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RESEARCH ARTICLE

OCCUPATIONAL HEALTH RISK ASSESSMENT FOR BENZENE EXPOSURE IN GASOLINE STORAGE AND DISTRIBUTION FACILITY: COMPARISON BETWEEN DEVELOPING AND INDUSTRIALIZED COUNTRIES FOR THE PERIOD OF 1986-2001

***[1]Antoine Francis OBAME NGUEMA, [2]Akihiro TOKAI, [3]Hoa THI NGUYEN and [4]Naoya KOJIMA**

[1]Osaka University, Department of Engineering, Graduate School of Engineering, Division of Sustainable Energy and Environmental Engineering, Environmental Management Laboratory (Tokai Laboratory). 2-1 Yamadaoka Suita City Suita, Japan
[2]Osaka University, Department of Engineering, Graduate School of Engineering, Division of Sustainable Energy and Environmental Engineering, Area of Environmental Management 2-1 Yamadaoka Suita City Suita, M 3 Building, Osaka Prefecture P.o. Box: 5650871, Japan
[3]Osaka University, Department of Engineering, Graduate School of Engineering, Division of Sustainable Energy Doctor of Engineering, Assistant Professor of Environmental Management laboratory (Tokai Laboratory) Division of Sustainable Energy and Environmental Engineering Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, JAPAN
[4]Osaka University Graduate School of Engineering Department of Environment and Energy Engineering Associate Professor of Environmental Management (Tokai Laboratory) 〒565-0871Osaka Prefecture Suita-shi Yamada Hill 2-1 M3 Building No. 510 Room, Japan

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ABSTRACT

Health risk assessment to chemical is usually carried out to evaluate the adverse health effects using single data point to quantify the risk. This approach to occupational health risk assessment derives to inconsistency in uncertainty and variability. However, the different exposure concentrations levels combine with their related risk adverse health effects are required to estimate health risk of benzene exposure in gasoline storage and distribution facility. Thus, this explorative study investigates health risk for occupational benzene exposure at gasoline storage and distribution facility in industrialized and developing countries; and compares them for the period of 1986 to 2001.The overall risk probability method based on probabilistic technic expresses the risk in terms of probability distribution, rather than the traditional deterministic method using a single-point risk estimation approach. The overall risk probability was used to quantify uncertainty and variability in assessing occupational health risk of benzene exposure at the operations level and site level. The results indicate a significant health risk for workers in gasoline storage and distribution facilities of developing countries, compared to the workers in industrialized countries. The above results were translated by the presence of high volume level of benzene content in petroleum products and the lack of implemented engineering controls measures such as vapor recovery system for countries with the highest health risk.

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INTRODUCTION

In order to convey refined petroleum products from the refinery to the end users, gasoline storage and distribution facility (GSDF) is considered as a critical step to successfully achieve this operation. The GSDF is concerned with the handling for storage and transfer of refined petroleum products in loading locations via pipelines to different petroleum storage transport mode (barge tanks, truck tank) (Carolyn *et al*., 2010; Paul Guyer, 2014). GSDF is as the same time a useful tool for a nation's economic growth and health issue to its working population; through economic gain from loading operations activities and health damage such as cancer risk from workers' exposure to petroleum products respectively.

Corresponding author: **Antoine Francis OBAME NGUEMA**

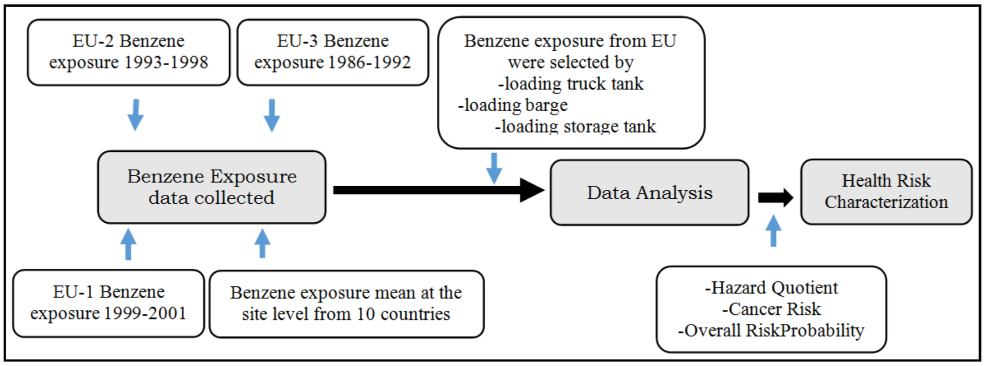


Fig. 1. Research framework

Loading operation is the process of transferring petroleum refined products from storage tank to operating tank (Paul Guyer, 2014). It is also the transfer of petroleum refined products from storage tank to various petroleum storage transport mode such as; barge tank; truck tank; through pipelines, hoses, flexible joint arms (Carolyn *et al.*, 2010). Loading operation is the main activity in GSDF and required well trained work force and functional equipment to be run properly (Paul Guyer, 2014). However, emissions from loading operations at GSDF, contain benzene vapors escape into the atmosphere (Pandya, 2006). Air toxics are released from the GSDF during gasoline loading truck tank; storage tank; barge tank and from the vapor leaks at loading pumps, valves and other equipment in the facility (Igor Burstyn *et al.*, 2007; EPA 450/2, 1977). In Industrialized countries, several studies from those of Parkinson *et al.*, 1971; Sherwood *et al.*, 1972; Phillips *et al.,* 1978; Irving and Grumbles 1979; Gjorloff *et al.,* 1982; Runion *et al.*, 1985; Halder *et al.,* 1986; Berlin *et al.*, 1988; Williams *et al.*, 2005 had evaluated benzene exposure during loading operations in the GSDFs. The results of those studies revealed that during loading operations benzene exposure concentrations were above the occupational exposure limit of the regulatory bodies such as the American Conference of Governmental Industrial (ACGIH) Hygienists and Occupational Safety and Health Administration (OSHA) at those periods, as describe in the table 5 in the appendix. The introduction of top loading method and vapor recovery system in loading operation reduced the benzene exposure significantly (Kawai *et al.*, 1991).

In other hand, in developing countries the scenario may be worse where management of such exposure-health problems is typically not well-implemented and workers may not be well-protected about such health risk (Ormrat Kampeerawipakorn *et al.*, 2017). Although, contamination with benzene is mostly due to uncontrolled industrial activity and lack of the awareness of workers (Tunsaringkarn *et al.,* 2012), the magnitude of the problem is said to be grave for developing countries (TIN Ezejiofor *et al.*, 2014). In most benzene occupational researches conducted in developing countries, a comprehensive and harmonious data collecting systems needed as first step to conduct an accurate health risk assessment are unavailable. Ezejiofor *et al.,* (2012) and Ezejiofor *et al.,* (2014) assessed chemical hazard at petroleum distribution industry in developing countries by using a check-list, oral interview and walk-through operational sites. This cannot insure an appropriate benzene exposure assessment for workers at the breathing zone. Benzene is one of the volatile components of petroleum products, like gasoline and is an established carcinogenic chemical for human health by the International Agency of Research on Cancer (IARC, 1987). Short term human exposures to benzene can give rise to various adverse effects such as headaches, dizziness, inability to concentrate, impaired short term memory and tremors (Navasumrit *et al.*, 2005) and is considered as acute exposure effects. Whilst long term human exposure can give rise to more complex health effects including haematotoxicity, genetoxicity, immunological and reproductive effects as well as various cancers (Keretetse *et al.*, 2008), and is considered as chronic exposure effects. In general, acute exposure effects are considered to be reversible, while chronic exposure effects are probably irreversible (Cheremisinoff *et al.,* 1979).

Therefore, benzene under a particular exposure concentration levels can generate cancer adverse effects or non-cancer adverse effects (IRIS, 2002) on workers' health. Exposure to toxicants can be evaluated using guidelines based on the Acceptable Daily Intake (ADI), Minimal Risk Level (MRL) and Reference Dose (RfD) as single points to quantify the risk (Edokpolo *et al.,* 2015). However, risk assessment using probabilistic techniques utilizes probability distributions to estimate the risk. This technique gives a quantitative description of uncertainty and variability in evaluating the risk of health adverse effects. Thus, the carcinogenic benzene for low level or high level exposure may potentially provide acute or chronic health adverse effect to workers. Therefore, the health risk assessment of benzene in GSDF for industrialized and developing countries are both relevant. The overall risk probability (ORP) is a probabilistic technic that, in assessing risk, takes into consideration the exposure concentration level and the overall exposed population (Qiming Cao *et al.*, 2011). The ORP seems to be the indicated health risk assessment methodology, to benzene exposure concentrations for the GSDFs.

Thus, this explorative study aims to:

- Produce a cumulative probability distribution of benzene exposure for loading operations levels of industrialized countries for the period of 1986-2001.
- Characterize the health risk and evaluate the overall risk probability of benzene exposure concentration of industrialized countriesfor the period of 1986-2001.
- Characterize health risk and evaluate the overall risk probability of benzene exposure estimate in developing countries.
- Compare the overall risk probability on industrialized countries and developing countries.

MATERIALS AND METHODS

In the section 2.1., briefly explained benzene occupational exposure limit evolution and gasoline storage and distribution facilities. Section 2.2. presents the health risk assessment methods. Finally, section 2.3. presents in details the research methodology on the investigation of health risk assessment in gasoline storage and distribution facilities.

Occupational exposure limit of benzene and gasoline storage and distribution facilities: Benzene is known to adversely affect human health and therefore, regulations have been promulgated to reduce the amount of benzene to which workers and general public are exposed (Karen *et al*., 1999). Regulatory occupational exposure limits (OELs), based on toxicology data, are set and enforced by government agencies to protect workers' health in the workplace (U.S. EPA, 1990). The OELs evolution of benzene exposure concentration from two internationally well-known regulatory bodies such as the American Conference of Governmental Industrial Hygienists (ACGIH) and Occupational Safety and Health Administration (OSHA) were continually reviewed. The different regulations set on OEL of benzene concentrations at various time periods for ACGIH and OSHA show the trends on benzene reduction in occupational settings. These regulations are used worldwide and are based on epidemiologically studies. The current OEL of benzene exposure at ACGIH and OSHA for 8-hour total weight average are 1.6 mg/m^3 and 3.25 mg/m^{3}respectively. In downstream petroleum industry, GSDF is the highest exposed occupations (Verma *et al*., 1992). During loading operations exposures of volatile organic compounds such as, benzene escaped from gasoline vapors (Pandya, *et al*., 2006). GSDF is concerned with the handling for storage and transfer of refined petroleum products in loading locations via pipelines to different petroleum storage transport mode (barge tanks, truck tank) (Carolyn *et al.,* 1978).

Health risk assessment: In health risk assessment of toxicants, many methods have been used to evaluate and quantify the adverse effects of the toxicants. These methods can be divided into 2 categories: conventional non-probabilistic (Deterministic) methods and probabilistic-based (Scholastic) methods (Qiming *et al.,* 2012). In a conventional method, an exposure dose (or concentration), usually in the form of an average or medium value, is compared with a threshold or reference value for a given adverse effect. The hazard quotient (or risk quotient) can be calculated from the ratio of the exposure value to the reference value (Qiming Cao *et al*., 2011). The larger the value of the hazard quotient, the higher the health risks for non-carcinogenic of adverse effects being observed. In order to provide a more accurate health risk assessment. Many methods exist to assess health risk in GSDFs such as deterministic and scholastic methods. The deterministic is made from a single model with an equation to be used. Deterministic method relies on single point value to estimate risk and the result is also a point value. Characterization of uncertainty and variability with deterministic method are limited (U.S. EPA, 1990). Health quantitative technics such as hazard quotient (HQ); cancer risk (CR) estimate risk for a specific population group only. Thus, providing a single point estimate, representing a part of the affected population. Scholastic method provides a distribution of possible exposure estimates. The overall risk probability technic is the combination of plotting together exposure cumulative curve and the dose-response cumulative curve. The overall risk probability takes into account multiple points in distribution of exposure and effects curves. Therefore, produces various exposures levels corresponding to different dose-responses (Qiming Cao *et al*., 2011).

Several studies, such as those of Kirkeleit *et al* (2010); Navasumrit *et al* (2017).; Kampeerawipakorn *et al* (2017); Heibati *et al*. (2017) had used biomonitoring health approach in order to assess health risk in gasoline storage and distribution facilities (Navasumrit *et al*., 2005; Kirkeleit *et al*., 2010; Heibati *et al*.,2017; CONCAWE, 2000). This approach evaluates human body burden through biomarkers, and quantify the amount of hazardous chemical absorbed by the exposed workers. The health biomonitoring is limited by not being able to specify the route of the toxicant exposure (U.S. EPA, 1990). Various sources of exposure, such as the workers' life style can also affect the results from biomonitoring health approach. From the studies of Qiming Cao *et al*. (2002); Qiming Cao *et al*. (2011); Edokpolo *et al*. (2014); used probabilistic technic to assess health risk of benzene exposure in petroleum environments and chemical for fish in water surface. This approach evaluates the possible adverse effects at different levels of exposure, which provides more detailed understanding of the hazard and the associated risks (Benjamin Edokpolo, 2014; Edokpolo, 2015; Qiming Cao, 2011 and Qiming, 2002). In the other hand, from environmental monitoring health approach derives the occupational health approach, and takes into consideration the assessment of air; soil; water; waste in the facility with the view of evaluating workers' health risk. This health approach quantify the amount of hazardous chemical worker is exposed in performing a specific task at the working place. This health approach evaluates only the current exposure concentration to be exposed to workers. Benzene is known as a carcinogenic chemical by International Agency for Research on Cancer, and exposure to certain level of concentration for at different time period can result of acute or chronic human health effects (Benjamin Edokpolo *et al.,* 2014). Therefore, there is a need to assess health risk of benzene at various exposures levels and for different adverse health effects outcomes.

Data collection: The exposure data used for the health risk assessment were obtained from the Conservation of Clean Air and Water in Europe (CONCAWE) database (N0 7/97; N0 2/00 and N0 9/02 Reports) and literature surveys on benzene exposure in GSDFs. The first set of data were collected from the CONCAWE reports with the aim to gather only exposure data for benzene concentrations during loading operations of truck tanks; barges and storage tanks. From the database, the years' periods mentioned below were able to satisfy the criteria on the type of data needed to conduct our research due to the non-significant improvement of technology change and facility conditions in developing countries to be compared with. These data were composed of short term exposure and full shift (8-hours Total Weighted Average - TWA) exposure data from industrialized countries for the period 1986 to 2001. Furthermore, these data provide details on monitoring of tasks description and are specific for the study conducted. However, the scope of several studies are more directed to general assessment of the facility and at the vicinity, and making them non less relevant from benzene occupational exposure in GSDF. One of the explanation for the lack of having huge number of specific and details monitoring data available to the general public, it is because those data are privately owned by companies and therefore, are out of reach to general public (CONCAWE, 2000). The second sets of data were collected from literature surveys. These data were composed of full shift of exposure concentrations mean in the GSDFs of various countries.

EU-3A

European Union (benzene exposure concentration data) for the period of the 1999-2001. These data represent loading truck tank; loading barge and loading storage tank data.

Table 1. Benzene exposure data set for loading operation from industrialized countries

<table>
<tr><td colspan="9">EU-1: Benzene exposure data for loading operations in petroleum storage and distribution facility (1986-1992)/Full shift (8h-TWA) (mg/m³)</td><td>References</td></tr>
<tr><td>Nbr of sample</td><td colspan="2">Loading truck tank mean (range)</td><td>Nbr of sample</td><td colspan="2">Loading barge mean (range)</td><td>Nbr of sample</td><td colspan="2">Loading tanker mean (range)</td><td rowspan="2">Report no. 7/94: Review of European oil industry benzene exposure data 1986-1992</td></tr>
<tr><td>5</td><td>0.08</td><td>(0.05-0.87)</td><td>6</td><td>0.06</td><td>(0.05-5.75)</td><td>11</td><td>0.23</td><td>(0.06-1.11)</td></tr>
<tr><td colspan="9">EU-2A: Benzene exposure data for loading operations in petroleum storage and distribution facility (1993-1998)/Full shift (8h-TWA) (mg/m³)</td><td rowspan="4">Report no. 2/00: A review of European gasoline exposure data for the period 1993-1998</td></tr>
<tr><td>7</td><td>0.64</td><td>(0.18-2.07)</td><td>5</td><td>0.56</td><td>(0.37-1.41)</td><td>2</td><td>0.32</td><td>(0.32-1.26)</td></tr>
<tr><td colspan="9">EU-2B: Benzene exposure data for loading operations in petroleum storage and distribution facility (1993-1998)/Short period (8h-TWA) (mg/m³)</td></tr>
<tr><td>6</td><td>2.2</td><td>(1.4-6.84)</td><td>3</td><td>0.7</td><td>(0.23-0.79)</td><td>2</td><td>2.01</td><td>(2.01-2.19)</td></tr>
<tr><td colspan="9">EU-3A: Benzene exposure data for loading operations in petroleum storage and distribution facility (1999-2001)/Full shift (8h-TWA) (mg/m³)</td><td rowspan="4">Report no. 9/02: A survey of European gasoline exposures for the period 1999-2001</td></tr>
<tr><td>38</td><td>0.4</td><td>(0.1-4.6)</td><td>4</td><td>0.1</td><td>(0.1-0.1)</td><td>5</td><td>0.1</td><td>(0.1-0.6)</td></tr>
<tr><td colspan="9">EU-3B: Benzene exposure data for loading operations in petroleum storage and distribution facility (1999-2001)/Short period (8h-TWA) (mg/m³)</td></tr>
<tr><td>22</td><td>0.8</td><td>(0.1-5.4)</td><td>15</td><td>0.2</td><td>(0.1-0.8)</td><td>19</td><td>0.7</td><td>(0.2-1.9)</td></tr>
</table>

Table 2. Benzene exposure mean data at the site level from various countries

Location	**Population size (million)**	**Mean, Range of benzene concentration (mg/m^3)**	**Gasoline consumption by country per year in million**	**GDP/Capita US Dollar/year**
Iran	76.45 (2012)	5.2975 mg/m^3 (0.52 mg/m^3 -5.2975 mg/m^3)Benzene exposure at petroleum depot. (Azari et al., 2012)	128115 (2012)	7 832.90 (2012)
United-Kingdom	58.32 (1998)	14.982 mg/m3 (9.75 mg/m3 - 26.650 mg/m3)Estimation of exposure benzene in petroleum marketing and distribution (Lewis et al.,1997)	187975 (1997)	26 621 (1997)
India	1161.98 (2006)	0.19 mg/m^3 (0.19 mg/m^3 – 0.81 mg/m^3) Assessment of benzene Exposure at the Gantry Gasoline Terminal (Pandya et al., 2006)	75555 (2006)	792.03 (2006)
Israel	5.97 (1998)	0.975 mg/m^3 (0.861 mg/m3-28.925mg/m^3) Exposure to benzene in the fuel distribution installations (Peretz et al., 1998)	17155 (1998)	19 423.75 (1998)
South-Africa	55.29 (2015)	29 mg/m^3 (21mg/m^3 to 35mg/m^3) Benzene exposure in Diesel-refueling station (Moola et al., 2015)	68620 (2014)	5 746.68 (2015)
Finland	5.19 (2001)	0.15 mg/m^3 (0.02 mg/m^3 0.6 mg/m^3) Benzene exposure for Offloading in a Tankers and Railway Wagon (Hakkola et al., 2001)	15330 (2001)	24 913.24 (2001)
Italy	56.97 (2001)	11.13 mg/m^3 (13.6 mg/m^3 -18.8 mg/m^3)Exposure to Benzene in Petroleum Transport Company. (Figa et al., 2001)	146730 (2001)	20 400.81 (2001)
France	59.75 (1996)	0.15 mg/m^3 (0.07 mg/m^3–0.43 mg/m^3) Benzene exposure in petroleum products distribution (Armstrong et al., 1996)	126655 (1996)	26 871.83 (1996)
Bulgaria	7.66 (1995)	1.495 mg/m^3 (0.0325mg/m^3 -1856.43 mg/m^3)Benzene exposure in petrochemical (Garte et al., 2005)	5475 (2005)	3 869.53 (2005)
Tunisia	9.86 (2002)	0.52 mg/m^3 (0.065 mg/m^3- 1.36 mg/m^3)Benzene Exposure Monitoring of Tunisian Workers (Chakroun et al., 2002)	3613.5 (2002)	2 346.06 (2002)

Full shift (8-TWA): this is the exposure concentration for the traditional 8 working hours on daily basis.

EU-2A: European Union (benzene exposure concentration data) for the period of 1993-1998. These data represent loading truck tank; loading barge and loading storage tank data.

Full shift (8-TWA): this is the exposure concentration for the traditional 8 working hours on daily basis.EU-2B: European Union (benzene exposure concentration data) for the period of 1993-1998. These data represent loading truck tank; loading barge and loading storage tank data.

Short period: this is the exposure concentration < 1-hour time period for loading truck tank; loading barge and loading storage tank data.

EU-3B: European Union (benzene exposure concentration data) for the period of the 1999-2001. These represent loading truck tank; loading barge and loading storage tank data.

Short period: this is the exposure concentration < 1-hour time period for loading truck tank; loading barge and loading storage tank data.

Data analysis

The loading operations data set of trucks tank; barges and storage tank from the CONCAWE database for the three periods (1986-1992; 1993-1998; 1999-2001), consisted of short terms exposure and full shift exposure as shown in Table 1. The data set from the different period were combined based on loading operation types and were plotted as cumulative probability distribution (CPD) by using Microsoft Excel. Then, each CPD was compared with the two OEL guidelines from ACGIH and OSHA. The mean of exposures from the data set in various countries were plotted as CPD by using also Microsoft Excel. The Table 2. shows the list of the countries and the mean of benzene exposure at the site level in gasoline storage and distribution facilities.

Health Risk Characterization for benzene exposure from industrialized countries: The data set for benzene exposure of each loading operations were used to develop CPD plots. From these CPD, the estimation of the concentration exposure at 50% (CEXP50) and 95% (CEXP95) representing the main exposed population segment and the highest exposed population segment respectively. Then, the benzene concentrations for each type of loading operations were calculated into Lifetime Average Daily Dose (LADD) by using the defaults parameters values summarized in the Table 3. The LADD were used to calculate the Hazard Quotient (HQ), Cancer Risk (CR) and Overall Risk Probability (ORP). The HQ was used to calculate the non-carcinogenic adverse health effect related to benzene exposure. The CR, to calculate the carcinogenic adverse health effect of being exposed to benzene concentrations. The ORP for cancer, was used to estimate the entire population health risk exposed to benzene exposure. The values of USEPA Inhalation Reference Dose (RfD) and Slope Factor (SF) were used to estimate HQ and CR as referred in the Table 3.

$\text{LADD} = (\text{CEXP} * \text{IR} * \text{EL} * \text{ED}) / (\text{BW} * \text{LT})$ ……….(2)

Where CEXP is exposure concentration (mg/m^3); IR, Inhalation Rate (m^3/day); EL, Exposure Length (day/day); ED, Exposure Duration (days); BW, Body Weight (kg); LT, Lifetime (days).

industrialized countries by using the equation (3). The benzene exposure at CEXP50 (representing the main population segment) and at CEXP95(representing the highest exposed population segment) were estimated in LADD for all loading operations by using the equation (3). converted to LADD by using the equation (3).

$\text{HQ} = \text{LADD} / \text{RfD}$ ……………..(3)

Where HQ is Hazard Quotient; LADD, Lifetime Average Daily Dose (mg/kg/day); RfD, USEPA reference dose (mg/kg/day)

Cancer Risk (CR): The Cancer risk is expressed as excess risk of developing a cancer over lifetime of exposure (70 years). The USEPA inhalation slope factor derived for benzene was used to quantify the estimate excess cancer risk for each exposures data of developing countries and industrialized countries at CEXP50 and CEXP95 for each loading operations by using the equation (4)

Cancer Risk = LADD (mg/kg/day) * SF (mg/kg/day)-1 (4)

Where SF is the slope factor for benzene.

Overall Risk Probability (ORP): The overall ORP method is based on the use of ORP curve. The ORP curve is the plot of the CP exposure exceedance values against the corresponding CP values for dose-adverse effects.

Table 3. Summary of default exposure factors

Parameter	Unit	Default values
Lifetime (LT)	Years	70
Body weight (BW)	Kg	70
Exposure Length (EL)	Day/day	0.33 (8h/day) (workers) 0.17 (4h/day) (outdoor)
Exposure Duration (ED)	Years	25 (commercial/industrial) 30 (residential)
Inhalation Rate (IR)	m^3/day	0.83 (indoor) 1.4 (outdoor)
Inhalation Reference Dose (RfD)	mg/kg/day	0.0085
Slope Factor (SF)	mg/kg/day	0.0273
	Value	
Lifetime (LT)	7 days/week * 52 weeks/year * 70 years =	25 480 days
Exposure Duration (ED)	5 days/week * 48 weeks/year * 25 years =	6 000 days
Exposure Duration (ED)	7 days/week * 52 weeks/year * 30 years =	10 920 days

Health Risk Characterization for benzene exposure from developing countries: The mean data set for benzene exposure at the site level for GSDF from the Table 2., was collected from literature surveys of various countries. Developing countries in the table 2 were selected and then, all the site levels exposures data of developing countries were used to develop the CPD. The CPD was plotted against the OEL Guidelines from ACGIH and OSHA. The CPD was converted into LADD by using the equation (2). The HQ was estimated by using LADD and RfD. The CR was estimated by using LADD and SF.

Hazard Quotient (HQ): The HQ method of risk characterization was used to estimate the adverse health effects for non-cancer risk of benzene exposure. In order to estimate the HQ, the USEPA Inhalation Reference Dose (RfD) derived from benzene was applied for each loading operations and all the exposures data set of developing countries and

Exposure Exceedence (%): 1-CP (%)

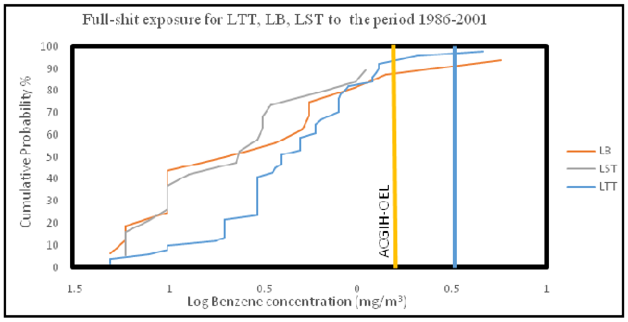
Where CP (%) represents the cumulative probability in percentage.

Affected Population (%): $i(\text{LADD})/(n+1) * 100$

Where *i*th point represents the LADD value; *n*, total number of LADD data points value.

RESULTS AND DISCUSSION

Benzene exposure concentration for loading operations from industrialized countries: The table1 presents the data on the mean and range of benzene exposure from industrialized countries for the period of 1986 to 2001, during loading operations in GSDF. The data availability was structured in the way that, benzene exposure for loading truck tank; loading barge and loading storage tank were selected. Then, the full shift exposure data was available for the 3 periods,1986 to 1992, 1993 to 1998 and 1999 to 2001. And then, the short term exposure data was available only for the time period of 1993 to 1998and 1999 to 2001. These data were reported by the conservation of clean air and water in Europe (CONCAWE) from its various countries members. The figure 2. discloses the CPD plots of benzene exposure data for full shift in the period of 1986 to 2001 for loading operations in industrialized countries. The loading storage tank is the only loading operation that did not exceed the OELs from ACGIH and OSHA. This implies that loading storage tank knows few activities for a full shift compare to the other two loading operations modes. The truck tank and loading barge operations have a benzene concentration exceeded the two OELs standards selected (ACGIH and OSHA) due to their intense activities compare to loading storage tank. The loading truck tank operation required less volume to be loaded and less time, thus an important number of operations can be performed in the day, therefore increasing the benzene exposure concentration at the breathing zone (Kawai *et al.,* 1990; Kawai *et al.,* 1991; Thomas *et al*., 1993).



LTT: Loading Truck Tank
LB: Loading Barge
LST: Loading Storage Tank
ACGIH-OEL: Occupational Exposure Limit of the American Conference of Governmental Industrial Hygienists
OSHA-OEL: Occupational Exposure Limit of the Occupational Safety and Health Administration

Fig. 2. CPD plots to benzene Log concentration for loading operations in Long term exposure from 1986 to 2001 of industrialized countries

For the period of 1986 to 2001, the short term exposure to benzene, from the fig. 3. presents that all the loading operations were below the OELs. This indicates that, despite the introduction of new OEL regulation on benzene of 1 ppm in 1997, and the EU Directive 63/94/EC, on storage installation and loading and unloading equipment, most facilities were still using the previous OEL of 10 ppm (Tuomi *et al*., 2018). This can also indicate that, for short term exposure a considerable change had occurred from the reduction of benzene contain in the gasoline to the implementation of vapor recovery system and best working practices (Pandya *et al*., 2006; Benjamin Edokpolo *et al*., 2014; Tuomi *et al.,* 2018; Alexander *et al*., 2005). The Fig. 4. Shows the benzene exposure concentration for the full shift at the site level for developing countries. From the observation, half of the dataset exceed the OELs, which presents a highly exposure concentration of benzene at the site level. This implies that, there is a significant benzene exposure concentration for the full shift at the site level, as a result of high benzene contain level in gasoline (Tuomi *et al.*, 2018), (Pandya *et al*., 2006; Ormrat Kampeerawipakorn *et al*., 2017; Tunsaringkarn *et al*., 2012; TIN Ezejiofor *et al*., 2014 and Peretz *et al.,* 2009) at site level in developing countries.

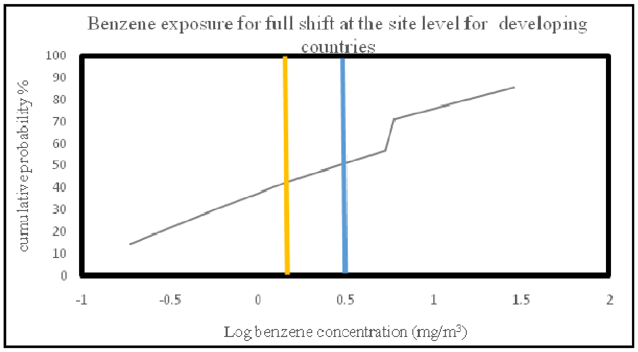


Fig. 4CPD plots to benzene Log concentration at the site level in developing countries

The LADD for the period of 1986 to 2001 at full shift presented a significant LADD level for loading barge and loading truck tank, as compared to loading storage operation in the Fig. 4. This implies that loading workers at the breathing zone for truck tank and loading barge are exposed to a significant average daily dose compare to loading storage tank workers at the breathing zone.

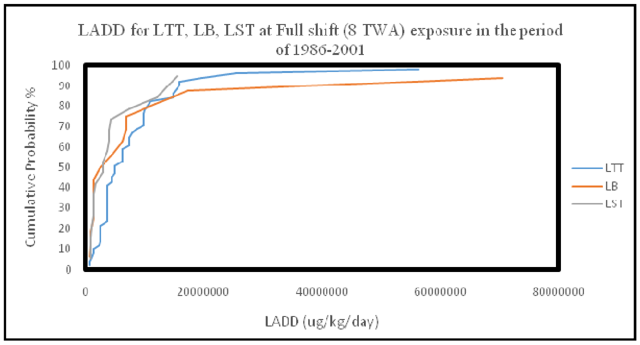


Fig. 5. CPD plots to benzene LADD exposure for long-term exposure of loading operations from 1986 to 2001 of industrialized countries

Long term benzene LADD exposure for the period of 1986 to 2001, indicates that loading truck tank and loading barge workers are highly exposed to adverse effects for a long period, due to repeated tasks as compared to loading storage tank which is seldom within a working day. From the short term benzene LADD exposure for the period of 1986 to 2001,

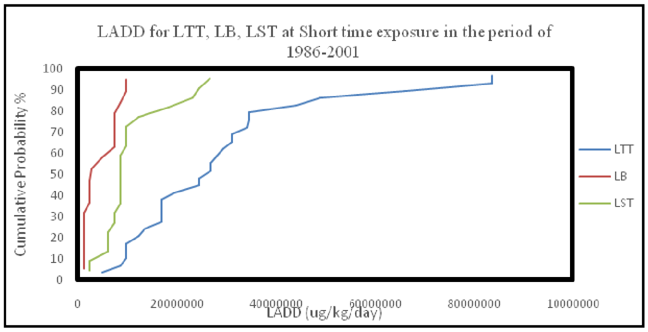


Fig. 6. CPD plots to benzene LADD exposure for short-term exposure of loading operations from 1986 to 2001 of

Table 4. Health characterization of benzene exposure for industrialized countries

Exposure Period	Tasks	Cexp50(mg/m^3)	Cexp95 (mg/m^3)	LADD50at 10^6(mg/m^3/kg/day)	LADD95at 10^6(mg/m^3/kg/day)	HQ at LADD50at 10^6	HQ at LADD95 at 10^6	CR at LADD50 at 10^6	CR at LADD95 at 10^6	CR at 10^6 estimated by ORP
(1986-2001)	LTT	0.4	1.6	4.89	19.57	572.18	2288.73	0.13	0.53	0.03
Full shift/8-	LB	0.2	5.75	2.45	70.32	286.09	8225.12	0.67	1.92	0.02
TWA	LST	0.23	1.26	2.81	15.41	329	1802.37	0.07	0.42	0.04
(1986-2001)	LTT	2.01	6.84	24.58	83.66	2875.21	9784.32	0.67	2.28	0.002
Short time	LB	0.2	0.8	2.45	9.78	286.09	1144.36	0.07	0.27	0.045
	LST	0.7	2.01	8.56	24.58	1001.32	2875.22	0.23	0.67	0.007

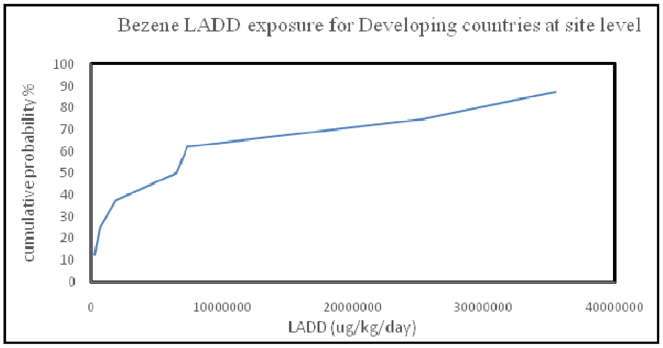


Fig. 7. CPD plots to benzene LADD exposure for full shift exposure of developing countries

Table 5. Health characterization of benzene exposure for developing countries

Nber	Developing countries	Benzene Exposure Estimate (mg/m^3)	LADD 10^6 (mg/m^3/kg/day)	Hazard Quotient (LADD 10^6)	Cancer Risk (LADD 10^6)
1	India	0.19	2.32	273.38	0.063
2	Tunisia	0.52	6.36	748.21	0.17
3	Bulgaria	1.49	18.22	2143.92	0.49
4	Iran	5.297	64.78	7621.69	1.76
5	Israel	5.97	73.015	8590.06	1.99
6	South-Africa	29	354.68	521591	9.68

a significant adverse effects for loading truck tank as compared to the loading barge and loading storage tank. This implies that, for short term loading truck tank being the task with highest rate of repetition, present the highly adverse effect as shown in the fig. 5. Thus, loading truck tank workers are exposed to high concentration as compared to the loading barge and storage tank. The benzene LADD exposure for developing countries presents a significant level of adverse effects pour workers at the site in developing countries. This indicates that, workers at site in developing countries are exposed to a highly adverse effect due to loading operations activities, consider as the most exposed occupational settings in petroleum downstream (Tunsaringkarn *et al*., 2012).

***Hazard Quotient for benzene exposure in loading operations*:** The Table 4 shows the estimating hazard quotient (HQ) for loading operation of benzene exposure from industrialized countries, calculated at Cexp50 and Cexp95of LADD. The HQ was calculated at Cexp50 and Cexp95 to assess tasks of the main population exposed and tasks of highest population. At the short term exposure, loading truck tank has the highest concentration for the main population and for the highly exposed population. In the full shift period of 1986 to 2001 for daily dose benzene exposure concentration at the main exposure population, loading truck tank has the highest daily dose concentration, and loading barge is the highest exposed population. For the Short time period of 1986 to 2001, loading truck tank is the main population exposed to benzene and the also the highest exposed population. This indicates, that

main exposure population at full shift and short time. Therefore, the most exposed workers at the facility are loading truck tank operators. At the highest exposed population, loading barge and loading truck tank for full shift and short time respectively. For the period 1986 to 2001 for all the loading operations, the estimating HQ at LADD50, showed that HQ at LADD50 were < 1. For the HQ at LADD95 two tasks were > 1. Loading barge workers for a full shift and Loading truck tank workers for short term exposure. Indicating that, loading barge operations are significantly high exposed tasks for full shift, with the connecting and disconnecting of hoses, and also the length of time of the operation, where main exposure population of loading operations workers remain in the breathing (Williams *et al*., 2000). The loading truck tank workers for a short time exposure, had a high exposed benzene concentration. The continuous repeated action of loading truck tank workers in checking the manhole, make loading truck tank workers the highest exposed population. This implies that, an excessive HQ exist for the industrialized countries workers, which reveals that the breathing zone for the loading barge and at full shift and loading truck tank at short term operations have significant level of benzene exposure concentration. From the developing countries the LADD, the HQ and CR were estimated at a single point value. The LADD from the Table 5 shows that, the workers at the site level in South-Africa and Israel had an excessive adverse effect exposure and India's workers has the lowest adverse effect. The HQ was >1 for Israel and South-Africa workers at the site level for these developing countries. This reveals that, the ratio gives an overview of the industry level contribute to high benzene concentration in these developing countries. Therefore, these countries have a highly HQ estimate.

Cancer risk for benzene exposure in loading operations: The excess CR was calculated for exposure to benzene at the Cexp50 and Cexp95 level representing the main group of the exposed workers and the highest exposed group of workers respectively as shown on Table 4. The CR at the main exposure population shown a low risk of cancer for the full shift loading operations and short time exposure. This implies that, for the main exposure population, workers are safe from cancer risk adverse effect. At the highly exposed population, only loading barge and loading truck tank for full shift exposure and short time exposure were exposed to CR respectively. This reveals that, for full shift, loading barge operation shown a high CR for workers at the breathing zone due to the duration loading barge operation, compare to loading truck tank for instance. Then, for the short time exposure, loading truck tank presents a CR, due to highly exposed repetitive tasks performed as gauging, checking the manhole (Nordlinder *et al*., 1987). From the developing countries, the CR was estimated at a single point at the site level. The CR was significant for South-Africa, then Israel and Iran workers. This implies that, workers at site in South-Africa are highly exposed to excess CR, workers in Israel and Iran sites are exposed to CR also. Revealing a lack of engineering control measures, such as vapor recovery system implemented in the site for loading operation. Further, a high level contains of benzene in the gasoline (Africa Refinery Association Report on specification, 2009) for the countries with excess CR.

Overall risk probability for benzene exposure in loading operations: In order to quantify the estimate of the ORP for benzene exposure, the exposure exceedance values as percentage were calculated and plotted against the percentage of the affected population to obtain an ORP curves for each set of periods at specific loading operation. The overall risk probability was plotted with the CP exposure exceedance values against the corresponding CP values for dose-adverse effects. The ORP at the full shift in the period of 1986 to 2001 for industrialized countries shown in the fig. 8, presents the loading truck tank, loading barge and loading storage tank ORP curves. The loading barge operation has the highest health risk adverse effects. Following by the loading storage tank and loading truck tank. This discloses that, workers at the breathing zone during loading barge operation are exposed in the long run to chronic adverse health effect.

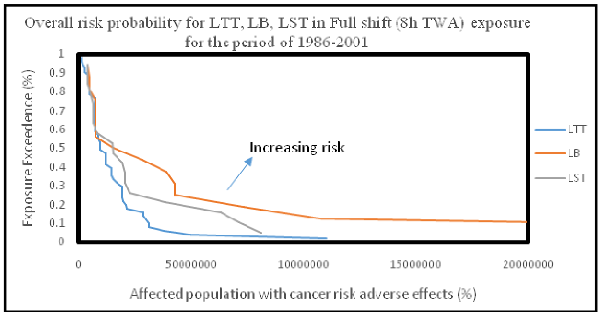


Fig. 8 Overall risk probability for cancer as a result of full shift exposure to benzene concentrations during loading operations from 1986 to 2001 from industrialized countries

The ORP at short time in the period of 1986 to 2001for

health risk adverse effect for loading truck tank as compared to loading storage tank and loading barge. This implies that, workers at the breathing zone for loading truck tank operation are exposed in the short time to significant acute adverse health effects.

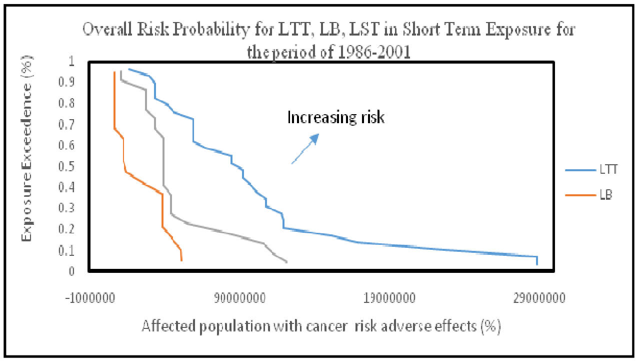


Fig. 9. Overall risk probability for cancer as a result of short time exposure to benzene concentrations during loading operations from 1986 to 2001 from industrialized countries

Comparison of Health risk exposure to benzene at full shift between developing and industrialized countries: In order to compare the overall risk probability to benzene exposure in developing and industrialized countries, only the full shift of exposure data from the table 4 on all the loading operations were considered. From the plotting of cumulative probability to the ORP, the data passed through the all process. In other hand, the countries' data selected from the table 5 as developing countries were used to be compared with industrialized countries. The results revealed that, for an ORP of health assessment for non-carcinogenic and carcinogenic adverse health effect to exposure on benzene, developing countries has a high health risk compare to industrialized countries which did not cross the 2.5%, considered as the safe health area. This can be translated by the investment made by industrialized countries in occupational health and safety, where developing countries are more focused on the economic benefits from gasoline storage and distribution activities (Ambisisi Ambituuni *et al*., 2013).

The high level of benzene volume percentage in gasoline and other petroleum products in developing country, representing 5% by volume content for oil exporting developing countries members of the Africa Refinery Association (Africa Refinery Association Report on specification, 2009), contributes to the results of this study. While in industrialized country, such as United State of America, the annual average benzene volume content in gasoline is 0.62% by volume (Derek Swick, 2014). The lack of engineering control measures such as vapor recovery system and outdated facilities in most of developing countries at GSDFs (TIN Ezejiofor, 2014), also witness the high level of the ORP of cancer risk in developing countries compare to industrialized countries; where vapor recovery system significantly reduces the benzene exposure (TIN Ezejiofor, 2014). Finally, a need for a strengthen regulation in developing countries for benzene exposure in GSDF is also revealed by this study (Behzad Heibatia, 2018). Meanwhile, industrialized countries have implemented a strong regulation for benzene exposure for loading operations in GSDF (Derek Swick, 2014).

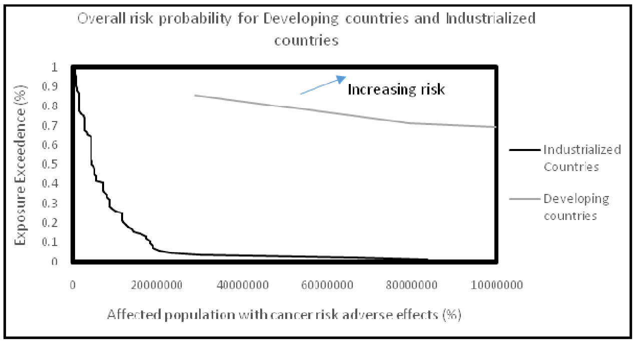


Fig. 11. ORP of cancer risk comparison for benzene exposure between industrialized and for developing countries

Conclusion

In order to estimate health risk of benzene exposure for loading operations, in gasoline storage and distribution facility, probabilistic method was used. This was more relevant for loading operations, where various levels of benzene concentrations occur in the breathing zone. Deterministic method which uses single point value to evaluate health risk would not be appropriate. The cumulative probability distribution (CPD) enables to show the trend of benzene exposures measured of loading operations in various locations of industrialized countries. The CPD for the period of 1986 to 2001 was plotted against occupational exposure limits (OEL) guideline of benzene; where loading barge, loading truck tank exceeded the OELs for the full shift exposure; and none of the loading operations exceeded the short time exposure for the industrialized countries. High benzene exposure concentration at the site level were observed for the countries. Health risk for benzene exposure was characterized through lifetime average daily dose and also by estimating the hazard quotient and the cancer risk at Cexp50 and Cexp95. Then, the overall risk probability was estimated to overcome variability and uncertainty while conducting health risk assessment. The overall risk probability of industrialized countries and developing countries were compared, and developing countries as a huge difference, as a result of high contains of benzene volume in gasoline; lack of engineering control measures such as vapor recovery system; poor regulations and working practice.

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