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Original Article

Evaluation of Respiratory Protection Program in Petrochemical Industries: Application of Analytic Hierarchy Process

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A B S T R A C T

Background: Respiratory protection equipment (RPE) is the last resort to control exposure to workplace air pollutants. A comprehensive respiratory protection program (RPP) ensures that RPE is selected, used, and cared properly. Therefore, RPP must be well integrated into the occupational health and safety requirements. In this study, we evaluated the implementation of RPP in Iranian petrochemical industries to identify the required solutions to improve the current status of respiratory protection.
Methods: This cross-sectional study was conducted among 24 petrochemical industries in Iran. The survey instrument was a checklist extracted from the Occupational Safety and Health Administration respiratory protection standard. An index, Respiratory Protection Program Index (RPPI), was developed and weighted by analytic hierarchy process to determine the compliance rate (CR) of provided respiratory protection measures with the RPP standard. Data analysis was performed using Excel 2010.
Results: The most important element of RPP, according to experts, was respiratory hazard evaluation. The average value of RPPI in the petrochemical plants was 49 ± 15%. The highest and lowest of CR among RPP elements were RPE selection and medical evaluation, respectively.
Conclusion: None of studied petrochemical industries implemented RPP completely. This can lead to employees' overexposure to hazardous workplace air contaminants. Increasing awareness of employees and employers through training is suggested by this study to improve such conditions.

1. Introduction

Iran petrochemical industries date back over 50 years, and play an important role in the country's economy. The petrochemical industries are, however, associated with vast quantities of airborne contaminants such as volatile organic compounds and other hydrocarbons released from industrial processes and wastes, which may put workers at risk of acute and chronic occupational diseases such as respiratory disorders or cancer [1–3].

It is well-known that engineering controls are the first and best strategy in controlling respiratory exposure to airborne pollutants [4]. However, there are many situations in petrochemical industries, in which engineering controls are not feasible and workers have to use respiratory protection equipment (RPE) as the last resort of protection, under normal or emergency situations [5].

The key factor in protection is not only correctly selecting an RPE in accordance with a given pollutant/pollutants, but also its proper wearing, which is crucial in ensuring effective protection [6]. Unsurprisingly, the lack of knowledge and adequate training on the selection and/or use of RPE and deficiencies in equipment have led to many fatal injuries such as asphyxiation or chemical poisoning among industrial workers [7]. Accordingly, it has been

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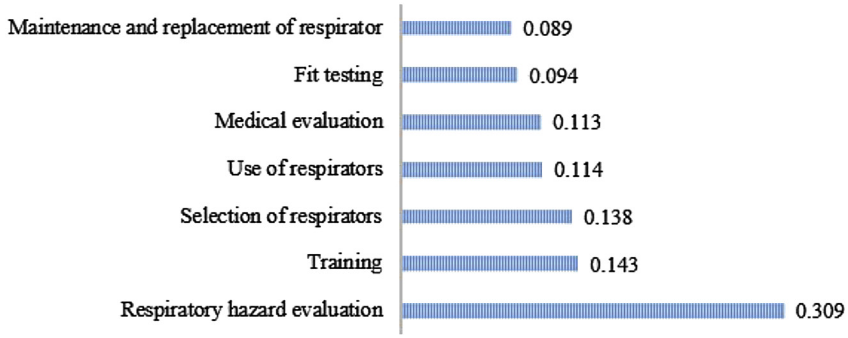

Fig. 1. Analytical hierarchy process weight coefficient of respiratory protection program dimensions.

recommended that RPE should be used only in a systematic and documented manner as detailed in the respiratory protection program (RPP). As part of respiratory risk control in the workplace, implementing an RPP can ensure that selection, use, and care of respiratory protective equipment have been conducted correctly and expected protection has been provided to the workers [8–11].

According to the Occupational Safety and Health Administration (OSHA) respiratory protection standard (29 CFR 1910.134), the components of RPP should be include respiratory hazard evaluation, proper selection of respirator, medical evaluation of employees, fit testing procedure for tight-fitting respirators, change schedule for canister/cartridge or filters, training of employees in the respiratory hazard and proper use of respirator in routine and emergency situations, and respiratory maintenance and regular evaluation of this program [12].

Respiratory hazard evaluation includes measuring given pollutants and comparing their concentration with occupational exposure levels. An exposure level higher than occupational exposure levels in a workplace characterized by a poor engineering control system underlines the necessary use of appropriate RPE to protect the workers. RPE should be selected based on the type and concentration of contaminants, environmental condition (oxygen rate, humidity, and temperature rate), worker characteristics, workplace limitations, capability of respirator and filter (such as assigned protection factor, maximum use concentration, filter type), as well as simultaneous use of multiple protection devices [13]. Furthermore, employees must be evaluated medically to be sure about their ability in using respirator, because using a respirator may create a psychological burden on employees, depending on the type of respirator, the type of job, and workplace condition in which the respirator is used [14,15]. A qualitative or quantitative fit test should also be performed to ensure that tight-fitting respirators properly fit with users' face and contaminants cannot leak into the respirator face piece. Proper maintenance, replacing respiratory cartridge or canister before its service life ends, training users on respiratory hazard and proper use of respirator, inspection, documentation, and periodic monitoring are other important aspects of RPP [8].

Today, most industries in many countries such as the United States are legally required to implement RPP [16,17]. However, in industries in Iran and other developing countries, implementation of RPP has not been well-integrated into the occupational health and safety requirement.

Therefore, this study aimed to evaluate the implementation of RPP in Iranian petrochemical industries to identify the solutions to improve the current status of employees' respiratory protection.

2. Materials and methods

This cross-sectional study was conducted among 24 petrochemical industries in different parts of Iran. As there are no standards for RPP in Iran, the survey instrument (checklist) was extracted primarily from the OSHA Respiratory Protection Standard (OSHA-29 CFR 1910.134). The checklist consisted of seven elements: 'respiratory hazard evaluation' (4 items), 'selection of respirators' (5 items), 'medical evaluation' (5 items), 'fit testing' (6 items), 'maintenance and replacement of respirator' (15 items), 'use of respirators' (6 items), and 'training' (9 items).

Content validity of the checklist was approved by nine occupational health experts and internal consistency was assessed using Cronbach α. An index called Respiratory Protection Program Index (RPPI) was developed to determine the compliance rate (CR) of provided respiratory protection measures with the RPP standard. RPPI is calculated as follows:

$$\mathrm{RPPI\%} = \sum\left[\left(\sum X_i/2n_i\right) \times W_i\right] \times 100 \quad (1)$$

where "X_i" is score for each item, "n_i" is the number of items in each element of RPE, and "W_i" is weight coefficient calculated by the analytical hierarchy process (AHP) technique (Fig. 1).

Table 1
Results of Respiratory Protection Program Index in the studied petrochemical plants ($n = 24$)

RPP elements	CR (%)			RPPI level*, *N* (%)				
	Mean ± SD	Min	Max	A	B	C	D	E
Respiratory hazard evaluation	65 ± 23	13	88	2 (8)	3 (13)	7 (29)	12 (50)	0 (0)
Selection of respirators	66 ± 24	10	100	2 (8)	2 (8)	12 (50)	6 (25)	2 (8)
Medical evaluation	16 ± 22	0	60	18 (75)	2 (8)	4 (17)	0 (0)	0 (0)
Fit testing	19 ± 21	0	58	16 (67)	4 (17)	4 (17)	0 (0)	0 (0)
Maintenance and replacement of respirator	61 ± 18	27	87	0 (0)	7 (29)	13 (54)	4 (17)	0 (0)
Use of respirators	56 ± 18	25	100	0 (0)	9 (38)	11 (46)	3 (13)	1 (4)
Training	52 ± 24	11	83	4 (17)	7 (29)	9 (38)	4 (17)	0 (0)
Respiratory Protection Program Index	49 ± 15	15	74	2 (8)	9 (38)	13 (54)	0 (0)	0 (0)

CR, compliance rate; RPP, respiratory protection program; RPPI, Respiratory Protection Program Index; SD, standard deviation.
* A (CR, from 0 to <25%), B (CR, from 25 to <50%), C (CR, from 50 to <75%), D (CR, from 75 to <100%), E (CR, 100%).

To calculate the RPPI, each item received 2 points if it was completely compliant with the RPP standard, 1 point if it was partially compliant with the RPP standard, and 0 points if it was not compliant with the RPP standard or has missing elements. In addition to weighting the checklist dimensions, the AHP technique was used. AHP, developed by Thomas L. Saaty (1980) [29], is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. AHP starts with pair-wise comparison of the alternatives for each of the decision criteria. To convert the verbal impression of importance into numerical values, the criteria are arranged as rows and columns of a matrix. Then, start with the first criterion in the first row and ask the question “How much more strongly does this criterion influence the outcome than the other criteria?” In answering this question, Saaty’s 9-point scale (from 1 for “equal importance” to 9 for “extreme importance”) is used by decision makers [18]. Accordingly, a questionnaire with 21 paired comparison questions was developed and it was completed by 12 safety and health experts. Results were then analyzed using the Expert Choice software (Expert Choice, Inc., Arlington, Texas, USA) and the relative weights of each element were determined. The RPPI was then categorized into five levels: from 0−<25% (Level A), 25−<50% (Level B), 50−<75% (Level C), 75−<100% (Level D), and 100% (full compliance; Level E).

In the next step, prepared questionnaires were distributed among industrial hygiene officers in each petrochemical plant and they were asked to complete the questionnaires according to the current situation of RPP in their companies. Data analysis was performed using Excel 2010 (Microsoft Corporation, Redmond, WA, USA).

3. Results

Fig. 1 shows the priorities of RPP elements with respect to their importance in respiratory protection against air contaminants. As can be seen, the most important element of RPP, according to experts, was respiratory hazard evaluation (0.309; Fig. 1).

Table 1 presents the CR of the provided RPP with the required standards in different elements among the surveyed petrochemical plants. Moreover, detailed results of completed checklists are presented in Appendix I.

The average value of RPPI in the petrochemical plants studied was 49 ± 15% and none of the surveyed plants had fully implemented the RPP standard (Table 1). Based on RPPI categorization from the studied plants, 13 plants had 50−75% compliance with the standard (Level A), nine plants had 25−50% compliance with the standard (Level B), and two plants had > 25% compliance with the standard (Level C).

4. Discussion

The aim of this study was to investigate the CR of RPP in Iran’s Petrochemical Industries and to determine the intervention solutions to improve the current state of their employees’ respiratory protection. The results revealed that the average RPPI was 49 ± 15%. Therefore, none of the petrochemical plants studied have fully implemented the RPP and most of them (13 plants) were classified as Level C (CR of 50% to <75%). The highest and lowest CR among RPP elements were RPE selection (66 ± 24%) and medical evaluation (16 ± 22%), respectively.

RPP has been evaluated in other workplaces in previous studies. For example, a study in Korea showed that the status of respiratory protection in small and medium industries was poor [19]. In addition, the study by Honarbakhsh et al. [20] in 36 Iranian hospitals showed that RPP was not fully implemented in the studied hospitals and the highest and lowest RPPI scores were related to training and fit testing, respectively. A survey in private sector companies in the United States showed that 54% of investigated companies were incompatible in at least five indices of the RPP standard and 91% of them were incompatible in one index of the standard [21]. The minimum degree of compliance with the RPP standard was reported for the dimension of medical evaluation (16 ± 22%) and 75% of companies were classified as Level A (CR, from 0 to <25%). The lack of medical evaluation, the related procedures followed, and recordkeeping were the causes for this incompliance. Previous studies have also reported a low level of compliance. Syamlal et al. [22] showed that 46% of private sector companies in the United States that needed a respirator have not done medical evaluation and 5% of them did not know if they were evaluated. In addition, 43% of employees reported that they had not done any fit test protocols. For smaller industries, this value was nearly 54% [23]. Furthermore, findings of a study conducted by Easterling and Prince [23] among the Kentucky fire departments showed that 49% of firefighters had not received fit testing for their respirator and that medical evaluation had not been provided for 77% of them [23]. According to the OSHA standard for RPP, employees need to be medically cleared to wear respirators before commencing use. All respirators generally place a burden on the employee. Negative-pressure respirators restrict breathing, some respirators can cause claustrophobia, and self-contained breathing apparatuses are heavy. Each of these conditions may adversely affect the health of some employees who wear respirators [24]. Adverse health effects associated with use of respirator may be greater in individuals with respiratory, cardiovascular, psychological diseases, or other diseases. Thus, it is important to evaluate medical fitness for use of respirator before workers use the device or are fit tested [24].

In this study, after medical evaluation, the lowest CR of RPP was in the dimension of fit test (CR, 19 ± 21%) and most plants (67%) were classified as Level A (CR, from 0 to <25%). A respirator cannot protect the user if it does not fit on his/her face. Tight-fitting respirators must form a tight seal with user’s face or neck to work properly. If it does not fit with the face properly, contaminated air can leak into the respirator face piece, and the user may breathe in hazardous substances. Therefore, before wearing a tight-fitting respirator at work, a fit test must be performed for workers with the same mark, model, and size of respirator used on the job to make sure that the respirator fits users properly [25].

Among the studied plants, only four plants stated that they replace cartridge or canister based on the calculated time schedule or end-of-service life indicator and others partially developed the cartridge/canister schedule (10 plants) or had no time schedule for cartridge change (10 plants). In studies by Jahangiri et al., conducted in Iran petrochemical industries [5] as well as paint spraying plants [26,27], there was no proper replacement schedule program and interval of cartridges replacement significantly differed with the calculated standard cartridges’ replacement schedule. This can lead to breakthrough and employees’ overexposure to hazardous chemicals [28].

4.1. Limitations

Importantly, it should be noted that this study was conducted using a self-reported checklist and heavily depended on participants’ perception of checklist sentences and the accuracy of their answers.

5. Conclusion

In conclusion, according to this study it is clear that the RPP standard has not been fully implemented in Iran petrochemical plants and there were numerous cases of noncompliance, which can lead to employees’ overexposure to respiratory contaminants.

Therefore, there is an urgent need to take interventional actions in all elements of the RPP standard, especially in the elements of medical evaluation and fit test of RPEs. Increasing awareness by training employees and employers is suggested to improve such conditions.

Conflicts of interest

None declared.

Acknowledgments

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Appendix I. Results of the completed checklist for evaluating the respiratory protection program in the studied petrochemical plants ($n = 24$)

	Items	Not implemented*	Partially implemented*	Fully implemented*	Not applicable*
Element 1: Respiratory hazard evaluation					
1	Workplace respiratory hazards is identified and evaluated.	1 (4.2)	6 (25.0)	17 (70.8)	0 (0.0)
2	The necessity of respiratory protection program is evaluated.	4 (16.7)	14 (58.3)	6 (25.0)	0 (0.0)
3	Where the employee exposure cannot be identified or reasonably estimated, the employer shall consider the atmosphere to be IDLH.	3 (12.5)	7 (29.2)	12 (50.0)	2 (8.3)
4	Respiratory hazards are evaluated regularly and revised after the workplace change takes place?	8 (33.3)	13 (54.2)	3 (12.5)	0 (0.0)
Element 2: Selection of respirators					
5	Respirators are selected based on the respiratory hazards and workplace conditions.	1 (4.2)	15 (62.5)	8 (33.3)	0 (0.0)
6	MUC and APF are considered during the selection of respirators.	8 (33.3)	11 (45.8)	5 (20.8)	0 (0.0)
7	Physical and chemical nature of contaminant is considered in the selection of cartridge/canisters.	2 (8.3)	5 (20.8)	17 (70.8)	0 (0.0)
8	Selected respirator is certified by the competent legal authorities.	3 (12.5)	6 (25.0)	15 (62.5)	0 (0.0)
9	Users' comments are considered in the selection of respirators.	7 (29.2)	11 (45.8)	6 (25.0)	0 (0.0)
Element 3: Medical evaluation					
10	The procedure for medical evaluation of employees required to use respirators is provided.	18 (75.0)	6 (25.0)	0 (0.0)	0 (0.0)
11	Medical evaluation is conducted, before fit test or use the respirator.	17 (70.8)	7 (29.2)	0 (0.0)	0 (0.0)
12	If some workers are medically unable to use respirator, they are protected by alternative methods such as by providing PAPR or appointment in nonhazardous area.	18 (75.0)	5 (20.8)	1 (4.2)	0 (0.0)
13	Medical evaluation is repeated after changes in workplace conditions that may result in substantial increase of physiological burden.	18 (75.0)	6 (25.0)	0 (0.0)	0 (0.0)
14	Records of medical evaluations are available.	18 (75.0)	2 (8.3)	4 (16.7)	0 (0.0)
Element 4: Fit testing					
15	Fit testing procedures for tight-fitting respirators are provided.	15 (62.5)	5 (20.8)	4 (16.7)	0 (0.0)
16	Employees do qualitative or quantitative fit test for tight-fitting respirators.	15 (62.5)	6 (25.0)	3 (12.5)	0 (0.0)
17	If the fit factor of the respirator was unacceptable, employees shall be given a reasonable opportunity to select a different respirator face piece and to be retested.	17 (70.8)	6 (25.0)	1 (4.2)	0 (0.0)
18	Whenever changes in the employee's physical condition that could affect respirator fit are reported and on an annual basis, the fit is retested.	19 (79.2)	4 (16.7)	1 (4.2)	0 (0.0)
19	Fit test shall be conducted under OSHA's qualitative or quantitative fit test protocol.	19 (79.2)	5 (20.8)	0 (0.0)	0 (0.0)
20	Records of fit test are available.	20 (83.3)	3 (12.5)	1 (4.2)	0 (0.0)

(*continued*)

	Items	Not implemented*	Partially implemented*	Fully implemented*	Not applicable*
Element 5: Maintenance and replacement of respirator					
21	The procedure for cleaning, maintenance, inspection, repair, and elimination of respirator shall be developed and made available.	8 (33.3)	10 (41.7)	6 (25.0)	0 (0.0)
22	Respirators used for the exclusive use of an employee are cleaned and disinfected as often as necessary to be maintained in a sanitary condition.	5 (20.8)	13 (54.2)	6 (25.0)	0 (0.0)
23	Respirators issued to more than one employee is cleaned and disinfected before being worn by different individuals.	0 (0.0)	9 (37.5)	7 (29.2)	8 (33.3)
24	All respirators are stored to protect them from damage, contamination, dust, sunlight, extreme temperatures, excessive moisture, and damaging chemicals and deformation.	0 (0.0)	10 (41.7)	14 (58.3)	0 (0.0)
25	Emergency respirators are stored in compartments or in covers that are clearly marked as containing emergency respirators and kept accessible to the work area.	0 (0.0)	8 (33.3)	12 (50.0)	4 (16.7)
26	All filters, cartridges, and canisters used in the workplace shall be labeled and color coded with the NIOSH or competent authorities' approval label.	1 (4.2)	3 (12.5)	19 (79.2)	1 (4.2)
27	All emergency respirators are inspected at least monthly in accordance with the manufacturer's recommendations, and shall be checked for proper function before and after use.	3 (12.5)	10 (41.7)	11 (45.8)	0 (0.0)
28	Respirator inspections at least should include the following: a check of respirator function, tightness of connections, condition of the respirator parts, etc.	3 (12.5)	9 (37.5)	12 (50.0)	0 (0.0)
29	Respirators that fail an inspection or are otherwise found to be defective shall be removed from service, and are discarded or repaired.	5 (20.8)	3 (12.5)	16 (66.7)	0 (0.0)
30	Air and oxygen cylinders are maintained in a fully charged state and shall be recharged when the pressure falls to 90% of the manufacturer's recommended pressure level.	0 (0.0)	2 (8.3)	20 (83.3)	2 (8.3)
31	Factors affecting the use of respirators such as proper respirator use and maintenance under the workplace conditions should be evaluated.	7 (29.2)	15 (62.5)	2 (8.3)	0 (0.0)
32	Canister/cartridge has End of Service Life Index (ESLI) or developed change schedule.	9 (37.5)	10 (41.7)	5 (20.8)	0 (0.0)
33	Canister/cartridge change schedule is developed based on objective information or data on workplace conditions and cartridge/canisters properties.	10 (41.7)	10 (41.7)	4 (16.7)	0 (0.0)
34	The effectiveness of schedule time must be tested.	15 (62.5)	9 (37.5)	0 (0.0)	0 (0.0)
35	Cartridges/canisters are changed according to the ESLI or developed schedule.	10 (41.7)	10 (41.7)	4 (16.7)	0 (0.0)
Element 6: Use of respirators					
36	Procedures for proper use of respirators in routine and reasonably foreseeable emergency situations are provided.	10 (41.7)	8 (33.3)	6 (25.0)	0 (0.0)
37	Employees do not have facial hair or any condition that interferes with the face-to-face piece seal.	0 (0.0)	19 (79.2)	5 (20.8)	0 (0.0)
38	Corrective glasses or goggles are worn in a manner that does not interfere with the seal of the face piece to the face of the user.	0 (0.0)	17 (70.8)	7 (29.2)	0 (0.0)
39	For all tight-fitting respirators, employees perform a user seal check each time they put on the respirator.	5 (20.8)	15 (62.5)	4 (16.7)	0 (0.0)
40	Employees are permitted to leave the respirator use area to change the respirator or the filter/cartridge/canister, to wash their faces and respirator face pieces as necessary, and if they detect vapor or gas breakthrough.	1 (4.2)	10 (41.7)	13 (54.2)	0 (0.0)
41	Supervisors monitor the use of respirators by workers.	7 (29.2)	15 (62.5)	2 (8.3)	0 (0.0)

(*continued on next page*)

(*continued*)

	Items	Not implemented*	Partially implemented*	Fully implemented*	Not applicable*
Element 7: Training					
42	The procedure for training for respiratory hazards avoidance and use of respiratory must be developed.	9 (37.5)	11 (45.8)	4 (16.7)	0 (0.0)
43	Employees are trained about necessity of using respirator and how improper fit, usage, or maintenance can compromise the protective effect of the respirator.	1 (4.2)	14 (58.3)	9 (37.5)	0 (0.0)
44	Employees are trained about the limitations and capabilities of the respirator.	3 (12.5)	15 (62.5)	6 (25.0)	0 (0.0)
45	Employees are trained about how to effectively use the respirator in emergency situations, including situations in which the respirator malfunctions.	5 (20.8)	14 (58.3)	5 (20.8)	0 (0.0)
46	Employees are trained about donning and doffing and seal check of respirators.	4 (16.7)	14 (58.3)	6 (25.0)	0 (0.0)
47	Employees are trained about how to inspect and check respirators.	7 (29.2)	12 (50.0)	5 (20.8)	0 (0.0)
48	Employees are trained about what the procedures are for maintenance and storage of the respirator.	4 (16.7)	12 (50.0)	8 (33.3)	0 (0.0)
49	It is ensured that each employee can demonstrate knowledge on how to recognize medical signs and symptoms that may limit or prevent the effective use of respirators.	7 (29.2)	14 (58.3)	3 (12.5)	0 (0.0)
50	Retraining is administered annually, and when changes occur in the workplace or the type of respirator and when inadequacies in the employee's knowledge or use of respirator indicate.	10 (41.7)	13 (54.2)	1 (4.2)	0 (0.0)

*All values are presented as *N* (%).

APF, assigned protection factor; IDLH, immediately dangerous to life or health; MUC, maximum use concentration; NIOSH, National Institute for Occupational Safety and Health; OSHA, Occupational Safety and Health Administration; PAPR, Powered Air Purifying Respirator.

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