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Semi-Quantitative Assessment of the Health Risk of Occupational Exposure to Chemicals and Evaluation of Spirometry Indices on the Staff of Petrochemical Industry

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Background & Aims of the Study: Petrochemical industry is an important industry in the economic development of the country that causes employees have exposure with several kinds of contamination. The aim of this study was Semi-quantitative assessment of the health risk of occupational exposure to chemical materials and investigation of spirometry indices between employees of petrochemical industry.

Material & Methods: This cross-sectional study was conducted in one of the petrochemical industry complex in a special area of Assaluyeh in Iran in 2016. Health risk assessment of exposure to harmful chemical agents was performed in all of units and during three stages (identification of harmful material, determination of hazard rate of the chemical material, exposure rate and estimate of risk rate). Spirometry indices were measured using spirometry.

Results: The results of chemical materials risk assessment showed that Raffinate in Butadiene unit has identified the highest amount of risk rank among 27 chemical materials in investigated units. In comparison with spirometry indices in Olefine unit between age with FVC parameter and history work with FVC and FEV1 parameters has observed a significant and negative correlation (P<0.05).

Conclusion: The results of risk assessment in all of the petrochemical units showed that 48.14% of materials were at low risk level, 29.62% medium risk, 18.51% high risk and 3.7% had very high risk level. The variables affecting on spirometry employees such as age and work experience play an important role in reducing the pulmonary function tests in exposed subjects.

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Background

Increasing growth of industry and industrial productions caused the exposure of more than 4 million people with a wide variety of chemicals in the world (1,2). So, the number of chemicals detected at present is over 18 million and 1000 to 2000 new chemicals are added to this number annually which toxicology information is available currently only for 10000 types of chemicals. Some of these substances are new compounds and mixtures which their toxicological properties have not been studied and may be dangerous for humans (3). Exposure to these substances without considering the precautionary principles and control measures, while working with them, can cause numerous health effects on people. Health effects depending on the type of chemicals, route of entry, duration of the exposure and their intensity are different and can cause numerous health such as acute or chronic effects, systemic or local, reversible and irreversible effects on people (4,5). So, according to statistics which are published by the World Health Organization, one million people die annually as a result of unsafe exposure with chemicals or become disabled (3). As well as, a lot of chemicals which were known previously as safe or low-risk substances for human, were introduced later as carcinogens (asbestos) or cause genital disorders (e.g. thalidomide) (3). Petrochemical industry, as an important industry in economic development of the country, provides petroleum products and raw materials which are required in many other industries from oil or natural gas through performing multiple processes. As a result, staffs are exposed to a variety of contaminants and are at serious risks including lung diseases. Banzene, Naphta, Ammonia and chlorine gas, acetic acid, Methanol, Epichlorohydrin and Methyl ethyl ketone have highest risk based on several studies which were conducted on the health risk of occupational exposure of chemicals in Iran petrochemical industry. Based on studies carried out in Saudi Arabia and Nigeria, the prevalence of respiratory symptoms in workers engaged in petrochemicals is more than the control group; also, the pulmonary function indices in exposed workers are lower than the control group (6,7). Investigating the prevalence of respiratory symptoms and airflow obstruction diseases in petrochemical workers is done by spirometry through a series of experiments on pulmonary function tests (PFTS).Spirometry has a significant role in the diagnosis and prognosis of pulmonary diseases (obstruction or restriction). Even, if workers appear normal clinically (8). Studies conducted on pulmonary function indices in exposed subjects have shown a significant reduction in some pulmonary function parameters (of forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), peak expiratory flow (PEF), forced expiratory flow (FEF) 25%, and forced expiratory flow (FEF) 50%) (6,7). In order to achieve health goals for protection of labor, preventing, deciding on control measures and reducing the risk of exposure to chemicals in the workplace, it is necessary that exposure of people to chemicals and the risks which were caused by these substances to be examined. Protecting employees from the adverse effects of chemicals is one of the primary duties of an employer under the Occupational Safety and Health Act 1994 (9). Risk assessment can be one of the most important strategies in determining hazardous and influential chemicals on human health, determining the processes and risky tasks. So, it can be used to protect individuals through prioritization and adoption of appropriate decision makings and taking necessary actions. Without a system of assessment which rank risks based on their risk potential may be time and resources of the organization focused for low-risk substances and neglect the important substances (2,5). In the last few decades, risk assessment in the industry has a special significance due to large losses entered to world petrochemical industries (1).

Aims of the study:

Due to the need for risk assessment of chemicals in the workplace, this study aimed to the semi-quantitative assessment of health risks of occupational exposure to chemicals and reviews of spirometry indices on staff of the petrochemical industry.

Materials & Methods

This is a descriptive-analytic and a cross-sectional study which was conducted in 2016 at one of the petrochemical industrial complex located in Assalooyeh in Iran. Assessing the health risk of exposure to chemical harmful factors was conducted with the method provided by the Safety and Health unit of Singapore's Ministry of Labor in all units at 3 stages including identifying hazardous substances and determining the risk factor of chemicals, determining coefficient of exposure and estimating risk factor which its steps are as follow (4):

After the formation of working groups, the desired company was divided into smaller units including olefin units (OL), high density polyethylene (HDPE), linear low density polyethylene (LLDPE) and butadiene (BD) to identify hazardous substances. In order to determine hazardous substances, then, all businesses were listed in reviewed units and duties of each job were analyzed. After that, all chemicals (including raw materials, intermediate materials, main products and by-products) which were used or produced during work processes were identified through reviewing process, studying process maps such as maps site, PFD, P&ID and examining chemical reactions.

(1) Determine the hazard rate (HR):

According to the proposed method, the hazard rate is determined by one of the following methods:

A) By toxic effects or harmful effects of chemicals (Table No. 1)

B) By acute toxicity of chemicals (Table No. 1)

Table 1) Determination of the degree of risk through the toxic or harmful effects of chemicals

By using toxic effects or harmful effects of chemicals

Hazard Rate (HR)	Describe the effects of chemicals in the division of chemical hazards	Example
1	-Substances that have no known health effects and have not been classified as toxic or harmful -Substances that have been categorized as group A5 (not suspected as a human carcinogen) by the ACGIH	Sodium chloride, butane, butyl acetate, calcium carbonate
2	-Substances that have reversible effects on the eyes, skin, andmucous membranes, but their effects are not severe enough to cause serious damage to human beings -Substances that the ACGIH has categorized as group A4 (not classifiable as a human carcinogen) -Substances that cause sensitivity and irritation in skin	Acetone, butane, acetic acid (10%), barium salts and.......
3	-Substances that are possibly carcinogenic ormutagenic to humans or animals, but there is not enoughinformation about cancer-causing -substances that the ACGIH has categorized as group A3 (confirmedanimal carcinogen with unknown relevance tohumans). -Substances that IARC has put them in group 2B -Corrosive substances (5 <PH 3> or 9> PH 12>) and sensitizing substances of respiratory system and....	Toluene, xylene, ammonia, butanol, acetaldehyde, aniline, antimony
4	-Substances that may be carcinogenic, mutagenic, and teratogen according to studies carried out on animals The number of these substance are more than the previous category -Substances that the ACGIH has categorized as group A2 (suspected human carcinogen). -Group 2A in the classification of IARC -Very corrosive substances (2> PH 0> or 14> PH 5.11>)	Formaldehyde, cadmium, methylene chloride ethylene oxide, acrylonitrile
5	-Substances known for their carcinogenic, mutagenic, andteratogen effects -Substances that have been categorized by the ACGIH as group A1 (confirmed human carcinogen) -Group 1 in the classification of IARC -Very toxic chemical substances	Benzene, benzidine, lead, arsenic, beryllium, bromine, polyvinyl chloride, mercury

Determination of the degree of risk using the acute toxicity of chemicals

Hazard Rate (HR)	LD50 absorbed orally (body weight of rat mg/kg)	LD50 dermal absorption (body weight of rat mg/kg)	LC50 absorbed through inhalation of rat (gases and vapors within 4 hours mg/lit)	LC50 absorbed through inhalation of rat (aerosols and suspended particles within 4 hours mg/lit)
2	>2000	>2000	>20	>5
3	200<LD50<2000	400<LD50<2000	2<LC50<20	1<LC50<5
4	25<LD50<200	50<LD50<400	0.5<LC50<2	0.25<LC50<1
5	LD50<25	LD50<50	LC50<0.5	LC50<0.25

In this study, required information has been obtained by material safety data sheet (MSDS) and the biggest number was considered as the basis of risk factor by using one of the sections presented in Table 1 and recorded for each studied compounds.

2- Determine the exposure rate (ER):

Exposure rate can be obtained by using information contained in relation to measuring the concentration of chemicals (the results of air monitoring) or by using Table No. 2.

Table 2) Determination of exposure index

Exposure Index/ Exposure Factor	1	2	3	4	5
Vapor pressure or particle size in terms of aerodynamic diameter	Less than 1 mmHg large coarseparticles And wet substances	Up to 1 mmHg coarse and dry particles	1-10 mmHg small and dry particles more than 100	10-100 mmHg small and dry particles 10-100 microns	More than 100mmHg Dry and small powder particles less than 10 micrometers
Ratio of OT/PEL	Less than 0.1	0.1 to 0.5	0.5 to 1	1 to 2	More than 2
Control measures	Adequate control with regular repair and maintenance	Adequate control with irregular repair and maintenance	Adequate control without repair and maintenance (dust average)	Inadequate control (much dust)	Without any control (very high level of dust)
Amount of material used per week	Negligible amount of use - Less than 1 kilogram or liter	low amount of use - 1-10 kilograms or liters	Average amount of use workers have been trained to transportation with chemicals 100 kilogram or liter	High usage rate - Workers have been trained to work with chemicals 100 to 1000 kilogram or liter	High usage rate - Workers more than1000 kilogram or liter
Working time per week	Less than 8 hours	8-16 hours	16-24 hours	24-32 hours	32-40 hours

Due to the lack of results from sampling and air monitoring on detected chemicals, exposure rate is calculated by Exposure Index (EI) which obtained from Table No. 2 by the following formula:

$$ER=[(EI)1 \times (EI)2 \times \ldots.(EI)]1/n$$

EI: Exposure Indexes

n: The number of factors used

Classification of exposure indexes is based on a rating scale from 1 to 5 and is in order of increasing the intensity of exposure.

3. Estimation of risk ratio (RR):

After identifying the risk and exposure rates, risk factor of chemicals which were used in the various units of petrochemical companies that were studied, was calculated by the following equation:

$$RR = \sqrt{HR \times ER}$$

Then, level of risk associated with each chemical was determined according to Table 3 in the range of 1 to 5 in such a way that grade 1 is small–negligible exposure intensity, grade 3 is medium one and grade 5 represents very high.

Table 3) Rating of risk

Risk level	Ranking of risk
1	Small–Negligible
2	Low
3	Medium
4	High
5	Very high

In order to determine the hygienic effects created in respiratory capacities of studied professionals and its correlation with chemicals in units, health records of workers were examined and their lung function indices such as FVC, FEV1, FEV1 / FVC, FEF25-75 were extracted. Then, the data collected was analyzed, using SPSS 16, descriptive statistical tests and Pearson correlation.

Results

27 chemicals were detected in surveyed units of petrochemical company. The results of qualitative and quantitative risk assessment of chemicals have been summarized in Table No.

4 (according to these results) Raffinate allocates the greatest amount of risk rating to itself with risk rate of 4.5 at quantitative risk level of 5.

Table 4) Determine the hazard rate, exposure rate and risk level of chemicals assessed in the studied units

Row	unit	Chemical	Formula	Hazard rate	Exposure rate	Risk rate	Risk level	Ranking Of risk
1	**Olefin**	Caustic soda	NaOH	3	4.57	3.7	4.3	high
2		Pyrolysis gasoline	Mixture	1	2.99	1.73	2	Low
3		Propylene	$C_3H_8O_2$	2	2.66	2.3	3.2	Medium
4		Fuel oil Quiench Oil	$C_{40}H_{82}$	2	1.8	1.9	2	Low
5		Gasoline	$C_{16}H_8$	3	3.16	3.08	3	Medium
6		Coal tar	Mixture	2	3	2.5	2.4	Low
7		DMDS	$C_2H_6S_2$	3	3	3	3	Medium
8	**Butadiene**	1,3 - Butadiene	C_4H_6	5	3.8	4.35	4.1	high
9		Raffinate	Mixture	5	4	4.5	5	Very high
10		NMP	C_5H_9NO	2	3.17	2.5	3.3	Medium
11		Polydimethylsiloxane (Silicon Oil)	Mixture	2	4	3	3	Medium
12		TBC	$C_{10}H_{14}O_2$	3	4	3.5	4	high
13	**HDPE**	Hexane WAX	C_6H_{14}	2	4	3	3	Medium
14		Hexane drum	C_6H_{14}	2	3.8	2.7	2.4	Low
15		Titanium tetrachloride	$TiCL_4$	2	2.94	2.4	2	Low
16		TEAL	$C_6H_{15}Al$	5	2.24	3.35	4	high
17		ethylene	C_2H_4	2	3	2.5	2.4	Low
18		Butane	C_4H_{10}	2	3.34	2.6	2.4	Low
19		propylene	C_3H_6	2	4.16	2.8	2.4	Low
20	**LLDPE**	Mineral Oil	Mixture	2	3.16	2.51	2.4	Low
21		Grease	C_31H_{64}	2	3.16	2.51	2.4	Low
22		Calcium stearate	$C_{36}H_{70}CaO_4$	5	3	3.87	3.9	high
23		Richfospowder	Mixture	2	3	2.4	2	Low
24		Evernoxpowder	$C_{35}H_{62}O_3$	2	4.16	2.88	2.4	Low
25		Cyclohexyl Methyl Dimethoxysilane (Donor-C)	$C_9H_{20}O_2Si$	3	3.55	3.27	3	Medium
26		alkylamineEthoxylate	RN(CH,CH,O), H (CH,CH,O),H	3	2.65	2.81	3	Medium
27		TEAL	$C_6H_{15}Al$	5	2.24	3.35	4	high

Assessment's results of risk level of chemicals in various units of petrochemical companies showed that the butadiene unit allocated the greatest total rank of high and very high quality risk to itself (Figure 1).

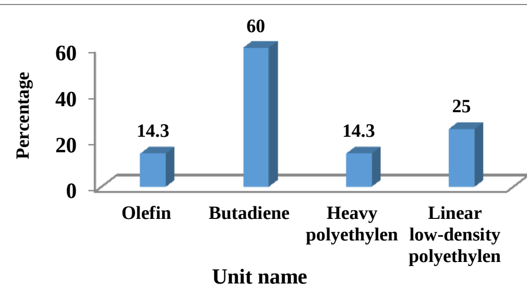

Figure 1) Percentage of total rankings of high and very high quality risk in various units of petrochemical companies

Mean age and the subjects' FVC were reported 34.6 years and 87.9 ml. Other demographic characteristics and results of staff's spirometry parameters have been presented in Table 5.

Table 5) Descriptive statistics of demographic characteristics and spirometry parameters in study subjects

Parameter		Mean±SD	Min	Max
Age(years)		34.58±8.3	25	58
Height(cm)		170.7±19.16	68	185
Weight(kg)		78.44±11.68	54	114
BMI(kg/m^2)		29.99±23.33	20.32	160.03
Duration of employment (years)		9.9±5.3	1	22
Smoking history	**Smokers**	70.6%		
	Non-smokers	29.4%	-	-
FVC(ml)		87.91±11.66	58	117
FEV1(ml)		95.2±12.27	62	116
FEV1/FVC		112.5±10.31	92	130
FEF25-75%		98.35±25.71	44	180

The correlation between demographic characteristics and spirometry parameters of the study subjects has been provided in Table 6. The results of this study showed a significant negative correlation between age with FVC parameter and working experience with FVC and FEV1 parameters in olefin unit at significance level of 0.05.

Table 6) Correlation between demographic characteristics and spirometry parameters in study subjects

Unit	Parameter	FVC	FEV1	FEV1 /FVC	FEF
Olefin	Age	-0.64*	-0.46	0.46	0.31
	Height	0.47	0.51	0.25	0.12
	Weight	0.31	0.36	-0.14	0.05
	BMI	0.03	-0.03	0.0	0.08
	Duration of employment	-0.65*	- 0.61*	0.31	0.04
Butadiene	Age	0.3	0.18	-0.63	-0.12
	Height	0.26	0.25	-0.30	0.24
	Weight	0.18	0.35	0.59	0.97
	BMI	-0.32	-0.29	0.43	-0.15
	Duration of employment	0.88	0.9	-0.44	0

Unit	Parameter	FVC	FEV1	FEV1 /FVC	FEF
HDPE	Age	-0.8	-0.7	0.85	0.08
	Height	0.46	0.48	0.4	0.37
	Weight	0.45	0.45	-0.34	0.39
	BMI	0.2	0.18	-0.3	0.16
	Duration of employment	-0.64	-0.54	0.78	0.15
LLDPE	Age	0.24	-0.23	-0.18	-0.21
	Height	0.54	0.38	0.05	0.27
	Weight	-0.63	-0.43	-0.08	-0.26
	BMI	-0.66	-0.47	-0.11	-0.31
	Duration of employment	-0.15	-0.06	0.06	0.0

*Significance level at 0.05

Discussion

Given the importance of risk assessment of chemicals, a variety of qualitative and quantitative methods have been presented by organizations and experts in the field of hygiene and safety issues. In this study, a semi-quantitative risk assessment method has been used for calculating the risk rate and exposure rate.

Among the substances listed at Olefin Unit, sodium hydroxide has achieved quantitative risk level 4.3 and a high qualitative risk ranking. The results of this study contradict the results of Golbabaei et al (2012) in the petrochemical industry on the quantitative risk factor of 1.4 that this discrepancy could be due to the openness of substance storage tank and the environmental conditions prevailing at the site (3).High risk ranking of sodium hydroxide can be due to the rate of substance consumption in a week and inappropriate control measures in the present study. The effects created by the sodium hydroxide can be problems such as sneezing, soreness of the mouth and nose by inhalation of vapors of this substance in the long term. As there is no possibility of removing sodium hydroxide through the replacement with a less hazardous substance, exposure rate can be decreased through proper engineering control measures such as designing reservoir contained cap in order to prevent the release of contents vapors inside the tank.

Other substances listed at olefin unit have a quantitative risk level of 2 to 2.3 and qualitative risk ranking from low to moderate that this may be due to the closure of material flow cycles in this unit. In order to reduce the health risk level of substance from moderate to low, regular maintenance and continuous monitoring are recommended as appropriate control measures. Results of the present study on the pyrolysis gasoline, fuel oil and gasoline with low to moderate risk level are consistent with study results of Karami et al (2014)in a petrochemical industry (1).

1, 3 butadiene, Tributyl-catechol and Raffinate have been identified substances with quantitative risk level 4, 5, high and very high qualitative risk ranking at butadiene (BD) unit. The high risk rate 1, 3 butadiene and Raffinate, with the risk rate 5 can be due to grouping in class A1 by American Conference of Governmental Industrial Hygiene (ACGIH); also, increase in exposure rate of these substances is due to its lower exposure limit. Results of this study regarding the risk level of 1, 3 butadiene are consistent with the study results of Golbabaei et al in a petrochemical industry with the cited substance (3) that it can be due to weekly consumption rate of Tributyl-catechol and inappropriate control measures. Systematic repair and maintenance of stream connection process, leakage detection and careful monitoring to prevent the release of these substances play an important role in reducing its risk level.

Among the substances raised at heavy polyethylene unit, tri-ethyl aluminum (TEAL) allocates the highest rate (quantitative risk 4 and high quality) to itself due to having carcinogenic effects and exposure in class A1. Due to the high activity of this substance, breathing the vapors of it is principally impossible, but smoke inhalation from the fire of this substance stimulates the respiratory system in the case of fire. To reduce the health risk of this substance through reducing risk rate, we can mention measures such as adequate ventilation of area, storage in a cool and dry place away from any sources of sparks and smoke, taking necessary precautions in the case of static electrical charge and maintenance in the fully closed containers. Other substances listed in heavy polyethylene have quantitative risk level 2-3 and low to moderate qualitative risk ranking. In a study conducted by Golbabaei et al on the hexane and butane substances in a petrochemical industry, the risk level was reported negligible and low which it is roughly in line with the results of this study with low and moderate risk level (3). Obtaining the average qualitative risk ranking for hexane at heavy polyethylene unit can be mentioned as direct monitoring of the operator on production process of wax. Installation of confining local exhaust ventilation system on the wax baths, separating the operator room to monitor the production process, spin off staff, the use of an appropriate personal protective equipment in the case of direct contact with vapors released via the wax baths including essential control measures in this process.

According to the results of Table 4 at linear low density polyethylene unit, tri-ethyl aluminum has a quantitative risk level 4 and high qualitative risk ranking among the evaluated substances. Despite the low quantitative risk derived from calcium powders, Richfos and Evernox, should be considered, because such powders are airborne. Respiratory system stimulation, respiratory problems and lung function changes resulting from pneumoconiosis, lung inflammation and mucous membranes, eye irritation and redness, drying, itching, cracking, flaking and skin inflammation are the long-term effects of exposure to these substances. Other substances which are listed at linear low density polyethylene unit allocated the quantitative risk level 2-3 with low to moderate qualitative risk ranking to themselves.

Other objective of this study was to evaluate lung function indices among exposed people. As it became clear, there was a significant correlation between the age and FVC parameter at olefin unit which this is consistent with the studies of Meo et al., Minov et al (6,10).So, a significant reduction was observed in the pulmonary parameters with increasing age (6). Age, as one of the individual and demographic variables, could have a crucial role in the occurrence of many diseases (11). Petrochemical pollutants may cause changes in the components and surfactant concentrations and may also cause closure of small airways (6). In addition, there was statistically negative and significant correlation between work experience and pulmonary function indices such as FVC and FEV1 at olefin unit that this is in consistent with the studies of Kesavachandran et al and Meo et al (12,13). Reduced pulmonary performance indicators in staff can be probably due to their occupational exposure with sodium hydroxide which assigned high qualitative risk ranking to itself. Inhalation of this substance may cause severe irritation of the respiratory tract, difficulty breathing and even pulmonary edema (14). At the end, it can be concluded that 48.1% of substances are at low risk level, 29.6% average risk, 18.5% high risk and 3.7% at very high risk level.

Conclusion

The results of this study can be acceptably used in allocating resources for control measures and prioritization to reduce the risk level of exposure in this industry.

Footnotes

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Conflict of Interest:

The authors declare no conflict of interest.

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