

## Original Article

# Characteristics of Occupational Exposure to Benzene during Turnaround in the Petrochemical Industries

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**Objectives:** The level of benzene exposure in the petrochemical industry during regular operation has been well established, but not in turnaround (TA), where high exposure may occur. In this study, the characteristics of occupational exposure to benzene during TA in the petrochemical companies were investigated in order to determine the best management strategies and improve the working environment. This was accomplished by evaluating the exposure level for the workers working in environments where benzene was being produced or used as an ingredient during the unit process.

**Methods:** From 2003 to 2008, a total of 705 workers in three petrochemical companies in Korea were studied. Long- and short-term (< 1 hr) samples were taken during TAs. TA was classified into three stages: shut-down, maintenance and start-up. All works were classified into 12 occupation categories.

**Results:** The long-term geometric mean (GM) benzene exposure level was 0.025 (5.82) ppm (0.005-42.120 ppm) and the short-term exposure concentration during TA was 0.020 (17.42) ppm (0.005-61.855 ppm). The proportions of TA samples exceeding the time-weighted average, occupational exposure level (TWA-OEL in Korea, 1 ppm) and the short-term exposure limit (STEL-OEL, 5 ppm) were 4.1% (20 samples of 488) and 6.0% (13 samples of 217), respectively. The results for the benzene exposure levels and the rates of exceeding the OEL were both statistically significant ( $p < 0.05$ ). Among the 12 job categories of petrochemical workers, mechanical engineers, plumbers, welders, fieldman and scaffolding workers exhibited long-term samples that exceeded the OEL of benzene, and the rate of exceeding the OEL was statistically significant for the first two occupations ( $p < 0.05$ ).

**Conclusion:** These findings suggest that the periodic work environment must be assessed during non-routine works such as TA.

**Key Words:** Benzene, Turnaround, Petrochemical industry, Occupational exposure level, Time-weighted average

## Introduction

Petrochemical work sites process and manufacture various chemical products based on volatile and flammable liquid

hydrocarbons [1].

Although the heavy chemical industry has played a significant role in improving Korea's economy, it also presents many dangers associated with toxic chemical materials. Petrochemical work sites mainly operate outdoors so the exposure level to hazardous chemical materials is usually low (0.009-0.105 ppm) during routine works [2]. However, recent reports have indicated a link between occupational diseases such as cancer and benzene exposure in petrochemical work sites [3]. Petrochemical workers in large-scale petrochemical industrial complexes are more at risk of benzene exposure

**Received:** May 14, 2010, **Accepted:** July 21, 2010

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compared to those in other industrial complexes.

Regular maintenance and repair of chemical equipment is conducted during turnaround (TA) in petrochemical plants. The highest risk of benzene exposure occurs while performing maintenance tasks during TA. Typical parameters for the assessment of workplace benzene exposure in petrochemical complexes have been proposed [2,4].

Full TAs are conducted on a regular basis and partial TAs are carried out when problems arise in facilities. When TA is carried out, production is stopped and the facilities are opened for a check-up, which increases the danger of exposure during TA compared to during routine works. Despite these concerns, almost no wide-ranging and detailed research has been conducted on benzene exposure among workers during TAs. Thus, this study aims to gather basic information required for protecting workers' health and improving working conditions during TAs in petrochemical work sites by investigating the exposure levels of benzene during TA.

## Materials and Methods

### Subjects

The number of petrochemical TA workers in Yeosu industrial complex selected study subject in this study was about 12,000

persons. Seven hundreds and five workers were randomly sampled among 3,517 plant workers who participate during TAs. There are three major industrial complexes of petrochemical industries in Korea.

Among factories that plan to do TAs in 2008, three factories that use or manufacture benzene were selected and 705 workers working in the factories had been checked up from March to December of 2008. A target processes were Benzene-Toluene-Xylene, Naphtha-based process, Cumene process, and Mono-Nitro-Benzene process.

Plant workers who take part in TAs are mechanical engineers, plumbers, electrical fitters, scaffold workers, welders, drain fitters, insulation fitters, tank fitters, painters, helpers, board men, and field men (Table 1). Plant construction workers work for about six months a year on such tasks in Korea [5].

### Pre-study

The processes in the petrochemical industry operate in a continuous and closed system in which an understanding of all the materials contained in each process is essential. This is achieved by using Process & Instrument Diagrams and Process & Flow Diagrams. The necessary information obtained by field study includes the types of operation being conducted, the major hazardous chemical materials in each operation,

**Table 1.** Major activities of plant workers who take part in turnarounds

Job	Task
Board men	Process system control in control room
Field men	Direct maintenance works according to schedules in field, such as patrolling sites and monitoring assembling or disassembling tasks
Mechanical engineer	After cleaning and lubricating machinery, performing basic diagnostic tests, checking performance, and testing damaged machine parts to determine whether major repairs are necessary, repair and replace
Plumber	Install and repair industrial process piping and heating/cooling systems. Cutting, threading, grooving, bending and welding of high pressure pipeline which is metals
Welder	Welding the process pipe and structural metal to join pipes in pipelines, power plants, and refineries
Tank fitter	Maintenance and cleaning of tank equipment in power plants and refineries
Insulation fitter	Install the materials (cement, staple, wire, tape, or spray insulation) which used to insulate to prevent the wasteful loss of heat or cold of equipment(vessels, boilers and steam pipes)
Electrical fitter	Fix and upgrade existing electrical systems and repair electrical equipment
Scaffold worker	Making a temporary frame or safeguard used to support people and material in the construction or repair of equipments and other large structures
Painter	Coat interior and exterior manufacturing facilities and equipment such as storage tanks, plant buildings, piping and structural steel
Drain fitter	Enforcement of plant structure and process of pressure vessels, making the construction and maintenance work, such as pipe work supports, duct, and boiler operations. All other iron work, except for plumbing equipment
Helpers	Safety manager, civil engineering, construction craftsmen, and other workers

the frequency of each job, the workers doing the job, and the timing of the job. Also, we surveyed techniques of TAs (open drain, steam purge, chemical cleaning etc.), the duration of purge or TAs, atmospheric condition, and the characteristics of task. In Such information is used to determine a monitoring schedule.

### Sampling and analysis

Personal air samples were taken from individual workers according to the work-environment regulations by the Labor Ministry in Korea. For the purpose of work-environment monitoring, TA was divided into three stages: shut-down, maintenance, and start-up. That is ranging from stopping the operation of a factory, cleaning the insides of pipes and equipment, and changing rusted or broken parts, to test-operating to ensure normal operation [6,7].

In order to measure the benzene concentration in the working environments, both passive sampling by organic vapor monitor and active sampling by charcoal tubes were used together. Although organic compounds should in principle be measured by active sampling, passive sampling was used because the workers are very mobile and work indoors with a minimum air stream of 0.4 m/sec.

Although the sampling equipment had already been verified by the National Institute of Occupational Safety and Health (NIOSH), it was re-verified to establish the validity of each method [8]. After installing the passive and active samplers on the same day in the same region, the samples were evaluated and the coefficient of correlation between the two methods was 0.95, which confirmed the absence of any difference between the two ( $p < 0.001$ ).

According to both domestic and international research, passive samplers have been proven as effective as active samplers for organic solvents such as benzene [9,10]. The passive samplers used in this survey have been used worldwide to collect samples of organic solvents in the industrial hygiene sector. Blank samples were collected to prevent contamination and errors that can occur in field samples. A total of 981 real field samples were collected: 493 by using charcoal tubes and 488 by using organic vapor monitors. According to collection method, 705 were personal air samples. According to time period, 764 were long-term samples and 217 were short-term samples. According to TA stage, 260 were collected at the shut-down stage, 589 at the maintenance stage, and 103 at the start-up stage.

The field benzene samples were stored in a cooling box for transport to the analysis center, where they were stored at  $-20^{\circ}\text{C}$  until analysis. The aliphatic and aromatic hydrocarbons such

as benzene were analyzed according to the NIOSH Manual of Analytical Methods 1,500 and 1,501 [11]. Active carbons were moved to a vial, to which 1 ml of carbon bi-sulfide was added, for gas chromatography and desorbed at room temperature for half an hour. To identify the unknown substances, after pretreatment the liquids underwent quantitative analysis by gas chromatography-mass spectrometry and flame ionization detection [12,13]. Calibration curves were differentiated according to the benzene concentration, thereby minimizing analysis errors. To evaluate the monitoring results, as many personal air samples were collected as possible during the continuous 8-hour shifts worked by the plant workers. Concentrations for an 8-hour, time-weighted average (TWA) of long-term samples were calculated to determine whether their exposure exceeded the occupational exposure level (TWA-OEL). In addition, each short-term exposure concentration was evaluated using a 15 minute TWA to determine whether it exceeded the short-term exposure limit (STEL-OEL) [14].

### Statistical analysis

Statistical analysis was carried out using SPSS ver. 17.0 (SPSS Inc., Chicago, IL, USA), in order to determine whether the results were normally or log-normally distributed. The distributions were then assessed by the Shapiro-Wilk and Kolmogorov-Smirnov tests. Differences between groups were assessed using the one-way ANOVA for independent samples. Correlations between variables were assessed by Pearson's  $r$  coefficient. In addition, it was replaced "not detected (ND)" with half the detection limit for statistics [15].

## Results

### General characteristics of the study subjects

The 705 study subjects who gave personal air samples were surveyed and their occupations were as follows: mechanical engineers 301 (42.7%), plumbers 104 (14.8%), drain fitters 6 (0.9%), welders 17 (3.4%), electrical fitters 43 (6.1%), scaffold workers 36 (5.1%), insulation fitters 42 (6.0%), painters 20 (2.8%), tank fitters 4 (0.6%), helpers 31 (4.4%), board men 16 (2.3%), field men 78 (11.1%). Mechanical engineers, plumbers, field men accounted for 68.6%.

The cumulative probability distribution of benzene concentration in each TA stage is shown in Fig. 1, which reveals a high linear correlation ( $r = 0.86-0.92$ ). The air samples of the work environment exhibited a lognormal distribution. In the Shapiro-Wilk and Kolmogorov-Smirnov tests, the short-term exposure samples exhibited neither lognormal distribution ( $p < 0.001$ ) nor normal distribution ( $p < 0.001$ ).

The distribution rates for benzene concentration in the long and short-term samples were 49.4% and 62.2% for non-detection, 29.5% and 6.5% for 0.01-0.1 ppm, 13.5% and 14.7% for 0.1-0.5 ppm, 3.5% and 6.0% for 0.5-1.0 ppm, and 4.1% and

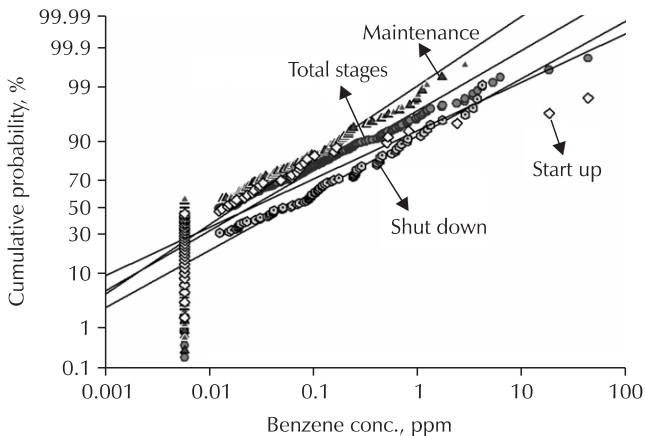
10.6% for 1 ppm and over, respectively.

### The long-term exposure concentration (LTEC)

#### Benzene concentration by job category

The arithmetic and geometric means for the LTEC of benzene were  $0.286 \pm 2.138$  ppm (arithmetic mean [AM]  $\pm$  standard deviation [SD]) and 0.024 (5.759) ppm (geometric mean, GM [geometric standard deviation, GSD]), which were 28.6% and 2.4% of the 8-hour TWA (1 ppm), respectively, indicating a wide variation in result depending on the measurement methods. Twenty cases (4.1%) exceeded the OELs and 37 (7.4%) exceeded the threshold limit value (TLV)-TWA (0.5 ppm) of the American Conference of Governmental Industrial Hygienists (ACGIH) in the USA [16]. The huge difference between the two means in Table 2 shows that the data distribution was largely tilted toward the left side. Aberrations exceeding the OELs do exist.

The TWA benzene concentration (AM) of the workers was the highest for field men, followed by plumbers, scaffold workers, welders, drain fitters, and mechanical engineers. The GM was the highest for plumbers, followed by field men,



**Fig. 1.** Cumulative probability distribution of benzene at turnaround (TA) stages in three petrochemical companies.

**Table 2.** Benzene concentration and frequency of exceeding occupational exposure limits (OELs) in personal air samples according to job categories

Job category	No.	Benzene conc. (ppm)				Range (ppm)	No. (> OELs*), %	
		AM	SD	GM	GSD		Korea	ACGIH
Mechanical engineer	142	0.119	0.433	0.021	4.751	ND-3.382	4 (2.8)	5 (3.5)
Plumber	72	0.411	1.024	0.058	7.642	ND-6.152	7 (9.7)	12 (16.7)
Scaffold	29	0.247	0.969	0.021	6.362	ND-5.240	1 (3.4)	2 (6.9)
Electric fitter	37	0.074	0.153	0.026	3.946	ND-0.838	0	1 (2.7)
Insulation fitter	38	0.017	0.026	0.009	2.461	ND-0.103	0	0
Welder	24	0.239	0.638	0.023	7.154	ND-2.822	3 (12.5)	3 (12.5)
Helper	25	0.049	0.110	0.015	3.839	ND-0.476	0	0
Drain fitter	6	0.225	0.537	0.015	9.095	ND-1.321	1 (16.7)	1 (16.7)
Painter	20	0.032	0.050	0.013	3.522	ND-0.166	0	0
Tank fitter	4	0.017	0.022	0.010	2.905	ND-0.050	0	0
Board man	16	0.048	0.099	0.013	4.091	ND-0.319	0	0
Field man	75	0.970	5.248	0.045	7.752	ND-42.120	4 (5.3)	13 (17.3)
Total	488	0.286	2.138	0.025	5.817	ND-42.120	20 (4.1)	37 (7.6)
p-value	-	0.477	-	<0.001	-	-	-	-

AM: arithmetic mean, SD: standard deviation, GM: geometric mean, GSD: geometric standard deviation, ACGIH: American Conference of Governmental Industrial Hygienists, ND: non detect.

\*Occupational exposure limits in Korea.

**Table 3.** Benzene concentration and frequency of exceeding occupational exposure limits (OELs) in personal air samples according to turnaround (TA) stages

TA stages	No.	Benzene conc. (ppm)				Range (ppm)	No. (> OELs*), %	
		AM	SD	GM	GSD		Korea	ACGIH
Shut down	107	0.311	0.715	0.055	6.912	ND-4.150	9 (8.4)	16 (15.0)
Maintenance	325	0.124	0.534	0.019	4.791	ND-6.152	8 (2.5)	15 (4.6)
Start up	56	1.173	6.071	0.026	7.478	ND-42.120	3 (5.4)	6 (10.7)
Total	488	0.286	2.138	0.025	5.817	ND-42.120	20 (4.1)	37 (7.6)
F-value	-	5.875	-	16.429	-	-	-	-
p-value	-	0.003	-	< 0.001	-	-	-	-

AM: arithmetic mean, SD: standard deviation, GM: geometric mean, GSD: geometric standard deviation, ACGIH: American Conference of Governmental Industrial Hygienists, ND: non detect.

\*Occupational exposure limits in Korea.

electrical fitters, and welders. Among all the jobs, mechanical engineers, plumbers, welders, scaffold workers, drain fitters, and field men showed samples that exceeded the OELs.

The long-term exposure concentrations of benzene according to job category are shown in Fig. 2. Aberrations clearly existed in some occupations exceeding OELs. It shows that mechanical engineers, plumbers, and field men suffer potential exposure to highly concentrated benzene, depending on the working conditions.

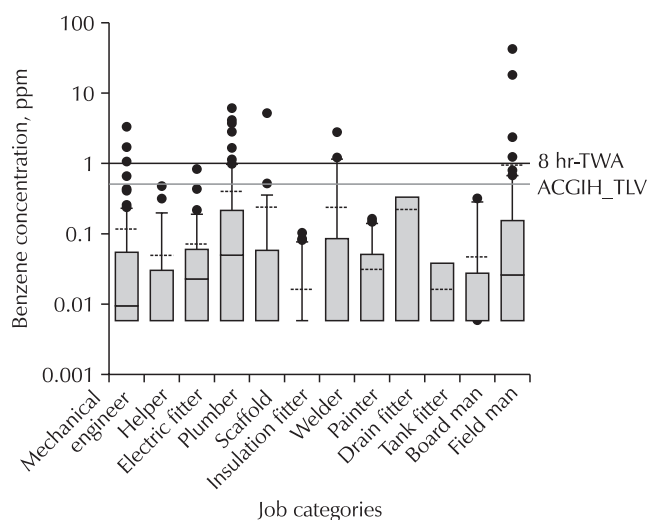
#### Benzene concentration by each stage during TA

The AM and GM for the TWA benzene concentration of long-term samples in each stage of TA were  $0.311 \pm 0.715$  ppm and 0.055 (6.912) ppm in the shut-down stage,  $0.124 \pm 0.534$  ppm and 0.019 (4.791) ppm in the maintenance stage, and  $1.173 \pm 6.071$  ppm and 0.026 (7.478) ppm in the start-up stage, respectively. During the shut-down, maintenance and start-up stages, 9, 8, and 3 samples exceeded the OELs, respectively. Table 3 shows the large difference between the two means, and the GSD was also very big at 4.791-7.478. This indicated that the danger to the workers of benzene exposure varies depending on the TA stages. Some of the samples exceeded the OELs and the exposure peaked in the start-up stage. The AM exceeded the OELs.

#### The short-term exposure concentration (STEC)

##### Benzene concentration by job categories

The AM ( $\pm$  SD) and GM (GSD) for the STEC of benzene according to job category during TAs were  $1.336 \pm 5.963$  and 0.020 (17.417) ppm, respectively. Table 4 shows the large difference between the two means. In addition, the GSD is



**Fig. 2.** Distribution of benzene concentration in personal air samples according to job categories. TWA: time-weighted average, ACGIH: American Conference of Governmental Industrial Hygienists, TLV: threshold limit value.

high, indicating the presence of a large amount of non-detected data and highly concentrated data that exceeded the OELs. Some of the samples exceeded the OELs.

The STEC (GM) of the workers according to their job was the highest for helpers (0.112 ppm), followed by scaffold workers (0.087 ppm), plumbers (0.054 ppm), and mechanical engineers (0.016 ppm). The AM was the highest for mechanical engineers (1.552 ppm), followed by plumbers (1.197 ppm), and scaffold workers (0.334 ppm). Among all the occupations, mechanical engineers and plumbers showed samples in which the STEC exceeded the STEL-OEL.



**Table 4.** Benzene concentration and frequency of exceeding Occupational Exposure Limits (OELs) in short-term personal air samples according to job categories

Job categories	No.	Benzene conc. (ppm)				Range (ppm)	No. (> OELs*), %	
		AM	SD	GM	GSD		Korea	ACGIH
Mechanical engineer	159	1.552	6.779	0.016	17.427	ND-61.855	11 (6.9)	12 (7.6)
Plumber	32	1.197	3.480	0.054	19.857	ND-18.916	2 (6.3)	3 (9.4)
Scaffold	7	0.334	0.335	0.087	12.554	ND-0.812	0	0
Electric fitter	6	0.154	0.371	0.007	11.061	ND-0.912	0	0
Helper	6	0.265	0.279	0.112	7.394	ND-0.785	0	0
Insulation fitter	4	ND	-	ND	-	ND	0	0
Field man	3	ND	-	ND	-	ND	0	0
Total	217	1.336	5.963	0.020	17.417	ND-61.855	13 (6.0)	15 (6.9)
F-value	-	0.196	-	2.302	-	-	-	-
p-value	-	0.978	-	0.036	-	-	-	-

AM: arithmetic mean, SD: standard deviation, GM: geometric mean, GSD: geometric standard deviation, ACGIH: American Conference of Governmental Industrial Hygienists, ND: non detect.

\*Occupational exposure limits in Korea.

The highest-exposure occupations were mechanical engineers, plumbers, and field men in the personal air samples, and mechanical engineers, and plumbers in the short-term exposure samples. However, the field-men did not exhibit any samples exceeding the STEL because relatively few samples were collected.

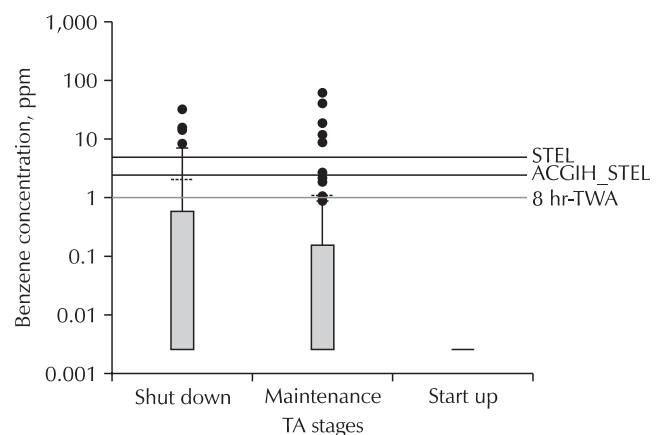
#### *Benzene concentration by each stage during turnaround (TA)*

The STEC of benzene during the shut-down, maintenance and start-up stages of the TAs was a GM of 0.040 (26.163) ppm, a GM of 0.016 (14.652) ppm, and an AM of ND, because of few samples, respectively. Seven samples during the shut-down stage (13.0%) and 6 during the maintenance stage (3.7%) exceeded the STEL-OEL. Thirteen cases (6.0%) exceeded the STEL-OEL (5.0 ppm) of the Ministry of Employment and Labor in Korea and 15 (6.9%) exceeded the TLV-STEL (2.5 ppm) of ACGIH in the USA.

Fig. 3 shows the distribution of STEC of benzene according to the stage during TA. Some of the samples at the shut-down and maintenance stages exceeded the STEL, but none at the start-up stage.

#### **Jobs and works of samples exceeded the OELs**

Table 5 shows the rates for the samples exceeding the various standards according to worker occupation. Among the 705 samples, 33 (4.7%) exceeded the OELs, 20 (4.1%) the 8-hr



**Fig. 3.** Distribution of benzene concentration in short-term personal air samples according to turnaround (TA) stages. STEL: short-term exposure limit, ACGIH: American Conference of Governmental Industrial Hygienists, TWA: time-weighted average.

TWA, and 13 (6.0%) the STEL. Among the 12 occupations, the exceeding rates were 2.5% for mechanical engineers, 1.5% for plumbers, and 4.3% for field men. Among only the mechanical engineers, 15 of the 301 samples (5.0%) exceeded the threshold, compared to 4 out of 78 (5.1%) for the field men.

Among the 33 samples that exceeded the benzene OELs, the specific tasks undertaken during sampling were blind in, valve maneuvering and locking, bolt disintegrating and drain

**Table 5.** Frequency of samples exceeding 8 hr-TWA or STEL according to job categories

Job categories	Total samples	No.* (> OELs*), (%)	8 hr-TWA		STEL	
			Samples	> 1.0 (%)	Samples	> 5.0 (%)
Mechanical engineer	301	15 (5.0)	142	4 (2.8)	159	11 (6.9)
Plumber	104	9 (8.7)	72	7 (9.7)	32	2 (6.3)
Scaffold	36	1 (2.8)	29	1 (3.5)	7	0
Electric fitter	43	0	37	0	6	0
Insulation fitter	42	0	38	0	4	0
Welder	24	3 (12.5)	24	3 (12.5)	0	0
Helper	31	0	25	0	6	0
Drain fitter	6	1 (16.7)	6	1 (6.7)	0	0
Painter	20	0	20	0	0	0
Tank fitter	4	0	4	0	0	0
Board man	16	0	16	0	0	0
Field man	78	4 (5.1)	75	4 (5.3)	3	0
Total	705	33 (4.7)	488	20 (4.1)	217	13 (6.0)

TWA: time-weighted average, STEL: short-term exposure limit.

\*Occupational exposure limits in Korea.

**Table 6.** Kinds of tasks exceeding occupational exposure levels (OELs) by turnaround (TA) stages

TA stages	No. of samples exceeding OELs	Range (ppm)	Contents of task
Shut-down	16	1.068-31.780	Blind in Opening and closing volts, valves, and flanges Removal of, changing or set up volts, drain valves, and steam lines Installation scaffold or safety guard in column, reactors, and vessels
Maintenance	14	1.006-61.855	Removal of, changing or set up valves, gaskets, pipes, and drums Draining or cleaning in reactors, vessels and heat exchangers Chemical make-up and maintenance of rotating motors
Start-up	3	2.361-42.120	Checking of pump and gauge pressure Blind out

valve changing, and safety net installing. Table 6 shows tasks exceeding the benzene OELs set by the Korean Ministry of Labor were handling, removal of, changing or set up volts, valves, pipes and drums (33.3%), blind in or out in pipe lines (21.2%), removal of scaffold or safety guard in benzene column (18.2%), draining or cleaning in reactors, vessels and heat exchangers (12.1%), checking of pump and gauge pressure

(9.1%), chemical make-up and maintenance of rotating motors (6.1%), etc.

## Discussion

The results presented here are based on the large-scale study in Korea to examine the characteristics of benzene exposure in

plant workers during TAs. The LTEC of benzene in the work sites was 0.024 ppm, which was only 2.4% of the 8-hr TWA (1.0 ppm). However, 20 cases (4.0%) exceeded the OELs in some occupations, with the rate decreasing in the order of plumbers, mechanical engineers, field men, welders, drain fitters, and scaffold workers ( $p < 0.001$ ). Among plant workers, the rate was higher among those exposed to benzene directly than among those exposed indirectly. The LTEC of benzene was 0.055 ppm, 0.026 ppm, and 0.019 ppm at the shut-down, start-up and maintenance stages, respectively. The rate of samples exceeding the OELs of the LTEC of benzene decreased in the order of the shut-down, maintenance, and start-up stages ( $p < 0.001$ ). The STEC was 0.020 ppm, and decreased in the order of helpers, scaffold workers, plumbers, mechanical engineers. However, only mechanical engineers and plumbers exhibited samples exceeding the STEL (5.0 ppm).

Workers in petrochemical factories can be exposed to numerous types of chemical, including carcinogens such as benzene. Routine works in the petrochemical industry include numerous maintenance tasks such as dismantling, assembling and blinding. Thus, the evaluation on benzene exposure can vary depending on the sampling strategies, schedules, and the types of operation. In addition, the effects of such exposure vary among individuals. Thus, this study applied a job-based sampling strategy and an individual-based sampling strategy based on the tasks for each job category.

According to the analysis of occupational health statistics (database) of KOSHA from 2005 to 2007, benzene was handled at 555 work sites, excluding gas stations. In 2007, 1,291 samples were examined and benzene concentration was  $0.197 \pm 0.274$  ppm (AM  $\pm$  SD) and  $0.099$  (3.515) ppm (GM [GSD]). In 2006, the results of 650 samples were  $0.300 \pm 0.253$  ppm and  $0.130$  (3.496) ppm, respectively. In 2005, the results of 1,152 samples were  $0.178 \pm 0.222$  ppm and  $0.091$  (3.734) ppm, respectively. For the overall distribution of the benzene concentration from 2005 to 2007, over 90% of the total samples were below 0.5 ppm and rate for exceeding the OELs was only 0.1-0.5% [17].

Kang and colleagues [18] examined 174 samples from 2002 to 2005 from workers who handled benzene in factories and reported an exposure concentration of benzene in working environments of  $0.229 \pm 0.471$  ppm. Among their samples, 9 showed a TWA benzene concentration higher than 0.5 ppm and 5 exceeded the OELs. Their results did not show a significant difference from the total GM of the benzene concentration found in the aforementioned KOSHA sample from 2005 to 2007, but the exceeding rate of the OELs was slightly high at 2.3%.

The petrochemical industry is a process industry, with low levels of benzene exposure in routine works and few exceeding cases. In addition, on the evaluation reports for the working environments of petrochemical factories in the Yeosu industrial complex over the last decade, routine works showed a benzene non-detection rate of 83.0%, compared to a non-detection rate of 49.4% in the LTEC and of 62.2% in the STEC in the present study. Although those values were lower in the routine works, the non-detection rates were high in both cases.

From 1986 to 1992, European petrochemical work sites reported on the benzene exposure levels. Under routine works, the operators who were exposed to benzene were oil refining workers, workers nearby oil refining jobs, refining/repairing workers, tank drivers, cargo workers, shipping workers, and gas station workers [19]. Meanwhile, a study from Conservation of Clean Air and Water in Europe (CONCAWE) reported that workers who take part in TAs are in charge of various jobs such as draining, manhole opening, cleaning, and blind in or out, and can therefore become exposed to benzene in case of a benzene leakage. The study also reported an STEC (AM) as high as 48.0 ppm (7.0-205.2 ppm) [20]. This study found a maximum STEC of 61.855 ppm, which was lower than that reported by CONCAWE, while the exposure standards were exceeded in similar operations in some cases.

KOSHA's 2004 report evaluated the benzene concentration in normal working conditions of work sites that handled benzene in the Yeosu industrial complex. In 2001, the GM of 298 samples was 0.065 ppm, with a maximum value of 2.080 ppm and three cases exceeded the OELs. In 2002, the GM of 401 samples was 0.041 ppm, with a maximum value of 0.442 ppm and 10 cases exceeded the standard. For these three years, 2001-2003, 13 out of 1,165 samples (1.1%) exceeded the standard, and the maximum was 6.170 ppm. From 2003, the benzene exposure concentration decreased [21].

In this study, among the many possible reasons explaining the low levels of total LTEC in the mechanical engineers compared to other workers, it can be to the efforts to minimize direct exposures to benzene. Mechanical engineers have job characteristics that leave them vulnerable to benzene exposure such as opening manholes, drains, valve operations and removal of device. In the present study, the exposure group was classified by considering the probability, strength and frequency of exposure [22]. In particular, given that mechanical engineers are the most common members of the TA workforce, benzene exposure concentration may vary among these workers depending on their unit operations and duties. Plumbers had the second-highest benzene exposure rate. They cut pipes in chemical facilities and assemble or disassemble blinds. Field



men had the third-highest benzene exposure rate due to their tasks such as patrolling sites and monitoring assembling or disassembling tasks. In this study, mechanical engineers, plumbers, and field men were the three most highly exposed groups, followed by welders, drain fitters, and scaffold workers.

In personal samples, the indirect exposure group (welders, drain fitters, scaffold workers) showed higher levels of LTEC than the direct exposure group. This may have been due to the small number of samples, but the indirect exposure group may have been directly exposed to benzene in situations where they were helping other workers or were in charge of other worker's jobs. This may have influenced the total average concentration, leading to cases that exceeded the TWA-OEL in welders, drain fitters, and scaffold workers. However, the samples that exceeded the TWA-OEL were mostly from mechanical engineers and plumbers. The lower than expected exposure concentration in the manhole opening jobs demonstrated the effectiveness of the preliminary safety measures such as air or steam purge on chemicals in the system. The TWA-OEL was exceeded in the tasks of changing heat exchangers, scaffold and blind operation during air or steam purges, and changing valves or gaskets.

The STEL-OEL was exceeded in the occupations of mechanical engineers and plumbers, and in the tasks of blind in or out operation, bolt disassembling works, drain valve exchanging in benzene columns, and gasket eliminating and exchanging. A lot of research has presented unexpectedly low exposure levels with no exceeding cases in manhole opening works where an instantaneous and highly concentrated exposure was expected. As in the case of the LTEC, this was attributed to the workers wearing half-mask respirators in operations expected to have highly concentrated exposure. Measures to minimize highly-concentrated exposures of volatile organic compounds such as benzene should be developed for use not only during routine works but also during TAs [23-25].

However, the results of this study cannot be generalized to represent the entire workforce because the study was conducted only with workers participating in TAs at three petrochemical factories. The study cannot be used to determine results for any time outside the sampling period because it was in tracing and selecting working schedules and worker conditions. In addition, the study was limited in that the benzene concentration cannot be the sole criterion for evaluating working conditions and their effects on workers' health as they can be exposed to numerous other harmful materials at petrochemical factories. Despite these study limitations, the study was worthwhile in its evaluation of the benzene exposure characteristics, classification of the exposure groups, and suggestions for

evaluation methods on the large-scale study in South Korea.

## Conclusion

This study evaluated the exposure patterns and levels in the working environments of workers who participated in TAs in three large-scale petrochemical factories. For the LTEC of benzene in air, the GM was 0.025 (5.82) ppm and the AM was  $0.286 \pm 2.14$  ppm. The TWA-OEL was exceeded in 20 out of 488 (4.1%) TA benzene samples. The GM and AM for the STEC of benzene in air during TAs were 0.020 (17.42) ppm and  $1.336 \pm 5.96$  ppm, respectively. Thirteen out of 217 (6.0%) TA samples exceeded STEL-OEL.

Among the various occupations involved in TAs, mechanical engineers, plumbers, welders, scaffold workers, and field men showed samples that exceeded either TWA-OEL or STEL-OEL ( $p < 0.001$ ). Mechanical engineers, plumbers, and field men were the three groups with the highest exposure. The rate of the samples exceeding the benzene OELs in tasks such as dismantling, changing, and assembling various bolts, valves, and pipes was the highest at 33.3%.

This study examined the risk of exposure to the carcinogen benzene during TAs in petrochemical complexes and focused on evaluating the working conditions during TAs. The study results are expected to be used in reducing the occupational diseases of workers, establishing industrial hygiene policies and improving the effectiveness of institutions related with TAs in the petrochemical industry.

## Acknowledgments

This research project would not have been possible without the support of many people. Thanks to all those who cooperated and participated in this research, including the officials of petrochemical companies in Yeosu National Industrial Complex and plant construction workers of the Trade Unions in Yeosu, and industrial hygienists of working environment measurement agencies. Funding for this study was provided through KOSHA. In addition, We would like to thank Director General Kang, Director Lee, Professor Kim, and Professor Choi who was abundantly helpful and offered invaluable assistance, support and guidance.

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