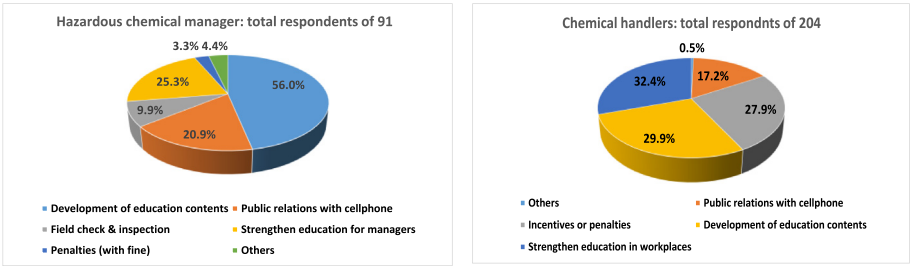

Fig. 6. Comparison of measures to improve awareness between managers and handlers of hazardous chemicals.

The study infers that the reason is that the respondents reflected their subjective thoughts for fear that this investigation would lead to legal problems. Nevertheless, the response that they do not own respirators owing to the low concentration exposed to chemicals in the workplace is subject to considerable controversy.

3.4.5. *Awareness of the regulation*

To gage the level of awareness of the regulation, the respondents were asked whether they were aware of the specifications of the regulation regarding the use of PPE.

Of the 91 managers, 71 (78.0%) responded with "yes," whereas 16 (17.6%) and 4 (4.4%) indicated "no" and "no responses." Out of the 204 handlers, 136 (66.7%) reported awareness, whereas 51 (25.0%) were unaware, and 17 (8.3%) did not respond. The study found that managers had better awareness of regulation than handlers do ($p < 0.05$) because managers were given more opportunities to contact regulation, e.g., to participate in education. Despite the implementation of this regulation since 2015, a considerable number of managers and handlers remain unaware of this regulation. Therefore, the study proposes that the education and promotion of the regulation should be strengthened in the future (Fig. 5).

3.4.6. *Measures to improve awareness of regulations*

Moreover, the respondents were asked for their opinion on how to best improve their awareness of regulations. Out of 91 managers, 51 (56.0%) suggested the development of various educational contents, whereas 66 out of 204 handlers (32.4%) implied that education should be reinforced in workplaces. Sixty-one respondents (29.9%) proposed the development of educational contents.

Therefore, the study highlights that developing educational content and strengthening education should be prioritized to increase the awareness of managers and handlers about the appropriate use of PPE and respirators (Fig. 6).

The study observed the lack of consensus between work process experts and field managers in terms of hazard assessment according to the seven work situations and 27 work types. The study first reflected on the opinions of work process experts because those of field managers were diverse, which may be inaccurate. Thus, the study remains limited in its distinction between the use of half- or full-masks using the matrix to assess risk according to work situations and hazard ranks of APCs.

4. Conclusion

This study briefly introduced the annual process in which the regulation was made and conducted field observations and surveys on the applicability of respirators to ensure that employees are wearing them as specified by the regulation. Workplaces that handle APCs were classified into seven work situations in terms of the risk of exposure to chemicals, whereas APCs were classified into six groups according to chemical hazards. Appropriate respirators were then allocated to each cell using the matrix method. The study is expected to be useful in the future in terms of the risk assessment of workplaces that handle hazardous chemicals.

According to the site applicability survey, although the regulation was implemented in 2015, only 70.4% of APCs handlers wore respirators that met the regulation. To increase awareness of the regulation, managers, or handlers suggested the development of various educational contents and the reinforcement of education within the workplace.

Conflicts of interest

None declared.

Acknowledgments

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