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Occupational Risk Assessment of Benzene in Rubber Tire Manufacturing Workers

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ABSTRACT

Tire manufacturing industry has a history of more than half a century in Iran, where 14 thousand workers are employed. The old and semi-automated processes equipment, backward technology, and raw materials impurity lead to significant exposures to occupational carcinogens such as benzene. This study was to assessment of benzene exposures and evaluation the resulting cancer risk in two tire-manufacturing factories. One hundred workers in two target tire-manufacturing factories selected as "exposed group". Personal monitoring was conducted in all process units according to NIOSH 1501 method. Inhalation health risk of benzene exposure was estimated via two assessment models. Data were analyzed using SPSS and quantitative values were reported as Mean ± Standard Error. Occupational exposure to benzene in 68 percent of workers has exceeded the current exposure limit. The highest level of benzene (5.06 ppm) found in cement making unit. The odds ratio of leukemia was 2.06 times the working population without benzene exposure, as well; the cancer incidence was 16.14 cases per 1000 workers. This study as screening approach is first on addressing the risk assessment of Iranian tire manufacturing workers. The levels of personal exposures and cancer risk were unacceptable and this may provide a basis for developing the control measures in future.

KEYWORDS: *Benzene, Occupational Exposure, Risk Assessment, Rubber Tire Manufacturing Workers*

INTRODUCTION

The rubber and tire manufacturing industry has a history of more than a hundred years, and its growth has been remarkable [1]. The health risk of rubber industry is still controversial and International Agency for Research on Cancer (IARC) designated ―the rubber industry‖ as group 1 carcinogenic [2-3]. Occupational exposure in rubber industry leads to leukemia and cancers of bladder, lung, stomach, and laryngeal [4] as well cardiovascular, nervous and reproductive disorders [5]. This industry has a complex work environment along with exposure to a variety of chemicals and airborne particles such as aromatic amines, carbon black, nitrosamines, phthalates, polycyclic aromatic hydrocarbons, solvents, and asbestos in many different processes [6-7].

Exposure to industrial organic solvents is common [8] and have a wide applications in the manufacture of a variety of products such as cosmetics, detergents and soaps, drugs, dyes, pigments, explosives, fertilizers, inks, pesticides, paints, plastics, shoes and tires [9].

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In the rubber tires manufacturing industry, light naphtha made of aliphatic hydrocarbon (n-hexane) and aromatic hydrocarbons (benzene, ethyl benzene, toluene, xylene, and cumene) is used as solvent in the production processes [9-10]. Exposure to organic solvents through skin or inhalation of the volatile vapors can affect the health [10].

Benzene is the simplest aromatic chemical and an excellent solvent [11]. It was one of the earliest industrial chemicals demonstrated to affect the health of numerous workers and agreed that the bone marrow is the target organ for its toxicity [12]. The IARC classified benzene as a group 1 human carcinogen [13-14] also is listed by the World Health Organization (WHO) as a top priority compound [15]. The first report linking benzene exposure to any disease (aplastic anemia) was presented in a rubber tire factory [12]. Workers with benzene exposure have increased risk of mortality due to Acute Myeloid Leukemia (AML), Non-Hodgkin Lymphoma (NHL), Myelodysplastic Syndromes (MDS), Acute Lymphoblastic Leukemia (ALL), Chronic Myeloid Leukemia (CML), Chronic Lymphocytic Leukemia (CLL), anemia, Non-Lymphocytic Leukemia (ANL) [11,16-18], aplastic anemia, impairment of immune [19-20] and central nervous systems and endocrine effects [15]. Breast cancer risk was higher in women workers exposed to high levels of benzene as an organic solvent [21].

Tire industry is riskier work environments that pose significant threat to workers' health. Risk assessment is determining the probability of getting an adverse health effect arises from hazardous exposure that is becoming a new technique for risk management in occupational toxicology [22]. Quantitative risk assessment expresses the risks from hazards via description the severity and likelihood of harm and it is a justification paradigm for corrective interventions [23]. Personal exposure assessment is an important tool for evaluating the likelihood and extent of exposure to chemical hazards and is an important component of any health risk assessment and epidemiological study. In this approach, the exact amounts of chemicals are estimated through exposure assessment models in the subjects' breathing zone, using personal monitors [24].

To date, actual and scientific levels of workers exposure to benzene have not been well characterized in Iranian tire manufacturing industries. The objectives of this study were set to monitor the personal benzene exposures and to quantify the resulting risks for exposed workers in two prominent tire-manufacturing factories of Iran.

MATERIALS AND METHODS

Factories and Subjects: This cross-sectional study was conducted in two target tire-manufacturing factories (factory A and B) of Iran in 2013. These companies produce various sizes of tires for use in passenger cars, light trucks, buses, and agriculture equipment. The main processing units of these fac¬tories included in cement making, banbury mixing, bead assembling, cord assembling, calendering, extruding, tire building, dyeing (cement spraying), curing, and inspection/finishing. Main application of solvents is in tire cement composition that due to some impurities, contain an ambiguous amount of benzene. One hundred of non-smoker male workers (50 workers in each factory) selected as ―exposed group‖. None of these workers used any type of respirator to prevent exposure to occupational respiratory health hazards. All workers voluntarily participated in this study and signed informed consent forms.

Personal Monitoring: Personal monitoring in the workers' breathing zone was conducted during morning shift (8 am to 4 pm) in all processing units according to optimized NIOSH 1501 method. Benzene content of breathing zone air, was trapped in the charcoal tubes (100:50 mg sections, 20:40 mesh) then extracted by carbon disulfide (CS2) and followed by injection to Gas Chromatograph equipped with Flame Ionization Detector (GC-FID, SHIMADZU Inc. GC-17A model, made in Japan). The GC was equipped with a HP-1 capillary column (Length: 30 m, Internal Diameter: 0.25 mm and Film Thickness: 0.25 μm of Dimethylpolysiloxane). The GC oven parameters was programmed to hold 40°C for 4 minutes then raised to 90°C at a rate of 30°C/min being held for 4 min, finally elevated to 125°C at the rate of 60°C/min and was held for 8 minutes. Nitrogen was used as the carrier gas with a flow rate of 1.02 ml/min and a split ratio of one. Retention times of benzene and cumene (as internal standard) were 7.9 and 14.3 minutes, respectively. One μL of treated samples was injected manually using the micro syringe at 140°C of injection port temperature.

Risk Assessment: The health risk assessment focused on chronic exposure to benzene that may cause cancer or other toxic effects. Due to volatile nature of this compound, the main exposure route was inhalation of contaminated indoor air. Therefore, respiration health risk of benzene exposure was calculated via two risk assessment models based on personal air sampling data. In the first model, expected Odds Ratio (OR) of leukemia was determined in all workers exposed to benzene according to Rinsky model [25]:

$$OR=\exp(0.0126\times \text{ppm-years})$$

Where, ppm-years considered as cumulative exposure during 30 years working life.

In the second model, inhalation intake has estimated by Yimrungruang et al. [26] as follows:

$$I=(C\times ET\times EF\times ED)/AT$$

Where, I is the average daily inhalation intake over the exposure period (µg/m3), C is the concentration of the related compound in the personal air monitoring sample (µg/m3), ET is the exposure time (hr/day), EF is the exposure frequency (days/year), ED is the exposure duration (years), and AT is an average lifetime (years). Risk characterization requires combining the estimated exposure concentrations with toxicity data to provide a quantitative estimate of the potential health impacts. Hence, the average lifetime risk of cancer incidence for workers exposed to benzene was estimated per thousand populations according to this equation:

Cancer Risk = I (µg/m$_3$) × cancer unit risk factor (µg/m$_3$)-1.

Table 1 summarizes the exposure, risk assessment and toxicity factors for benzene.

Table 1. The Exposure, Risk Assessment and Toxicity Factors

Factors	Value
Exposure Time (h/day)	8
Exposure Frequency (days/yr)	300
Exposure Duration (yr)	30
Average life Time (yr)	70
Cancer Unit Risk Factor (µg/m3)-1	2.9E-05

Statistical Analysis: Data were analyzed using the statistical software of SPSS version 18 via t-test, Tukey and one-way ANOVA tests. Quantitative values were reported as Mean±Standard Error (M±SE).

RESULTS

Both studied plants are considered as the most important tire manufacturing factories in Iran, which are located in the suburbs of the Tehran. The rates of tire production were about 79 and 85 tons of rubber tires per day in factories A and B, respectively. The amounts of solvent application were 2666 and 3100 liters per day in factories A and B, respectively.

The mean and standard error of workers age and work history were 33.2±0.50, 10.2±0.60 years and 34.6±0.64, 11.9±0.78 years in factories A and B, respectively. These variables had no statistical significant difference between two factories (P>0.05). Analysis of personal monitoring samples showed that the occupational exposure to benzene had a statistical significant higher level in factory B compared to A (Table 2). Totally, benzene exposure in forty-six and ninety percent of workers has exceeded the current occupational exposure limit of benzene (0.5 ppm) according to the Labor and Environment Health Center of Iran, in factories A and B, respectively.

Except four working groups (banbury mixing, bead assembling, cord assembling, and inspection/finishing), occupational exposure to benzene in other corresponding units had significant differences between two factories. Maximum concentration of benzene was observed in cement making and banbury mixing units of both factories. The highest level of benzene (5.06 ppm) found in cement making unit of factory B (Table 2).

Table 2. Benzene Concentration in Breathing Zone of Exposed Workers as ppm

Units	Factory A			Factory B			Pvalue
	M	SE	N*	M	SE	N	
Cement Making	3.12	0.25	5	5.06	0.46	5	0.006
Banbury Mixing	3.40	0.22	5	2.83	0.36	5	0.21
Bead Assembling	0.47	0.09	5	0.56	0.06	5	0.40
Cord Assembling	1.90	0.26	5	1.44	0.09	5	0.16
Calendering	0.32	0.12	5	1.18	0.13	5	0.002
Extruding	0.12	0.01	5	2.61	0.22	5	<0.001
Tire Building	0.22	0.01	5	1.60	0.15	5	0.001
Dyeing (Cement Spray)	0.90	0.05	5	1.70	0.12	5	<0.001
Curing	0.19	0.004	5	1.44	0.13	5	<0.001
Inspection/Finishing	0.26	0.05	5	0.37	0.06	5	0.24
Total	**1.09**	**0.18**	**50**	**1.88**	**0.19**	50	0.003

*Number of workers in unit

The overall odds ratio of leukemia resulting from exposure to benzene based on Rinsky model was 2.06 times the general working population without any active exposure. Yimrungruang et al. model estimated the incidence of 16.14 cases of cancer per thousand of tire manufacturing workers for thirty years lifetime occupational exposure to benzene As well.

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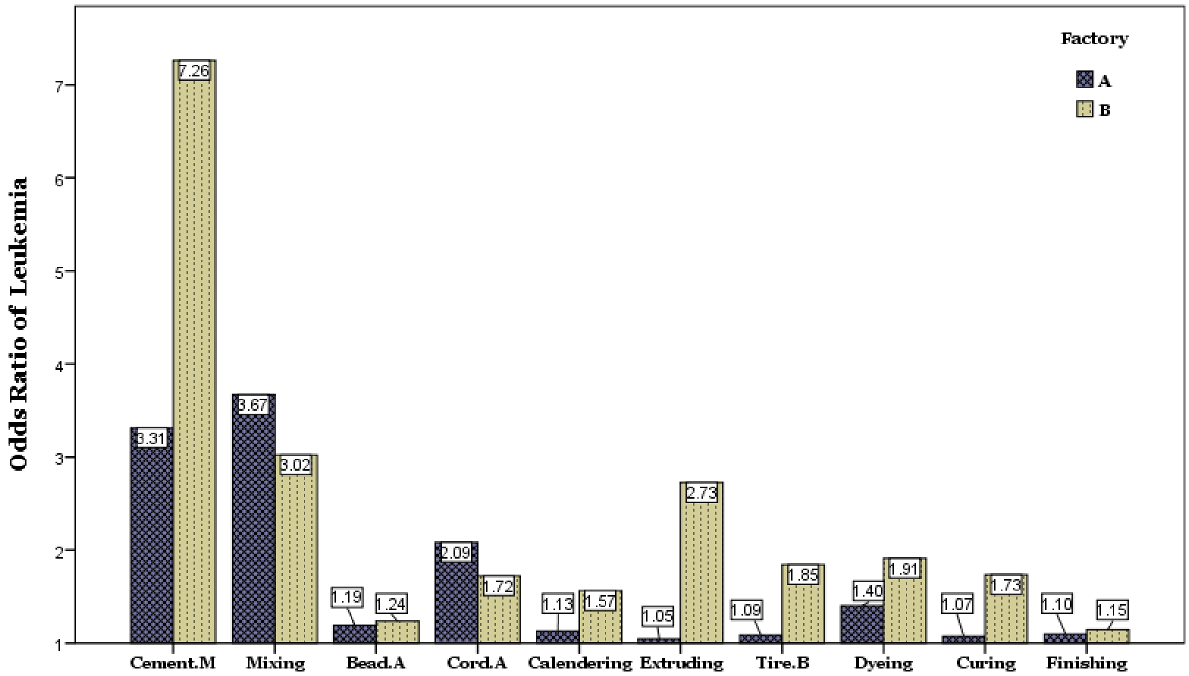

Figure 1. Risk assessment of workers in two factories according to Rinsky model

Comparison of Rinsky and Yimrungruang risk values between similar exposure groups of two factories showed that except banbury mixing and cord assembling, higher risk of leukemia was existed in other groups of factory B. Banbury mixing and cement making groups in both factories had the highest risk of cancer due to corresponding higher personal exposures. Minimum risk based on both models has belonged to extruding, tire building, and finishing units of factory A. In addition, as can be seen, even the lowest occupational exposures to benzene result in OR and incidence risk of leukemia higher than one (Figure 1 and 2).

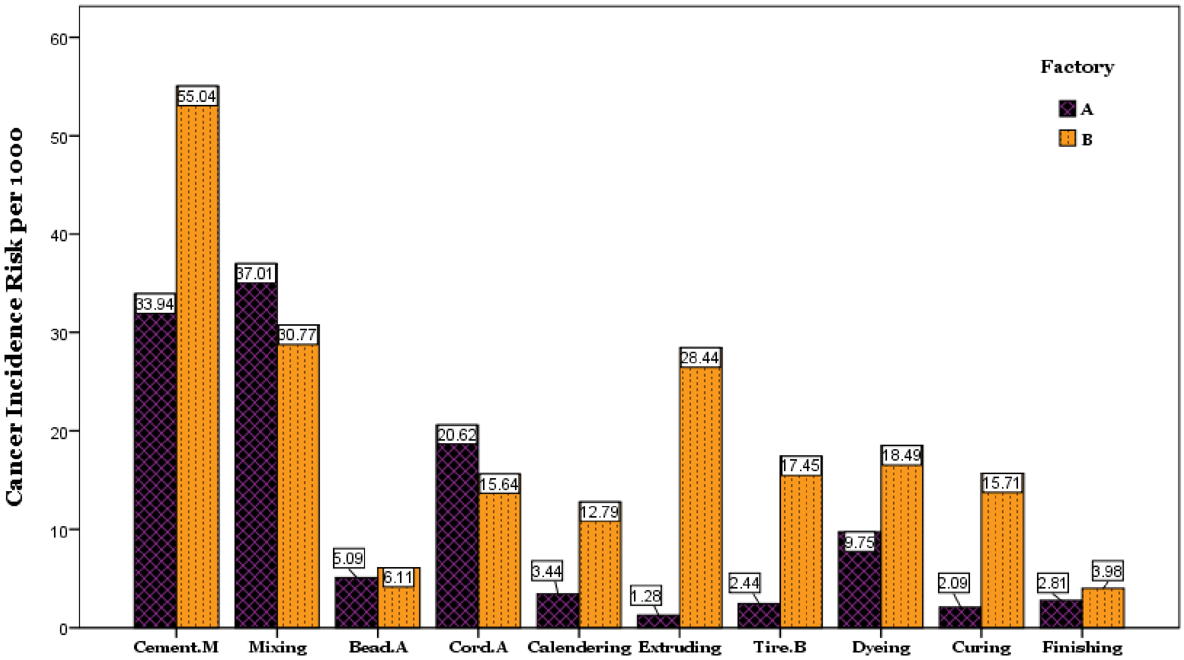

Figure 2. Risk assessment of workers in two factories according to Yimrungruang et al. Model

DISCUSSION

Tire manufacturing industry has a history of more than half a century in Iran. There are nine tire factories with a capacity of about 14 thousand people employment. The old and semi-automated processes equipment, backward technology, and low quality of raw materials lead to significant

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exposures to occupational hazards. The present study is a field research in the tire industries that measured personal occupational exposures to benzene in workers breathing zone and estimated a quantitative values of cancer risk resulting from these exposures.

Occupational exposures in the developing countries are sometimes very high because of the continuing presence of benzene in industrial solvents and glues [11]. Despite of governmental forces directed to prohibition the benzene content of the solvents, still, this compound is detected in the workplace air of Iranian tire manufacturing industries [7]. This may be due to impurities of applied solvents that contain a trace amount of this chemical [27].

Considering the current occupational exposure limit of benzene (0.5 ppm) according to the Labor and Environment Health Center of Iran, generally, sixty-eight percent of workers exposures exceeded the occupational limit. In this study, Iranian tire manufacturing workers had higher exposures to benzene compared to their counterparts in the developed countries [28-29] and approximately had the same exposures as South Korean workers [30]. While, occupational exposure to benzene in a rubber cord manufacturing plant in Turkey was much more than the current study [31].

According to occupational hygiene survey of workplace condition, exposure differences between two factories and higher levels of benzene in factory B can be due to some factors. These includes the nature of the work process, the amount and type of used solvent, ingredients and degree of solvent purity, the rate of tire production per day, the use of gasoline in some working groups to facilitate assembly works, and the efficacy of ventilation systems. In some cases, the solvent in uncovered containers was applied with a brush and used to facilitate assembly works without gloves, which creating both inhalation and dermal exposures. In the dyeing unit, presence of high efficiency local exhaust ventilation system has controlled emission of vapors and mists to the workplace.

Odds ratio of leukemia due to cumulative occupational exposure to about 45 ppm-years of benzene in the tire manufacturing factories was greater more than two times the expected risk in general working population. It is worth noting that the highest risk of cancer were related to banbury mixing and cement making units, respectively, which can be considered as a warning sign. In other studies, risk of leukemia was increased at cumulative exposures above 2 ppm-years and with intensity of highest exposed job more than routine exposure to benzene at 24 ppm-years that induced 11.3 odds ratio [11]. As well, other studies were reported that Standardized Mortality Ratio (SMR) increased from 109 to 322 then to 1186 and to 6637 with respective increases in cumulative benzene exposure from less than 40 ppm-years, 40-199, 200-399, and greater than 400 [25].

The cancer incidence risk of more than one per thousand typically deemed "unacceptable‖, but less than one per thousand considered as "acceptable‖ in workforces according to Occupational Safety and Health Administration (OSHA) [32]. Therefore, considering the cancer incidence risk greater than sixteen cases per thousand of Iranian tire manufacturing workers, occupational exposure to benzene is definitely unacceptable.

According to mentioned risk assessment models, mean of quantitative risk in factory B was significantly higher than factory A, which could be related to higher amounts of solvent application and the tire production capacity.

In a cohort study at one of the rubber hydrochloride plants in Ohio, five new leukemia cases were observed in benzene-exposed white males and cumulative exposure was significantly associated with elevated relative risks of leukemia mortality. However, in the summary, SMR for this group declined from 3.37 to 2.56 [33]. In male workers employed in the rubber tire production in Poland observed insignificant increased deaths from myeloma and leukemia than expected [34]. Workers in rubber industry with historically high benzene exposures may be at the risk of cancer [35-36] and significant cancer risk and mortality was observed in tire industries [22,37]. Nevertheless, inconsistent results, reported significant lower mortality than expected for leukemia as well no excess cancer risk among Italian male rubber tire workers [38].

In general, our results suggests that it is necessary for tire manufacturing factories to take account numbers of chemicals control measures such as high quality solvents with minimum content of benzene to mitigation the exposures to respiratory health hazards. Therefore, a risk management approach and routine health surveillance such as biological monitoring need to be implemented in order to prevent or limit the workers' exposure.

CONCLUSION

The current ventilation is not enough, being the only control measure for carcinogens such as benzene. This study is the first documented risk assessment survey of Iranian tire manufacturing industries and our results demonstrated unacceptable risk for workers exposed to benzene. Therefore, tire manufacturers are advised to consider more stringent chemical control measures for protection of their workforce health and remove such known carcinogens from production processes.

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