Occupational exposure to BTEX and styrene in West Asian countries: a brief review of current state and limits

Razzagh Rahimpoor1, Fatemeh Sarvi2, Samira Rahimnejad3, and Seyed Mohammad Ebrahimi4

1 Larestan University of Medical Sciences Faculty of Evaz Health, Department of Occupational Health Engineering, Research Center for Health Sciences, Larestan, Iran
2 Larestan University of Medical Sciences, School of Health, Department of Public Health, Larestan, Iran
3 Kurdistan University of Medical Sciences Faculty of Health, Department of Occupational Health Engineering, Sanandaj, Iran
4 Ahvaz Jundishapur University of Medical Sciences, Pharmacy School, Department of Toxicology, Ahvaz, Iran

[Received in February 2022; Similarity Check in February 2022; Accepted in June 2022]

The aim of introducing occupational exposure limits (OELs) is to use them as a risk management tool in order to protect workers’ health and well-being against harmful agents at the workplace. In this review we identify OELs for benzene, toluene, ethylbenzene, xylene (BTEX), and styrene concentrations in air and assess occupational exposure to these compounds through a systematic literature search of publications published in West Asian countries from 1980 to 2021. OELs for BTEX and styrene have been set in Iran and Turkey to levels similar to those in European countries and the US. The search yielded 49 full-text articles that cover studies of exposure assessment in six countries, but most (n=40) regard Iran. Average occupational exposure to benzene of workers in oil-related industries is higher than recommended OEL, while average occupational exposure to other compounds is lower than local OELs (where they exist). Currently, information about levels of occupational exposure to BTEX and styrene is insufficient in West Asian countries, which should be remedied through OEL regulation and application. Furthermore, coherent research is also needed to determine actual levels of occupational exposure, dose-responses, and the economic and technical capacity of local industries to address current issues.

KEY WORDS: benzene; ethylbenzene; OEL, oil industry; risk management; toluene; xylene

As far as national income is concerned, West Asian countries vary largely, spanning from low- to high-income. Over the last hundred years, some of them have made great strides in development thanks to oil resources. Oil and gas-related industries are the leading sources of uncontrolled hydrocarbon emissions, including volatile organic compounds (VOCs), aldehydes, alkenes, and phenols and present increased health risks for workers in oil-related industries (1, 2). Chronic occupational exposure to these compounds can lead to various adverse health effects and place considerable pressure on already high global burden of diseases (3).

This in particular concerns highly volatile, non-methane, and aromatic hydrocarbons benzene, toluene, ethylbenzene, xylene (BTEX), and styrene, which are extracted from petroleum and used in petroleum and chemical industries (4, 5). These compounds are released during various industrial processes and are quickly absorbed by workers through inhalation and skin (6–11), which can, in turn, lead to neurological, psychological, developmental, liver, and respiratory adverse effects, lung cancer and leukaemia (11–14).

Increased awareness of health hazards of exposure has led to the introduction of occupational exposure limits (OELs), first in Germany in 1877 and then in the USA in 1910 (15). In the 1940s, the American Conference of Governmental Industrial Hygienists (ACGIH) proposed the threshold limit values (TLVs) (16, 17) and other countries or organizations gradually followed suit with their own OELs to protect the health and well-being of workers and ensure effective risk management strategies (18).

This, however, resulted in uneven standards between countries, so that we now distinguish those “health-based” from those that are adjusted to technical and economic considerations (18, 19).

West Asian countries have used various methodologies to regulate their own OELs. In Iran, the legal authority for OELs is the Centre for Environmental and Occupational Hygiene at the Ministry of Health and it has relied on the ACGIH TLVs in setting the OELs.

The objectives of this review were threefold: 1) to identify available data about exposure to airborne BTEX and styrene at workplaces in West Asian countries, 2) to relate these data to applicable OELs, and 3) to identify research needs for the development of new regulations concerning OELs for chemical pollutants in West Asian countries.
METHODS

Compiling OELs for West Asian countries

To get as complete coverage of current OELs across the countries in West Asia, we compiled available information from the GESTIS database and online searches for OEL lists from West Asian countries. The European Chemicals Agency (ECHA) webpage was searched for recent EU level recommendations and derived no-effect levels (DNELs) based on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation (20). Scientific documentation about OELs from the US ACGIH, German maximum workplace concentrations (MAK), Scientific Committee on Occupational Exposure Limits (SCOEL) and ECHA Committee for Risk Assessment (RAC) were compiled and reviewed for information on critical effects, skin notation, carcinogen classifications, and biological monitoring guidance values.

Systematic literature searches for occupational exposure data

We systematically searched international datasets including PubMed, Scopus, Cochrane Library, CINAHL, ISI Web of Science, ScienceDirect, PROSPERO, and EMBASE to identify articles in English related to occupational exposure to BTEX and styrene in West Asian countries and published between 1980 and 2021. For this purpose, we used several combinations of the key words (benzene, toluene, ethylbenzene, xylene, styrene, occupational exposure, industrial exposure, threshold limit value, occupational exposure limit, recommended exposure level, permissible exposure limit, West Asia, and Middle East) and search criteria, including language and publication year (Table 1).

Study selection

First we identified 4199 references that matched our search key terms. Figure 1 shows how we proceeded until we got the final number of 49 full-text articles that met the inclusion criteria: they all had to be original articles in English reporting airborne workplace concentrations of the studied chemicals from 1980 to 2021. We excluded articles not containing original data, such as review articles, case series, and case reports. Each included article was individually assessed for completeness of reporting by two independent reviewers according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist (21).
Table 1 Search strategy for articles on occupational exposure to BTEX and styrene across major literature databases (slight differences in search strings are owed to different functionality of these systems)

| Database                  | Search Strategy                                                                 |
|---------------------------|----------------------------------------------------------------------------------|
| Web of Science            | *(TITLE-ABS-KEY)* (Benzene OR Toluene OR Ethylbenzene OR Xylenes OR Styrene AND Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure) AND *(Threshold limit value OR Occupational exposure limit OR Recommended exposure level OR Permissible exposure limit)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND LANGUAGE: (English) Indexes=SCI-EXPANDED, SSCI, AND Time span=1980-2021 |
| Science direct from inception | *(TITLE-ABS-KEY)* (Benzene OR Toluene OR Ethylbenzene OR Xylenes OR Styrene and Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure) AND *(Threshold limit value OR Occupational exposure limit OR Recommended exposure level OR Permissible exposure limit)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND PUB YEAR ≥ 1980 |
| Scopus                    | *(Title/Abstract)* OR Toluene *(Title/Abstract)* OR Ethylbenzene *(Title/Abstract)* OR Xylenes *(Title/Abstract)* OR Styrene *(Title/Abstract)* OR Volatile Organic compound *(Title/Abstract)* AND *(Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure)* AND *(Threshold limit value OR Occupational exposure limit OR Recommended exposure level OR Permissible exposure limit)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND PUB YEAR ≥ 1980 |
| PubMed                    | *(Title/Abstract)* OR Toluene *(Title/Abstract)* OR Ethylbenzene *(Title/Abstract)* OR Xylenes *(Title/Abstract)* OR Styrene *(Title/Abstract)* OR Volatile Organic compound *(Title/Abstract)* AND *(Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure)* AND *(Threshold limit value OR Occupational exposure limit OR Recommended exposure level OR Permissible exposure limit)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND PUB YEAR ≥ 1980 |
| Cochrane Library          | *(Title/Abstract)* OR Toluene *(Title/Abstract)* OR Ethylbenzene *(Title/Abstract)* OR Xylenes *(Title/Abstract)* OR Styrene *(Title/Abstract)* OR Volatile Organic compound *(Title/Abstract)* AND *(Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure)* AND *(Threshold limit value OR Occupational exposure limit OR Recommended exposure level OR Permissible exposure limit)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND PUB YEAR ≥ 1980 |
| EMBASE                    | *(TITLE-ABS-KEY)* (Benzene OR Toluene OR Ethylbenzene OR Xylenes OR Styrene AND Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure) AND *(Threshold limit value OR TLV OR Occupational exposure limit OR OEL OR Recommended exposure level OR REL OR Permissible exposure limit OR PEL)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND PUB YEAR ≥ 1980 |
| CINAHL (EBSCO)            | *(TITLE-ABS-KEY)* (Benzene OR Toluene OR Ethylbenzene OR Xylenes OR Styrene AND Occupational exposure OR Industrial exposure OR Workplace exposure OR Chemical exposure) AND *(Threshold limit value OR TLV OR Occupational exposure limit OR OEL OR Recommended exposure level OR REL OR Permissible exposure limit OR PEL)* AND *(West Asia OR Middle East OR Iran OR Iraq OR Kuwait OR Syria OR Jordan OR Bahrain OR Lebanon OR Oman OR Qatar OR Saudi Arabia OR Afghanistan, Armenia OR Azerbaijan OR Yemen OR Israel OR Turkey OR Palestine)* AND PUB YEAR ≥ 1980 |

MESH terms in PubMed and Cochrane including: benzene, toluene, ethylbenzene, VOCs, occupational exposure, occupations, occupational groups, Asia western, oil and gas industry, threshold limit values
Both static and personal monitoring studies were included. Quality of sampling was considered sufficient if sampling pump flow rate was between 0.1 and 0.3 L/min, and in case of static monitoring if samplers were placed at the height of 1.5 to 2 m.

Data extraction

After the screening, the data were extracted and cross-checked. Any inconsistencies were resolved by consultation with a third reviewer. The following information was extracted and tabulated: bibliographic information (reference ID, authors, year published, publication type), country where study was performed, industry sector, type of sampling (static or personal monitoring), type of sampler (active/pump or passive sampling), number of exposed workers and non-exposed workers (not applicable to static monitoring), number of area samples (not applicable to personal monitoring), number of individual samples (may be more than one per worker or area), duration of sampling, gender distribution (male/female; not applicable to static monitoring), mean and standard deviation of age (of exposed and unexposed groups, not applicable to static monitoring), means and standard deviations of BTEX and styrene concentrations across all sections of investigated workplace, and, if applicable, range of means for subsections of investigated workplace and whether the reported concentrations were recalculated to represent the eight-hour (workday) exposure scenario (where the workday was shorter than 8 h).

All reported airborne concentrations were converted to ppm, using the following equation:

$$\text{ppm} = \frac{\text{mg/m}^3 \times 24.45}{\text{molecular weight}}$$  \[\text{Equation 1}\]

This assumes 25°C and air pressure of 101.325 kPa (760 Torr).

Data analysis

Descriptive results of variables are given as means and standard deviations. For all analyses we used the Statistical Package for Social Sciences (SPSS), version 22 (IBM, Armonk, NY, USA).

Evaluating compliance with an OEL requires assessment of exposure variability for an exposed group. There is also a normative aspect, that is, how certain we wish to be that exposure is unlikely to be exceeded for a small part of the exposed group and how small that group should be. Industrial hygiene guidance documents refer to 70% certainty that no more than 5% of similarly exposed workers would experience exposures exceeding the OEL. (22, 23). We, however, approached OEL compliance in a simpler fashion, by comparing reported average exposure to the applicable OEL, as the reviewed papers do not report their results in sufficient detail. As airborne exposures are generally log-normally distributed, the arithmetic mean will be a slightly more conservative than the true central estimate of the median or geometric mean. Where reported, we also compared the full range (min–max) of reported exposure to applicable OELs.

RESULTS

Overview of OELs

Benzene is a well-known carcinogen, although conclusions as to whether its mechanism of action supports a threshold or not differs between OEL expert groups. However, more recent assessments tend to conclude that benzene can be viewed as a threshold carcinogen, and consequently that sufficiently low exposures would protect against cancer risk. Most eight-hour time-weighted averages (TWA) for OELs are 1.6 mg/m$^3$ (0.5 ppm) while the most recent recommendation of ECHA RAC is that of 0.16 mg/m$^3$ (0.05 ppm) (Table 2).

Carcinogenicity is generally not considered critical for the other substances. However, the International Agency for Research on Cancer (IARC) has classified ethylbenzene as possibly carcinogenic to humans (group 2B) and styrene as probably carcinogenic to humans (group 2A). All of the reviewed substances are potentially neurotoxic, and most of the OELs for toluene, xylene, and styrene take into account some form of neurotoxicity and irritation as critical effects. Assignment of skin notation varies: ACGIH has a skin notation only for benzene, whereas the German MAK commission and SCOEL have assigned skin notations to all BTEX substances but not to styrene. All the substances have several biological guidance values, mostly in urine.

Overview of occupational exposure to BTEX and styrene in West Asian countries

Our review of the 49 full-text articles shows that occupational exposure levels to BTEX and styrene in West Asian countries have not been measured and reported in a structured or uniform manner, and that most reports refer to Iran. Furthermore, studies investigating occupational exposure to styrene are few and far between. The summary of the extracted data is available in Table 3 (24–65). Most studies address exposure in oil-related industries (such as petrochemical, oil refineries, petrol and compressed natural gas stations, and petroleum depots), while the rest looks into exposure in the shoe factories, plastic industries, pesticides production factories, printing, electronics, or steel industries or among beauty salon workers, drivers, and traffic policemen. Average occupational exposure to benzene in oil-related industries is higher than the OELs recommended in Table 2. As shown in Table 4, the mean air concentrations of toluene, ethylbenzene, xylene isomers, and styrene reported by most studies are lower than the recommended OELs for the same country (if any, see Table 2).

Table 4 shows the analysis of reported occupational exposure to BTEX and styrene narrowed down to oil-related and solvent-related industries (such as shoe factories, printing, electronics, automobile industry, pesticide production factory, tyre factories, steel industries, chemical industry, plastic industry, and beauty salons).
DISCUSSION

Our research shows that occupational exposure limits have been set only in Iran and Turkey, while other countries, even the oil-rich ones of the Persian Gulf, have not set or formally proposed any (Table 4).

Oil and gas industry is run by some of the largest companies in the world, many of which are based in West Asian countries (66) whose gross domestic product (GDP) and economic development significantly surpass that of other countries in the region. Highly developed industry has attracted migrant workers to the point that they make as much as 48.1 % of the total population of the Gulf Cooperation Council countries (67–70). Yet, despite reports of occupational diseases among migrant workers in West Asian countries (70–72), levels of occupational exposure to BTEX and styrene are poorly reported.

OELs recommended by different organisations and countries are mostly the product of current scientific knowledge and reflect scientific judgment of those researchers who develop them and they should be reviewed periodically as this scientific knowledge grows (18, 73–75). Furthermore, it is necessary to assess and record new hypotheses, data, and methods used, as this guarantees the validity of the proposed OELs. Current scientific data and hypotheses used in regulating OELs of chemical compounds are ambiguous or completely unavailable in some countries (76, 77).

However, OEL regulations are not only evidence-based in terms of determining threshold exposure dose without adverse health effects. They also take into account economic and technical capability of the country that is to apply them (78), even though feasibility issues of achieving exposure lower than OELs should not drive decision making. Instead, industrial managers and health experts should be encouraged to lower occupational exposure below science-based limits through effective engineering control, replacement of production sore spots, administrative management control, separation, elimination, or personal protective equipment (PPE) as needed (18, 79).

Currently, however, data needed to accurately assess the risk of occupational exposure to BTEX and styrene are scarce. This

**Table 2** Comparison of existing OELs and DNELs of BTEX and styrene by institutions and countries

| Institution or country | Benzene | Toluene | Ethylbenzene | Xylene (isomers) | Styrene |
|------------------------|---------|---------|--------------|-----------------|---------|
|                        | mg/m³   | ppm     | mg/m³        | ppm             | mg/m³   |
| ACGIH, USA             | 1.6     | 0.5     | 75.37        | 20              | 86.84   |
| OSHA, USA              | 3.19    | 1       | 376.85       | 100             | 434.22  |
| NIOSH, USA             | 0.32    | 0.1     | 753.7        | 200             | 434.22  |
| Australia              | 3.19    | 1       | 188.43       | 50              | 434.22  |
| Brazil                 | -       | -       | 293.94       | 78              | 338.69  |
| Canada                 | 1.6     | 0.5     | 75.37        | 20              | 86.84   |
| Japan                  | 3.19    | 1       | 188.43       | 50              | 86.84   |
| South Korea            | 3.19    | 1       | -            | -               | -       |
| MAK, Germany           | -       | -       | 188.43       | 50              | 86.84   |
| AGS, Germany           | 1.92    | (0.19*) | 0.6          | (0.06*)         | -       |
| Netherlands            | 0.7     | 0.22    | 150.74       | 40              | 214.07  |
| Poland                 | 1.6     | 0.5     | 99.87        | 26.5            | 198.87  |
| United Kingdom         | 3.19    | 1       | 188.43       | 50              | 434.22  |
| European Union         | 0.32    | 0.1     | 188.43       | 50              | 434.22  |
| REACH RAC              | 0.16    | 0.05    | -            | -               | -       |
| REACH DNELs**          | 0.8     | 0.25    | 192          | 50              | 77      |
| Iran                   | 1.6     | 0.5     | 75.37        | 20              | 86.84   |
| Turkey                 | 0.32    | 0.1     | 188.43       | 50              | 434.22  |

* Value corresponding to the proposed tolerable cancer risk, 4:1000 (value corresponding to the proposed preliminary acceptable cancer risk, 4:10000).

** DNELs – derived no-effect levels for workers with long-term inhalation exposure submitted by registrants (available at: https://echa.europa.eu/information-on-chemicals/registered-substances); values calculated to ppm by authors. ACGIH – American Conference of Governmental Industrial Hygienists; AGS – German Committee on Hazardous Substances (Ausschuss für Gefahrstoffe); MAK – German maximum workplace concentrations; NIOSH – National Institute for Occupational Safety and Health; OSHA – Occupational Safety and Health Administration; RAC – Committee for Risk Assessment; REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals.
Table 3 Summary of occupational exposure to BTEX and styrene in West Asian countries from data gathered from 49 published articles between 1999 and 2021 (mean ± SD)

| References | Publication type | Country | Type of sampling | Industry or workplace | Number of workers (exposed vs unexposed) | Concentration (ppm) Mean ± SD |
|------------|-----------------|---------|------------------|-----------------------|------------------------------------------|-----------------------------|
|            |                 |         |                  |                       |                                           | Benzene  | Toluene  | Ethylbenzene | Xylene | Styrene |         |         |
| (Alabdulhadi et al., 2019) (24) | Cross-sectional | Kuwait | Static           | Printing industry     | -                                       | 0.0028±0.076 | 0.062±0.101 | 0.118±0.071 | 0.311±0.174 | -       |
| (Alfoldy et al., 2019) (25)    | Cross-sectional | Qatar  | Static           | Traffic police, Petrochemical | -                                         | 0.038±0.025 | 0.07±0.05 | 0.007±0.009 | 0.009±0.007 | -       |
| (Al-Harbi et al., 2020) (7)    | Cross-sectional | Kuwait | Static           | Gasoline station      | -                                         | 0.23±0.062 | 0.14±0.07 | 0.085±0.07 | 0.16±0.12 | -       |
| (Azari et al., 2012) (26)      | Cross-sectional | Iran   | Personal         | Shoe factory          | 12 (12:0)                                | 1.33±0.11* | 14.24±1.77 | -           | -       | -       |
| (Baghani et al., 2018) (27)    | Cross-sectional | Iran   | Static           | Beauty salon          | -                                         | 0.01±0.009 | 0.0045±0.0041 | 0.0143±0.007 | 0.0031±0.002 | -       |
| (Baghani et al., 2019) (28)    | Cross-sectional | Iran   | Static           | Gas & CNG station     | -                                         | 0.145±0.045 | 0.231±0.053 | 0.113±0.031 | 0.209±0.016 | -       |
| (Bahrami et al., 2007) (29)    | Cross-sectional | Iran   | Personal         | Petrol station        | 145 (80:65)                              | 1.41±0.80* | -           | -           | -       | -       |
| (Bakhtiari et al., 2018) (30)  | Cross-sectional | Iran   | Static           | Taxi driver           | -                                         | 0.088±0.008 | 0.088±0.011 | 0.073±0.009 | 0.126±0.015 | -       |
| (Bakolh et al., 2004) (31)     | Cross-sectional | Turkey | Static           | Waste Incinerator     | -                                         | 1.33±0.08* | 0.051±0.003 | 0.015±0.03 | 0.041±0.08 | 0.0057  |
| (Dehghani et al., 2020) (32)   | Cohort          | Iran   | Personal         | Steel factory         | 372 (372:0)                              | 2.17±0.11* | 4.08±3.25 | 0.32±1.39 | 1.38±1.35 | -       |
| (El-Hashemy and Ali, 2018) (33) | Cross-sectional | Saudi Arabia | Static           | Printing and copy centre | -                                         | 0.0067±0.002 | 0.25±0.32 | 0.022±0.005 | 0.73±0.005 | -       |
| (Farshad et al., 2014) (34)    | Cross-sectional | Iran   | Static           | Waste disposal in hospital | -                                        | 0.57±0.1* | 1.23±1.1 | 1.18±1.2 | 0.58±0.6 | -       |
| (Golbabaei et al., 2018) (35)  | Cross-sectional | Iran   | Personal         | Automobile Industry   | 40 (36:4)                                | 0.96±0.05* | 0.28±0.08 | 2±0.2    | 3.02±0.08 | -       |
| (Golkhorshidi et al., 2019) (36) | Cross-sectional | Iran   | Static           | Bus driver: terminal | -                                         | 0.108±0.001 | 0.235±0.002 | 0.188±0.001 | 0.304±0.06 | -       |
| (Hadei et al., 2018) (37)      | Case-control    | Iran   | Static           | Beauty salon          | -                                         | 0.0034±0.002 | 0.0026±0.0018 | 0.0054±0.004 | 0.0043±0.006 | -       |
| (Harati et al., 2018) (38)     | Case-control    | Iran   | Personal         | Automobile Industry   | 80 (40:40)                               | 0.775±0.12* | 1.2±2.08 | 45.8±8.5 | 42.5±23.9 | -       |
| (Harati et al., 2020) (39)     | Cross-sectional | Iran   | Personal         | Petrochemical industry | 50 (50:0)                                | 2.12±0.95* | 9.84±2.53 | -         | 11.87±4.44 | -       |
| (Heibati et al., 2018) (4)     | Cross-sectional | Iran   | Personal         | Petroleum transfer station | 50 (50:0)                                | 2.7±2.91* | 4.07±3.65 | 0.535±0.412 | 0.752±0.812 | -       |
| (Hormoz et al., 2019) (9)      | Case-control    | Iran   | Personal         | Printing industry     | 84 (44:40)                               | 37.64±24.09* | -        | 105±20.05** | -       | -       |
| References                      | Publication type | Country      | Type of sampling | Industry or workplace | Number of workers (exposed vs unexposed) | Concentration (ppm) Mean ± SD | Benzene | Toluene | Ethylbenzene | Xylene | Styrene |
|--------------------------------|-----------------|--------------|------------------|-----------------------|------------------------------------------|-------------------------------|---------|---------|-------------|--------|---------|
| (Hosseini et al., 2015) (40)   | Cross-sectional | Iran         | Personal         | Tyre Factory          | 100 (100:0)                              | 1.88±1.37*                    | -       | -       | -           | -      | -       |
| (Jalai et al., 2017) (10)      | Cross-sectional | Iran         | Personal         | Chemical industry & police officer | 260 (185:75)                            | 1.56±0.34**                   | -       | -       | -           | -      | -       |
| (Javadi et al., 2017) (41)     | Cross-sectional | Iran         | Personal         | Petrol station        | 24 (24:0)                                | 0.56±0.102**                  | 0.242±0.033 | 0.223±0.041 | 0.109±0.025 | -      | -       |
| (Karbasi et al., 2020) (42)    | Cross-sectional | Iran         | Personal         | Oil pit worker        | 40 (40:0)                                | 0.82±0.38**                   | -       | -       | -           | -      | -       |
| (Maghsodi Moghadam et al., 2013) (43) | Cross-sectional | Iran         | Personal         | Petrochemical industry | 204 (204:0)                            | 2.0±1.83**                   | 0.27±0.50 | 0.16±0.59 | 0.8±2.7     | -      | -       |
| (Mohamadyan et al., 2019) (44) | Cross-sectional | Iran         | Personal         | Plastic industry      | 53 (53:0)                                | -                             | -       | -       | -           | -      | 19.56±9.03 |
| (Mohamadyan and Baharfar, 2015) (45) | Cross-sectional | Iran         | Personal         | Pesticide production factory | 100 (100:0)                            | -                             | -       | -       | -           | -      | 4.7±5.5  |
| (Mohamadyan et al., 2019) (46) | Cross-sectional | Iran         | Personal         | Electronic industry   | 59 (59:0)                                | -                             | -       | -       | -           | -      | 18.68±5.68 |
| (Moradi et al., 2019) (47)     | Case-control    | Iran         | Personal         | Beauty salon          | 72 (36:36)                               | 0.015±0.019                   | 0.31±0.36 | 0.017±0.021 | 0.055±0.051 | -      | -       |
| (Moradpour et al., 2017) (48)  | Cross-sectional | Iran         | Personal         | Petrochemical industry | 358 (358:0)                            | 1.08±1.46**                   | 9.19±1.68 | 11.56±2.94 | 8.88±2.46   | 8.45±8.29 | -       |
| (Moshirani et al., 2021) (49)  | Cross-sectional | Iran         | Personal         | Petrochemical industry | 50 (50:0)                                | -                             | -       | -       | -           | -      | 0.455±0.392 |
| (Moslem et al., 2020) (50)     | Cross-sectional | Iran         | Static           | Surgery room          | -                                         | 0.003±0.0005                  | 0.002±0.0004 | 0.004±0.0006 | 0.001±0.0003 | -      | -       |
| (Nabizadeh et al., 2020) (51)  | Cross-sectional | Iran         | Static           | Paper recycling       | -                                         | 0.27±0.01                     | 0.28±0.01 | 0.151±0.02 | 1.7±0.007   | -      | -       |
| (Nasrin and Golbabai, 1999) (52) | Cross-sectional | Iran         | Personal         | Paint industry        | 54 (54:0)                                | -                             | 11.2±7.3 | -       | -           | 20.2±4.1 | -       |
| (Nazarparvar-Noshadi et al., 2021) (11) | Cross-sectional | Iran         | Personal         | Tyre factory          | 38 (38:0)                                | 2.306±2.63**                  | 8.65±7.7  | 0.07±0.09 | 0.10±0.14   | 0.07±0.08 | -       |
| (Nehab et al., 2015) (12)      | Cross-sectional | Iran         | Personal         | Petrol station        | 60 (60:0)                                | 0.25±0.083                    | 0.39±0.071 | -       | 0.69±0.36   | -      | -       |
| (Omidi et al., 2019) (53)      | Cross-sectional | Iran         | Personal         | Poultry slaughterhouse | 20 (20:0)                               | 1.34±0.75**                  | 3.65±1.12 | 15.4±0.68 | -           | -      | -       |
| (Partovi et al., 2018) (54)    | Cross-sectional | Israel       | Personal         | Petrol station        | 258 (258:0)                              | 0.41±0.18*                    | -       | -       | -           | -      | -       |
| References                  | Publication type | Country   | Type of sampling | Industry or workplace                        | Number of workers (exposed vs unexposed) | Concentration (ppm) Mean ± SD |
|-----------------------------|------------------|-----------|------------------|---------------------------------------------|----------------------------------------|----------------------------------|
|                            |                  |           |                  |                                             |                                        | Benzene  | Toluene | Ethylbenzene | Xylene | Styrene |
| (Rahimpoor et al., 2014) (1) | Cross-sectional  | Iran      | Personal         | Petrochemical industry                      | 104 (104:0)                           | 1.19±0.63* | 1.3±4.74 | -           | 3.2±7.94 | -       |
| (Rahimpoor et al., 2018) (55)| Cross-sectional  | Iran      | Personal         | Petrochemical and petroleum depot industry | 84 (84:0)                             | 0.657±0.791* | 12.42±5.95 | -           | 32.24±22.1 | -       |
| (Ramadan, 2010) (56)        | Cross-sectional  | Kuwait    | Static           | Police officer                              | -                                      | 0.004±0.001 | 0.01±0.008 | 0.0026±0.003 | 0.0138±0.008 | -       |
| (Rashnoodi et al., 2021) (57)| Cross-sectional  | Iran      | Personal         | Petrochemical industry                      | 30 (30:0)                             | 1.28±1.10* | 2.62±4.50 | 4.45±7.35   | 2.41±1.07 | -       |
| (Rezazadeh Azari et al., 2012) (58) | Cross-sectional | Iran      | Personal         | Petroleum depot industry                    | 78 (46:32)                            | 1.63±3.92** | 2.72±19.33 | 0.46±1.61   | 3.53±10.84 | -       |
| (Rostami et al., 2021) (59) | Cross-sectional  | Iran      | Personal         | Printing and copy centre                    | 136 (136:0)                           | 0.029±0.019 | 0.039±0.026 | 0.007±0.0038 | 0.006±0.003 | -       |
| (Salama et al., 2020) (60)  | Cross-sectional  | Saudi Arabia | Static           | Petrol station                              | -                                     | 11.7±3.1*  | 4.09±1.09 | -           | 3.97±2.25 | -       |
| (Salehpour et al., 2019) (61)| Cross-sectional  | Iran      | Personal         | Petrochemical industry                      | 80 (40:40)                            | 1.03±1.40* | 5.6±13.66 | -           | 8.19±22.20 | 3.48±10.75 |
| (Sarkhosh et al., 2012) (62) | Cross-sectional  | Iran      | Static           | Printing and copy centre                    | -                                     | 0.0257±0.029 | 0.0713±0.0328 | 0.0083±0.056 | 0.0063±0.024 | 0.0016±0.0352 |
| (Shahin et al., 2017) (63)  | Cross-sectional  | Iran      | Personal         | Petrochemical industry                      | 169 (169:0)                           | 1.25±2.28** | 1.21±4.17 | 2.975±6.125 | 3.6±24.32 | 1.97±3.01 |
| (Yaghmaien et al., 2019) (64)| Cross-sectional  | Iran      | Personal         | Landfill plant                              | -                                     | 0.009±0.005 | 0.011±0.006 | 0.014±0.009 | 0.024±0.014 | -       |
| (Zokiha et al., 2017) (65)  | Cross-sectional  | Iran      | Personal         | Petrol station                              | 15 (15:0)                             | 1.28±0.447** | 0.337±0.71 | 0.124±0.13   | 0.092±0.012 | -       |

* above ACGIH OELs (benzene 0.5 ppm; toluene 20 ppm; ethylbenzene 20 ppm; xylene 100 ppm; styrene 20 ppm). *above national OELs SD – standard deviation
information may be available to authorities and organisations in West Asian countries, which we could not access. To the best of our knowledge, in Iran, biological indicators that could help to accurately evaluate occupational exposure to BTEX and styrene during annual worker examinations are not available. Occupational exposure to chemical pollutants in any industry is not regularly monitored.

Our findings, we believe, point to a large problem with (or rather, lack of) occupational exposure and health monitoring in West Asian countries. What each country urgently needs is to identify its own weaknesses in collecting and reporting data from occupational medical surveillance, in economic and technical capabilities of their industries, and in exposure monitoring and control. In addition to respiratory exposure to BTEX and styrene, future studies should also include skin. There is also a need to study dose-response relationships and combined exposure, including alcohol and smoking. Namely, before OELs are adopted or adjusted, it is important to establish actual exposure and health effects in local workers.

CONCLUSION

For the time being, our results suggest that occupational exposure to benzene may present increased health risk in West Asian countries, whereas exposure to the other compounds is generally lower than the OELs given above. However, these data are random and do not provide a reliable picture of actual exposure in these countries. Given the industrial burden in each of these countries, but most particularly in those with developed oil industry, understanding the current state of exposure and adopting local OELs is crucial to protect the health of a vast number of workers.

Table 4: Occupational exposure to BTEX and styrene reported for oil-related and solvent-related professions in West Asian countries (mean ± SD, where available)

| Country       | National OELs | Industry | Benzene (ppm) | Toluene (ppm) | Ethylbenzene (ppm) | Xylenes (ppm) | Styrene (ppm) |
|---------------|---------------|----------|---------------|---------------|--------------------|---------------|---------------|
| Qatar         | No            | Oil-related | 0.39          | 7.02          | 0.75               | 0.32          | -             |
|               |               | Solvent-related | 0.004        | 0.012        | 0.0046             | 0.016         | -             |
| Kuwait        | No            | Oil-related | 0.23          | 0.144        | 0.085              | 0.16          | -             |
|               |               | Solvent-related | 0.003±0.038  | 0.03±0.05    | 0.0063±0.03       | 0.162±0.09    | -             |
| Iran          | Yes           | Oil-related | 1.165±0.69,* | 5.87±8.18    | 2.28±8.93         | 12.104±17.7  | 3.588±4.52    |
|               |               | Solvent-related | 0.785±0.49,* | 4.53±4.01    | 4.34±5.11         | 10.56±12.28  | 9.585±3.70    |
| Turkey        | Yes (except for styrene) | Oil-related | 1.33*,#       | 0.051        | 0.015              | 0.041         | 0.0057        |
|               |               | Solvent-related | -            | -            | -                  | -             | -             |
| Saudi Arabia  | No            | Oil-related | 11.7*         | 4.09         | -                  | 3.97          | -             |
|               |               | Solvent-related | 0.0067      | 0.253        | 0.022              | 0.73          | -             |
| Israel        | No            | Oil-related  | 0.41          | -            | -                  | -             | -             |
|               |               | Solvent-related | -            | -            | -                  | -             | -             |

* above ACGIH OELs; # above national OELs; SD – standard deviation

Conflict of interests

None to declare.

Acknowledgements

This study was supported by Larestan University of Medical Sciences, Larestan, Iran (grant No. 1400-93). We thank Dr. Linda Schenk of the Institute of Environmental Medicine, Karolinska Institutet, Sweden for her expertise and assistance throughout all aspects of our study and for her wonderful collaboration.

REFERENCES
1. Rahimpoor R, Bahrami AR, Ghorbani F, Assari MJ, Negahban AR, Rahimnejad S, Mehdiizadegan B. Evaluation of urinary metabolites of volatile organic compounds and some related factors in petrochemical industry workers. J Mazandaran Univ Med Sci 2014;24:119–31.
2. Negahban SAR, Ghorbani Shahna F, Rahimpoor R, Jalali M, Rahimnejad S, Soltanian A, Bahrami A. Evaluating occupational exposure to carcinogenic volatile organic compounds in an oil-dependent chemical industry: a case study on benzene and epichlorohydrin. J Occup Hyg Engin 2014;1(1):36–46.
3. Prüss-Ustün A, Vickers C, Haefliger P, Bertollini R. Knowns and unknowns on burden of disease due to chemicals: a systematic review. Environ Health 2011;10:9. doi: 10.1186/1476-069X-10-9
4. Heibati B, Godri Pollitt KJ, Charati JY, Ducatman A, Shokrzadeh M, Karimi A, Mohammadyan M. Biomonitoring-based exposure assessment of benzene, toluene, ethylbenzene and xylenes among workers at petroleum distribution facilities. Ecotoxicol Environ Saf 2018;149:19–25. doi: 10.1016/j.ecoenv.2017.10.070
5. Kuranchie FA, Angnanavuri PN, Attigbe F, Nqueraye-Tetteh EN. Occupational exposure of benzene, toluene, ethylbenzene and xylenes (BTEX) to pump attendants in Ghana: Implications for policy
18. Deveau M, Chen C, Johanson G, Krewski D, Maier A, Niven K, Ripple

17. Hansson SO. Setting the Limit: Occupational Health Standards and

16. Rappaport SM. Threshold limit values, permissible exposure limits,

15. . Setting the Limit: Occupational Health Standards and

14. Werder EJ, Beier JI, Sandler DP, Falkner KC, Gripshover T, Wahlang

13. Chambers D, Reese C, Thornburg L, Sanchez E, Rafson J, Blount B,

12. Neghab M, Hosseinzadeh K, Hassanzadeh J. Early liver and kidney

dysfunction associated with occupational exposure to sub-threshold

11. Jalai A, Ramezani Z, Ebrahim K. Urinary trans, trans-muconic acid is not a reliable biomarker for low-level environmental and occupational benzene exposures. Saf Health Work 2017;8:220–5. doi: 10.1016/j.shaw.2016.09.004

10.5812/jhealthscope.82962

10. Dehghani F, Omidi F, Heravizadeh O, Barati Chamgordani S, Gharibi

9. Hormoz M, Mirzaei R, Nakhaee A, Payande A, Izadi S, Haghighi JD, Rahimpoor R. Quantification of urinary metabolites of toluene and xylene isomers as biological indices of occupational exposure in printing industry workers. Health Science 2019;8(1):e82962. doi: 10.5812/jhealthscope.82962

8. Ghanbarian M, Nazmara S, Masinaei M, Ghanbarian M, Mahvi AH.
Evaluating the exposure of general population of Tehran with volatile organic compounds (BTEX). Int J Environ Anal Chem 2020;20:1–11. doi: 10.1080/03067319.2020.1781839

7. Al-Harbi M, Alhajri I, AlAwadhi A, Whalen JK. Health symptoms associated with occupational exposure of gasoline station workers to BTEX compounds. Atmosph Environ 2020;241:117847. doi: 10.1016/j.atmosenv.2020.117847

6. Tunsarungkarn T, Siriwong W, Rungsiyothin A, Nopparatbundit S. Occupational exposure of gasoline station workers to BTEX compounds in Bangkok, Thailand. Int J Occup Environ Med 2012;3:117–25. PMID: 23022861

5. Al-Harbi M, Alhajri I, AlAwadhi A, Whalen JK. Health symptoms associated with occupational exposure of gasoline station workers to BTEX compounds. Atmosph Environ 2020;241:117847. doi: 10.1016/j.atmosenv.2020.117847

4. Deveau M, Chen C, Johanson G, Krewski D, Maier A, Niven K, Ripple

3. Chambers D, Reese C, Thornburg L, Sanchez E, Rafson J, Blount B,

2. Ghanbarian M, Nazmara S, Masinaei M, Ghanbarian M, Mahvi AH.
Evaluating the exposure of general population of Tehran with volatile organic compounds (BTEX). Int J Environ Anal Chem 2020;20:1–11. doi: 10.1080/03067319.2020.1781839

116
plant. Int J Occup Saf Ergon 2020;26:227–32. doi: 10.1080/10803548.2018.1443593
33. El-Hashemy MA, Ali HM. Characterization of BTEX group of VOCs and inhalation risks in indoor microenvironments at small enterprises. Sci Total Environ 2018;645:974–83. doi: 10.1016/j.scitotenv.2018.07.157
34. Farshad A, Gholami H, Farzadkia M, Mirkazemi R, Kermani M. The safety of non-inoculation waste disposal devices in four hospitals of Tehran. Int J Occup Environ Health 2014;20:258–63. doi: 10.1179/104936714Y.0000000072
35. Golbabaei F, Dehghani F, Saatci M, Zakerian SA. Evaluation of occupational exposure to different levels of mixed organic solvents and cognitive function in the painting unit of an automotive industry. Health Promot Perspect 2018;8:296–302. doi: 10.15171/hpp.2018.42
36. Golkhorshidi F, Sorooshian A, Jafari AJ, Baghani AN, Kermani M, Kalantary RR, Ashournej Q, Delikhoon M. On the nature and health impacts of BTEX in a populated middle eastern city: Tehran, Iran. Atmos Pollut Res 2019;10:291–30. doi: 10.1016/j.apr.2018.12.020
37. Hadii M, Hopke PK, Shahsavani A, Moradi M, Yarahmadi M, Emam B, Rastkari N. Indoor concentrations of VOCs in beauty salons; association with cosmetic practices and health risk assessment. J Occup Med Toxicol 2018;13(1):30. doi: 10.1186/s12955-018-0213-x
38. Harati B, Shahtaheri SJ, Karimi A, Azam K, Ahmadi A, Afzali Rad M, Harati A. Evaluation of respiratory symptoms among workers in an automobile manufacturing factory, Iran. Iran J Public Health 2018;47:237–45. PMCID: PMC5810387
39. Harati B, Shahtaheri SJ, Yousefi HA, Harati A, Askari A, Abdolmohamadi N. Cancer risk assessment for workers exposed to pollution source, a petrochemical company, Iran. Iran J Public Health 2020;49:1330–8. doi: 10.18502/ijiph.v49i17.3587
40. Hosseini SY, Azar MR, Zendeherd R, Souri H, Rahimian RT. Feasibility of the biological monitoring of workers exposed to benzene and toluene via measuring the parent compounds in the exhaled breath. Health Scope 2015;4(3):e25774. doi: 10.17795/healthscope-25774
41. Javadi I, Mohammadian Y, Elyasi S. Occupational exposure of shahindej county refueling stations workers to BTEX compounds, in 2016. J Res Environ Health 2017;3:74–83.
42. Karbasi A, Khorrarnazhadan S, Asemie Zavareh SR, Pejman Sani G. Urinary and air biomonitoring of occupational exposure to benzene in oil pit workers. Human Ecol Risk Assess 2012;18:430–44. doi: 10.1080/10807039.2018.1513318
43. Maghsodi Moghadam R, Bahrami A, Ghorbani F, Mahjoob H, Malaki D. Investigation of qualitative and quantitative of volatile organic compounds of ambient air in the Mahshahr petrochemical complex in 2009. J Res Health Sci 2013;13:69–74. PMID: 23771208
44. Mohamadyan M, Moosazadeh M, Borji A, Khanjani N, Moghaddam SR. Occupational exposure to styrene and its relation with urine mandelic acid, in plastic injection workers. Environ Monit Assess 2019;191(5):262. doi: 10.1007/s10661-019-7191-z
45. Mohamadyan M, Baharfary Y. Control of workers’ exposure to xylene in a pesticide production factory. Int J Occup Environ Health 2015;21:121–6. doi: 10.1179/104936714Y.0000000098
46. Mohamadyan M, Moosazadeh M, Borji A, Khanjani N, Rahimi Moghadam S, Behjat Moghadam AM. Health risk assessment of occupational exposure to styrene in Neyshabur electronic industries. Environ Sci Pollut Res Int 2019;26:11920–7. doi: 10.1007/s11356-019-04582-8
47. Moradi M, Hopke P, Hadii M, Eslami A, Rastkari N, Naghdali Z, Kermani M, Emam B, Farhadi M, Shahsavani A. Exposure to BTEX in beauty salons: biomonitoring, urinary excretion, clinical symptoms, and health risk assessments. Environ Monit Assess 2019;191(5):286. doi: 10.1007/s10661-019-7455-7
48. Moradpour Z, Ghorbani Shahna F, Bahrami A, Soltanian A, Hesam G. Evaluation of volatile organic compounds at petrochemical complexes in Iran. Health Scope 2017;6(4):e62595. doi: 10.5812/jhealthscope.62595
49. Moshiran VA, Karimi A, Golbabaei F, Yarandi MS, Sajedian AA, Koozekonan AG. Quantitative and semiquantitative health risk assessment of occupational exposure to styrene in a petrochemical industry. Saf Health Work 2021;12:396–402. doi: 10.1016/j.shaw.2021.01.009
50. Moslem AR, Rezaei H, Yektay S, Mori M. Comparing BTEX concentration related to surgical smoke in different operating rooms. Ecotoxicol Environ Saf 2020;203:111027. doi: 10.1016/j.ecoenv.2020.111027
51. Nabizadeh R, Sorooshian A, Delikhoon M, Baghani AN, Golbaz S, Aghaei M, Barkhordari A. Characteristics and health effects of volatile organic compound emissions during paper and cardboard recycling. Sustain Cities Soc 2020;56:102005. doi: 10.1016/j.scs.2019.102005
52. Nassiri P, Golbabai F. Assessment of workers’ exposure to aromatic hydrocarbons in a paint industry. Ind Health 1999;37:469–73. doi: 10.2486/indhealth.37.469
53. Omid F, Dehghani F, Fallahzadeh RA, Mori M, Taghavi M, Eynpour A. Probabilistic risk assessment of occupational exposure to volatile organic compounds in the rendering plant of a poultry slaughterhouse. Ecotoxicol Environ Saf 2019;176:132–6. doi: 10.1016/j.ecoenv.2019.03.079
54. Partovi E, Fathi M, Assari MJ, Esmaeili R, Pourmohamadi A, Rahimpour R. Risk assessment of occupational exposure to BTEX in the National Oil Distribution Company in Iran. Chronic Dis J 2018;4:48–55. doi: 10.22122/cdj.v4i2.223
55. Rahimpour R, Farhadi S, Jalali M. Lifetime cancer risk and hazard quotient of BTX compounds in Iranian petrochemical and petroleum depot workers. Iranian J Health Saf Environ 2018;5:982–90.
56. Ramadan A. Air quality assessment in Southern Kuwait using diffusive passive samplers. Environ Monit Assess 2010;160:413–23. doi: 10.1007/s10661-008-0705-8
57. Rashnuodi P, Dehghani BF, Rastgoh H, Amiri A, Poor SM. Evaluation of airborne exposure to volatile organic compounds of benzene, toluene, xylene, and ethylbenzene and its relationship to biological contact index in the workers of a petrochemical plant in the west of Iran. Environ Monit Assess 2021;193(2):94. doi: 10.1007/s10661-021-08878-6
58. Rezaeie Azari M, Naghvi Konjin Z, Zayeri F, Salehpour S, Seyedi MD. Occupational exposure of petroleum depot workers to BTEX compounds. Int J Occup Environ Med 2012;3:39–44. PMID: 2302850
59. Rostami R, Fazlzadeh M, Babaei-Pouya A, Abazari M, Rastgo H, Ghasemi R, Saranjani B. Exposure to BTEX concentration and the related health risk assessment in printing and copying centers. Environ Sci Pollut Res 2021;28:31195–206. doi: 10.1007/s11356-021-12873-2
60. Salama KF, Omar EOM, Zafar M. Assessment of BTX concentration related to surgical smoke in different operating rooms. Environ Sci Pollut Res Int 2021;28:31195–206. doi: 10.1007/s11356-021-12873-2
61. Salehpour S, Amani R, Nili-Ahmadabadi A. Volatile organic compounds as a preventive health challenge in the petrochemical...
Profesionalna izloženost BTEX-u i stirenu u zemljama (jugo)zapadne Azije – kratak pregled trenutačnog stanja i graničnih vrijednosti

Svrha je uvodenja graničnih vrijednosti profesionalne izloženosti (engl. occupational exposure limits, krat. OELs) upravljanje rizikom ne bi li se zaštitilo zdravlje i dobrobit radnika od štetnih agenata kojima su izloženi na radnom mjestu. U ovom smo pregledu izdvojili granične vrijednosti i primjenjivati ih. Osim toga, potrebno je provoditi sustavna istraživanja ne bi li se utvrdile stvarne razine profesionalne izloženosti, odgovori na koncentracije onečišćiva i gospodarske i tehničke mogućnosti industrija tih zemalja da riješe trenutačne probleme.