Occupational exposure to PCDD/PCDF from industrial boilers at a whisky factory and vegetable oil factory in Samutsakorn Province, Thailand

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Abstract

It is well known that polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) are carcinogens and mutagens, which are mainly released from industrial sectors. Fossil fuel fired utilities and industrial boilers are considered as two main sources responsible for the emissions of dioxins. As a consequence, the regional project "Demonstration of BAT and BEP in the Fossil Fuel-fired Utilities and Industrial Boilers in response to the Stockholm Convention on POPs", officially approved for full implementation by the Global Environmental Facility (GEF) in April 2010 in order to investigate the emissions of dioxins from various types of industrial sectors in ESEA (East and South East Asia) countries. This study aims to quantify the emissions of dioxins from industrial boilers at a whisky factory and vegetable oil factory in Samutsakorn Province, Thailand.
Keywords: PCDD/PCDF, mercury, dioxins, industrial boilers.

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1 Introduction

Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) are ubiquitous environmental pollutants and classified as persistent organic pollutants (POPs) that are mostly of industrial origin. These compounds are generally acknowledged as dioxin-like compounds, or more basically 'dioxins.' Once dioxins released into the atmosphere as air pollutants, it can be directly transmitted to human body through inhalation and distributed across various environmental media such as marine, riverine and lake sediments, terrestrial soils, vegetation, water, biota, etc. Therefore, all human tissues have had measurable levels of dioxin congeners as detected by the most accurate methods. Tetrachlorodibenzo-p-dioxin (TCDD), the most toxic dioxin has an estimated half-life of 7–11 years in humans. Recent studies reveal the adverse health effects of dioxins which responsible for an enhancement in cancers, liver damage, endocrine disruption, neurotoxicity, reproductive disorders and various immune system alterations. According to our best knowledge, there is no known method to reduce an elevated dioxin human body burden. International publications of dioxin emission levels and its adverse health impacts are few in number and strictly limited to certain countries. The majority of studies have been focused in the US [1, 2], Denmark [3, 4], UK [5, 6], Italy [7, 8], Japan [9, 10] and China [11, 12] and other geographical regions. As a part of UNIDO (United Nation Industrial Development Organization)'s primary objective, which believes that competitive and environmentally sustainable industry has a crucial role to play in accelerating economic growth, reducing poverty and achieving the Millennium Development Goals, several attempts have been made in order to reduce dioxins' emissions from fossil fuel-fired utilities and industrial boilers particularly in developing countries.

With reference to the Stockholm Convention, the ESEA (East and South East Asia) countries are committed to reduce/eliminate UP-POPs emission releases. Formally launched on October 5, 2007, the ESEA Forum is a programmatic regional initiative of UNIDO on the introduction of the BAT/BEP measures on priority sectors defined by participating countries. The main objective of the Forum is to serve as a platform for information dissemination and exchange of experiences between countries in the region on different aspects of implementation of BAT/BEP and provide regular reporting on the impact of these in the industrial sectors cited in Annex C of the Convention. Countries have been grouped based on their priority sectors of interest, as mentioned in annex C of article 5 of the Stockholm Convention.

The regional project "Demonstration of BAT and BEP in the Fossil fuel-fired Utilities and Industrial Boilers in response to the Stockholm Convention on POPs", officially approved for full implementation by the Global Environmental Facility (GEF) in April 2010, is the first integral sectoral project of the ESEA BAT/BEP FORUM. In accordance with the relevant resolutions of the third session of the Conference of the Parties (COP3) of the Stockholm Convention (SC), the overall objective of the regional project aims at reducing and, where feasible, eliminating unintentionally produced POPs (UP-POPs) releases (in particular, PCDDs – polychlorinated-dibenzo-para-dioxins and PCDFs-polychlorinated-dibenzofurans) by enhancing guidelines and guidance on best available techniques and best environmental practices (BAT/BEP) for fossil fuel-fired utilities and industrial boilers through addressing specific features of industry, common practices in the region and related socio-economic considerations. In addition, the project also targets the identification of possible options for the simultaneous reduction of PCDD/PCDFs and CO_2 from fossil fuel-fired utilities and industrial boilers in response to the Stockholm Convention and climate change requirements. While it focuses on the introduction of BAT/BEP measures, it also considers increasing energy efficiency, as required in Annex C Part V B (a)(iv) of the convention. The evaluation of the mercury emissions by specific monitoring programs has been added afterwards according to the raising concerns on these pollutants.

In particular, in Thailand two boilers in a whisky factory and vegetable oil factory have been selected as potential pilot facilities to implement the above indicated project activities. Industrial boiler selection criteria and BAT/BEP implementation program were discussed with company managers. It was agreed that the activities for BAT/BEP implementation will mainly focus on boiler modifications and efficiency improvement, as mean to simultaneously reduce the emissions of PCDD/PCDFs, mercury and CO_2. Sampling campaigns were carried out before the implementation of the related interventions in order to measure the background of pollutant releases.

2 Methodology

2.1 Dioxin

Undertake sampling and chemical determination of PCDD/PCDFs in the flue gases emitted by the stack of the boiler in the two factories and in samples of ashes released by the multicyclone and in samples of bottom ashes of the burning chamber

Solid residues were collected as follows:

- 1 sample representing 3 mixture samples taken from ashes of the multicyclone (morning, midday, and at the end of the sampling day).
- 1 sample representing 3 mixture samples taken from bottom ashes of the burning chamber.

Flue gas samples were collected as follows:

- 3 samples at the stack (one per day).

For the sampling of flue gases, the USEPA Method 23/23A, European Method EN 1948-1 were applied. For PCDDs/PCDFs analysis, the USEPA Method 1613B, USEPA Method 8290 or European Method EN 1948 2-3 were applied. All chemical analyses were conducted at SGS laboratories.

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2.2 Trace gaseous species

During the sampling activity at the stacks, the relevant operational parameters in the sampled flue gases needed for normalization of data were measured and registered by manual methods or portable detectors. The parameters requested are:

- Temperature, pressure, gas velocity, gas flow rate, oxygen, H_2O content (humidity), CO and CO_2, SO_x, NO_x by portable detectors

Table 1: Boiler information at the whisky factory, Samutsakorn, Thailand.

Information	Unit	Detail
Stack		
1.Height	m	~22
2.Diameter	m	0.8
Boiler		
1.Fuel used	-	Fuel Oil
2.Fuel feeding rate	liters/hr.	- 329.5 (Date 15/08/2012) - 398.3 (Date 16/08/2012) - 385.4 (Date 17/08/2012)
3.Production rate of Ash	Kg/day.	- Fly ashes 8 kg/d - Bottom ashes 3 kg/d

Table 2: Boiler information at the vegetable oil factory, Samutsakorn, Thailand.

Information	Unit	Detail
Stack		
1.Height	m	~25
2.Diameter	m	0.64
Boiler		
1.Fuel used	-	Coal
2.Fuel feeding rate	Kg/hr.	1,601.3
3.Capacity of boiler	Ton	16
4.Production rate of Ash	g/hr.	77

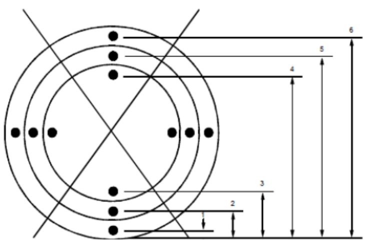
2.3 Quality control and quality assurance (QA/QC)

All SGS environmental laboratories have ISO 17025 accreditations and demonstrate the effectiveness to properly execute testing methods practices, inspection routines, data validation and employee competences. ISO 17025 is an

Table 3: Location of transverse point in circular stacks.

Traverse Point Number	(Fraction of Stacks Diameter from Inside Wall to Traverse Point)					
	Number of Traverse Point on a Diameter					
	2	4	6	8	10	12
1	.146	.674	.044	.032	.026	.021
2	.854	.250	.146	.105	.082	.067
3		.750	.296	.194	.146	.118
4		.933	.704	.323	.226	.177
5			.854	.677	.342	.250
6			.956	.806	.658	.356
7				.895	.774	.644
8				.968	.854	.750
9					.918	.823
10					.974	.882
11						.933
12						.979

TRAVERSE POINT	DISTANCE % of diameter
1	4.4
2	14.7
3	29.5
4	70.5
5	85.3
6	95.6



international standard, which sets the general requirements for the competence of testing and calibration laboratories. In addition, QA/QC for emission air measurements are as follows:

- The isokinetic rate must be conducted and the result must be between 90 and 110%.
- Conduct sampling equipment leak check and equipment calibration.
- Conduct sample control using Chain of custody (COC) form for the sample delivery and controlling to laboratory.
- Conduct field blank to check about any contamination.

3 Results

3.1 Vegetable oil factory

The emission air quality of stack was monitored during July 31 and August 3, 2012, at the beginning and at the end of the PCDD/PCDF sampling and calculated at the temperature of 0°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, temperature of 25°C, 11% oxygen pressure of 1 atm

Table 4: Flow chart of dioxins analysis.

Item	Activities	Scope of Work
1.	Prepare equipments	1.1 Prepare equipments, filters and sorbent resin.
2.	Preliminary Field Determinations (0.5 hr.)	2.1 Select the sampling site and the minimum number of sampling points according to USEPA Method 1 2.2 Determine the stack pressure, temperature, the range of velocity heads and moisture content 2.3 Select a nozzle size based on the range of velocity heads. 2.4 Select a suitable probe liner and probe length (0.5 hr)
3.	Sampling Train Preparation (0.5 hr.)	3.1 Clean and set up the train
4.	Sampling and Leak Check Procedures (0.5 hr.)	4.1 Pretest Leak-Check 4.2 During the sampling run, maintain an isokinetic sampling rate and a temperature around the probe of 120+14 °C and the filter of 120 ± 14°C. 4.3 Post-Test Leak-Check
5.	Sample Recovery (6 hrs.)	5.1 Seal the nozzle end of the sampling probe with Teflon tape or aluminum foil. 6.2 Carefully remove the filter from the filter holder and transfer to the container any particulate matter and filter fibers which adhere to the filter holder gasket, seal the container. 5.3 Remove the adsorbent module from the train, tightly cap both ends, label it, and cover with aluminum foil. 5.4 Quantitatively recover material deposited in the nozzle, probe transfer lines, and the front half of the filter holder, by brushing while rinsing three times each with acetone then collect all the rinses in container. 5.5 Measure the liquid record the volume or weight of liquid present to calculate the moisture content of the effluent gas. 5.6 Note the color of the indicating silica gel and make a notation of its condition.
6.	Analysis	6.1 Sending to SGS Laboratory for analysis.

or 760 mm.Hg., dry basis and the temperature of 20°C, 7% oxygen pressure of 1 atm or 760 mm.Hg., dry basis.

- At the temperature of 0°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, the total suspended particulate (TSP), SO_2, NO_x (as NO_2) and CO was calculated. TSP ranged from 165–463 mg/m^3, SO_2 was 127–328 mg/m^3, NO_x was 95–251 mg/m^3 and CO was 1,241–2,759 mg/m^3. The dioxins and furans (TEQ) were 0.0038–0.0089 ng l-TEQ/m^3. For stack condition measurement, the percent of O_2 was 14.73–16.08% (see Table 5).

Figure 1: Emission air sampling of stacks at the whisky factory at Samutprakarn Province, Thailand.

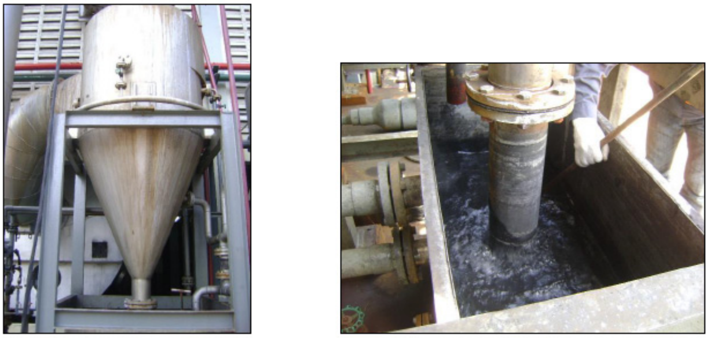


Figure 2: Ash sampling with wet cyclone at the whisky factory, Samutprakarn Province, Thailand.

Figure 3: Emission air sampling of stacks at the vegetable oil factory at Samutprakarn Province, Thailand.

Table 5: Dioxin emissions from stacks at a vegetable oil factory at the temperature of 0°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis.

Parameters	TEF	Sampling date								
		31/07/12			01/08/12			02/08/12		
		ng/Nm^3	at actual O_2 (0°C) (ng I-TEQ/Nm^3)	at 0°C and 11% O_2 (ng I-TEQ /Nm^3)	ng/Nm^3	at actual O_2 (0°C) (ng I-TEQ/Nm^3)	at 0°C and 11% O_2 (ng I-TEQ /Nm^3)	ng/Nm^3	at actual O_2 (0°C) (ng I-TEQ/Nm^3)	at 0°C and 11% O_2 (ng I-TEQ /Nm^3)
Determination of PCDD/PCDFs **1.3 Total I-TEQ**										
1) 2,3,7,-8TCDD	1	0.0007	0.0007	0.0011	0.0010	0.0010	0.0018	0.0005	0.0005	0.0010
2) 1,2,3,7,8-PeCDD	0.5	0.0024	0.0012	0.0019	0.0022	0.0011	0.0020	0.0021	0.0010	0.0021
3) 1,2,3,4,7,8-HxCDD	0.1	0.0018	0.0002	0.0003	0.0015	0.0001	0.0003	0.0012	0.0001	0.0003
4) 1,2,3,6,7,8-HxCDD	0.1	0.0031	0.0003	0.0005	0.0034	0.0003	0.0006	0.0033	0.0003	0.0007
5) 1,2,3,7,8,9-HxCDD	0.1	0.0044	0.0004	0.0007	0.0036	0.0004	0.0007	0.0041	0.0004	0.0008
6) 1,2,3,4,6,7,8-HpCDD	0.01	0.0131	0.0001	0.0002	0.0088	0.0001	0.0002	0.0093	0.0001	0.0002
7) OCDD	0.001	0.0181	0.00002	0.00003	<0.0175	<0.00002	<0.00003	<0.0178	<0.00002	<0.00004
8) 2,3,7,8-TCDF	0.1	0.0010	0.0001	0.0002	0.0047	0.0005	0.0009	0.0049	0.0005	0.0010
9) 1,2,3,7,8-PeCDF	0.05	0.0013	0.0001	0.0001	0.0019	0.0001	0.0002	0.0013	0.0001	0.0001
10) 2,3,4,7,8-PeCDF	0.5	0.0009	0.0005	0.0007	0.0012	0.0006	0.0011	0.0018	0.0009	0.0018
11) 1,2,3,4,7,8-HxCDF	0.1	0.0014	0.0001	0.0002	0.0016	0.0002	0.0003	0.0018	0.0002	0.0004
12) 1,2,3,6,7,8-HxCDF	0.1	<0.0009	<0.00009	<0.00014	0.0011	0.0001	0.0002	0.0016	0.0002	0.0003
13) 2,3,4,6,7,8-HxCDF	0.1	<0.0009	<0.00009	<0.00014	<0.0008	<0.00009	<0.0002	<0.0009	<0.00009	<0.0002
14) 1,2,3,7,8,9-HxCDF	0.1	<0.0009	<0.00009	<0.00014	<0.0008	<0.00009	<0.0002	<0.0009	<0.00009	<0.0002
15) 1,2,3,4,6,7,8-HpCDF	0.01	0.0042	0.00004	0.0001	0.0050	0.00005	0.0001	0.0048	0.00005	0.0001
16) 1,2,3,4,7,8,9-HpCDF	0.01	<0.0035	<0.00003	<0.00006	<0.0034	<0.00003	<0.0001	<0.0034	<0.00003	<0.0001
17) OCDF	0.001	<0.0181	<0.00002	<0.00003	<0.0175	<0.00002	<0.00003	<0.0178	<0.00002	<0.00004
PCDD/PCDFs-TEQ			**0.0038**	**0.0060**		**0.0045**	**0.0083**		**0.0043**	**0.0089**

Remarks : - Nm^3 = Normal cubic meter for gas condition means at temperature of 0 °C, pressure of 1 atm and dry basis. (European Union)
- I-TEQ (International Toxicity Equivalence) = the value is calculated by using the toxicity equivalence factors (TEF).
1/ Polychlorinated Dibenzo-p-Dioxins
2/ Polychlorinated Dibenzofurans

- At the temperature of 25°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, the total suspended particulate (TSP), SO_2, NOx (as NO_2) and CO was calculated. TSP ranged from 154–424 mg/Nm^3, SO_2 was 116–300 mg/Nm^3, NOx was 87–230 mg/m^3 and CO was 1,137–2,527 mg/m^3. The dioxins and furans (TEQ) were 0.0034–0.0081 ng l-TEQ/m^3. For stack condition measurement, the percent of O2 was 14.73–16.08% (see Table 6).
- At the temperature of 20°C, 7% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, the total suspended particulate (TSP), SO_2, NOx (as NO_2) and CO was calculated. TSP ranged from 153–605 mg/m^3, SO_2 was 118–428 mg/Nm^3, NOx was 88–328 mg/m^3 and CO was 1,156–3609 mg/m^3. The dioxins and furans (TEQ) were 0.0040–0.0116 ng l-TEQ/m^3. For stack condition measurement, the percent of O2 was 14.73–16.08%.
- Soil residues and ashes from the multicyclone and bottom ashes from the burning chamber. The soil residues of stack were monitored during July 31–August 3, 2012. TEQ of dioxins and furans in ashes of the multicyclone ranged from 0.0024 (OCDF) to 11 (TCDDs) ng l-TEQ/kg. On the other hand, the result of dioxins and furans (TEQ) in bottom ashes of the burning chamber show the minimum value at 0.0024 ng l-TEQ/kg and the maximum value at 29 for OCDF and TCDDs respectively.

3.2 Whisky factory

The emission air quality of stack were monitored during August 15–17, 2012, at the beginning and at the end of the PCDD/PCDF sampling and calculated at the temperature of 0°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, temperature of 25°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis and the temperature of 20°C, 7% oxygen pressure of 1 atm or 760 mm.Hg., dry basis.

- At the temperature of 0°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, the total suspended particulate (TSP), SO_2, NOx (as NO_2) and CO was calculated. TSP ranged from 52–159 mg/m^3, SO_2 is 310–1,022 mg/m^3, NOx was 217–332 mg/m^3 and CO was 1.3–3.8 mg/m^3. The dioxins and furans (TEQ) were 0.0010–0.0142 ng l-TEQ/m^3. For stack condition measurement, the percent of O_2 was 13.40–15.52% (see Table 7).
- At the temperature of 25°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, the total suspended particulate (TSP), SO2, NOx (as NO2) and CO was calculated. TSP ranged from 48–146 mg/Nm_3, SO_2 was 284–936 mg/Nm_3, NOx was 199–304 mg/m^3 and CO is 1.1–3.5 mg/m^3. The dioxins and furans (TEQ) were 0.0009–0.0130 ng l-TEQ/m^3. For stack condition measurement, the percent of O_2 was 13.77–15.49% (see Table 8).
- At the temperature of 20°C, 7% oxygen pressure of 1 atm or 760 mm.Hg., dry basis, the total suspended particulate (TSP), SO2, NOx (as NO_2) and CO was calculated. TSP ranged from 49–208 mg/m^3, SO_2 is 289–1,337 mg/Nm3, NOx was 202–435 mg/m^3 and CO was 1.2–5.0 mg/m^3. The dioxins and furans (TEQ) were 0.0009–0.0186 ng l-TEQ/m^3. For stack condition measurement, the percent of O_2 was 13.77–14.41%.

Table 6: Dioxin emissions from stacks at a vegetable oil factory at the temperature of 25°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis.

Parameters	TEF	Sampling date								
		31/07/12			01/08/12			02/08/12		
		ng/Nm^3	at actual O_2 (25°C) ($ng\ I\text{-}TEQ/Rm^3$)	at 25°C and 11% O_2 ($ng\ I\text{-}TEQ/Rm^3$)	ng/Nm^3	at actual O_2 (25°C) ($ng\ I\text{-}TEQ/Rm^3$)	at 25°C and 11% O_2 ($ng\ I\text{-}TEQ/Rm^3$)	ng/Nm^3	at actual O_2 (25°C) ($ng\ I\text{-}TEQ/Rm^3$)	at 25°C and 11% O_2 ($ng\ I\text{-}TEQ/Rm^3$)
Determination of PCDD/PCDFs **1.3 Total I-TEQ**										
1) 2,3,7,-8TCDD	1	0.0006	0.0006	0.0010	0.0009	0.0009	0.0016	0.0005	0.0005	0.0010
2) 1,2,3,7,8-PeCDD	0.5	0.0022	0.0011	0.0017	0.0020	0.0010	0.0018	0.0019	0.0009	0.0019
3) 1,2,3,4,7,8-HxCDD	0.1	0.0017	0.0002	0.0003	0.0014	0.0001	0.0002	0.0011	0.0001	0.0002
4) 1,2,3,6,7,8-HxCDD	0.1	0.0028	0.0003	0.0004	0.0031	0.0003	0.0006	0.0030	0.0003	0.0006
5) 1,2,3,7,8,9-HxCDD	0.1	0.0041	0.0004	0.0007	0.0033	0.0003	0.0006	0.0038	0.0004	0.0008
6) 1,2,3,4,6,7,8-HpCDD	0.01	0.0120	0.0001	0.0002	0.0080	0.0001	0.0001	0.0085	0.0001	0.0002
7) OCDD	0.001	0.0165	0.00002	0.00003	<0.0161	<0.00002	<0.00003	<0.0163	<0.00002	<0.00003
8) 2,3,7,8-TCDF	0.1	0.0009	0.0001	0.0001	0.0043	0.0004	0.0008	0.0045	0.0005	0.0009
9) 1,2,3,7,8-PeCDF	0.05	0.0012	0.0001	0.0001	0.0017	0.0001	0.0002	0.0012	0.0001	0.0001
10) 2,3,4,7,8-PeCDF	0.5	0.0008	0.0004	0.0007	0.0011	0.0005	0.0010	0.0016	0.0008	0.0017
11) 1,2,3,4,7,8-HxCDF	0.1	0.0013	0.0001	0.0002	0.0015	0.0001	0.0003	0.0016	0.0002	0.0003
12) 1,2,3,6,7,8-HxCDF	0.1	<0.0008	<0.0008	<0.0001	0.0010	0.0001	0.0002	0.0015	0.0002	0.0003
13) 2,3,4,6,7,8-HxCDF	0.1	<0.0008	<0.0008	<0.0001	<0.0008	<0.00008	<0.0001	<0.0008	<0.00008	<0.0002
14) 1,2,3,7,8,9-HxCDF	0.1	<0.0008	<0.0008	<0.0001	<0.0008	<0.00008	<0.0001	<0.0008	<0.00008	<0.0002
15) 1,2,3,4,6,7,8-HpCDF	0.01	0.0038	0.00004	0.0001	0.0046	0.00005	0.0001	0.0044	0.00004	0.0001
16) 1,2,3,4,7,8,9-HpCDF	0.01	<0.0032	<0.00003	<0.00005	<0.0031	<0.00003	<0.0001	<0.0031	<0.00003	<0.0001
17) OCDF	0.001	<0.0165	<0.00002	<0.00003	<0.0161	<0.00002	<0.00003	<0.0163	<0.00002	<0.00003
PCDD/PCDFs-TEQ			**0.0034**	**0.0055**		**0.0041**	**0.0075**		**0.0040**	**0.0081**

Remarks : - Rm^3 = Reference cubic meter for gas condition means at temperature of 25 °C, pressure of 1 atm and dry basis. (Canada Region)
- I-TEQ (International Toxicity Equivalence) = the value is calculated by using the toxicity equivalence factors (TEF).
1/ Polychlorinated Dibenzo-p-Dioxins
2/ Polychlorinated Dibenzofurans

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Table 7: Dioxin emissions from stacks at a whisky factory at the temperature of 0°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis.

Parameters	TEF	Sampling date								
		15/08/12			16/08/12			17/08/12		
		ng/Nm³	at actual O_2 (0°C) (ng I-TEQ/Nm³)	at 0°C and 11% O_2 (ng I-TEQ /Nm³)	ng/Nm³	at actual O_2 (0°C) (ng I-TEQ/Nm³)	at 0°C and 11% O_2 (ng I-TEQ /Nm³)	ng/Nm³	at actual O_2 (0°C) (ng I-TEQ/Nm³)	at 0°C and 11% O_2 (ng I-TEQ /Nm³)
Determination of PCDD/PCDFs 1.3 Total I-TEQ										
1) 2,3,7,-8TCDD	1	<0.0004	<0.0004	<0.0007	<0.0005	<0.0005	<0.0007	<0.0005	<0.0005	<0.0007
2) 1,2,3,7,8-PeCDD	0.5	<0.0009	<0.0004	<0.0007	<0.0010	<0.0005	<0.0007	<0.0010	<0.0005	<0.0007
3) 1,2,3,4,7,8-HxCDD	0.1	<0.0011	<0.0001	<0.0002	<0.0013	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002
4) 1,2,3,6,7,8-HxCDD	0.1	<0.0011	<0.0001	<0.0002	<0.0013	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002
5) 1,2,3,7,8,9-HxCDD	0.1	<0.0011	<0.0001	<0.0002	<0.0013	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002
6) 1,2,3,4,6,7,8-HpCDD	0.01	<0.0044	<0.00004	<0.0001	<0.0013	<0.00005	<0.0001	0.0085	0.0001	0.0001
7) OCDD	0.001	<0.0230	<0.00002	<0.00004	<0.026	<0.00003	<0.00004	<0.0257	<0.00003	<0.00004
8) 2,3,7,8-TCDF	0.1	0.0015	0.0001	0.0002	0.0028	0.0003	0.0004	0.0032	0.0003	0.0004
9) 1,2,3,7,8-PeCDF	0.05	<0.0009	<0.00004	<0.0001	0.0024	0.0001	0.0002	0.0032	0.0002	0.0002
10) 2,3,4,7,8-PeCDF	0.5	0.0010	0.0005	0.0007	0.0028	0.0014	0.0019	0.0038	0.0019	0.0026
11) 1,2,3,4,7,8-HxCDF	0.1	0.0012	0.0001	0.0002	0.0020	0.0002	0.0003	0.0197	0.0020	0.0028
12) 1,2,3,6,7,8-HxCDF	0.1	<0.0011	<0.0001	<0.0002	0.0019	0.0002	0.0003	0.0178	0.0018	0.0025
13) 2,3,4,6,7,8-HxCDF	0.1	<0.0011	<0.0001	<0.0002	0.0014	0.0001	0.0002	0.0097	0.0010	0.0014
14) 1,2,3,7,8,9-HxCDF	0.1	<0.0011	<0.0001	<0.0002	<0.0013	<0.0001	<0.0002	0.0032	0.0003	0.0004
15) 1,2,3,4,6,7,8-HpCDF	0.01	0.0110	0.0001	0.0002	0.0126	0.0001	0.0002	0.1717	0.0017	0.0024
16) 1,2,3,4,7,8,9-HpCDF	0.01	0.0051	0.0001	0.0001	0.0070	0.0001	0.0001	0.0553	0.0006	0.0008
17) OCDF	0.001	0.0530	0.0001	0.0001	0.0539	0.0001	0.0001	0.3750	0.0004	0.0005
PCDD/PCDFs-TEQ			0.0010	0.0015		0.0026	0.0036		0.0101	0.0142

Remarks :
- Nm³ = Normal cubic meter for gas condition means at temperature of 0 °C, pressure of 1 atm and dry basis. (European Union)
- I-TEQ (International Toxicity Equivalence) = the value is calculated by using the toxicity equivalence factors (TEF).

1/ Polychlorinated Dibenzo-p-Dioxins

2/ Polychlorinated Dibenzofurans

Table 8: Dioxin emissions from stacks at a whisky factory at the temperature of 25°C, 11% oxygen pressure of 1 atm or 760 mm.Hg., dry basis.

Parameters	TEF	Sampling date								
		15/08/12			16/08/12			17/08/12		
		ng/Nm^3	at actual O_2 (25°C) ($ng\ I\text{-}TEQ/Rm^3$)	at 25°C and 11% O_2 ($ng\ I\text{-}TEQ/Rm^3$)	ng/Nm^3	at actual O_2 (25°C) ($ng\ I\text{-}TEQ/Rm^3$)	at 25°C and 11% O_2 ($ng\ I\text{-}TEQ/Rm^3$)	ng/Nm^3	at actual O_2 (25°C) ($ng\ I\text{-}TEQ/Rm^3$)	at 25°C and 11% O_2 ($ng\ I\text{-}TEQ/Rm^3$)
Determination of PCDD/PCDFs **1.3 Total I-TEQ**										
1) 2,3,7,-8TCDD	1	<0.0004	<0.0004	<0.0006	<0.0005	<0.0005	<0.0006	<0.0005	<0.0005	<0.0006
2) 1,2,3,7,8-PeCDD	0.5	<0.0008	<0.0004	<0.0006	<0.0009	<0.0005	<0.0006	<0.0009	<0.0005	<0.0006
3) 1,2,3,4,7,8-HxCDD	0.1	<0.0010	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002	<0.0011	<0.0001	<0.0002
4) 1,2,3,6,7,8-HxCDD	0.1	<0.0010	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002	<0.0011	<0.0001	<0.0002
5) 1,2,3,7,8,9-HxCDD	0.1	<0.0010	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002	<0.0011	<0.0001	<0.0002
6) 1,2,3,4,6,7,8-HpCDD	0.01	<0.0040	<0.00004	<0.0001	<0.0046	<0.00005	<0.0001	0.0078	0.0001	0.0001
7) OCDD	0.001	<0.0211	<0.00002	<0.00003	<0.0238	<0.00002	<0.00003	<0.0235	<0.00002	<0.00003
8) 2,3,7,8-TCDF	0.1	0.0014	0.0001	0.0002	0.0026	0.0003	0.0004	0.0029	0.0003	0.0004
9) 1,2,3,7,8-PeCDF	0.05	<0.0008	<0.00004	<0.0001	0.0022	0.0001	0.0002	0.0029	0.0001	0.0002
10) 2,3,4,7,8-PeCDF	0.5	0.0009	0.0004	0.0007	0.0026	0.0013	0.0018	0.0034	0.0017	0.0024
11) 1,2,3,4,7,8-HxCDF	0.1	0.0011	0.0001	0.0002	0.0018	0.0002	0.0003	0.0181	0.0018	0.0025
12) 1,2,3,6,7,8-HxCDF	0.1	<0.0010	<0.0001	<0.0002	0.0017	0.0002	0.0002	0.0163	0.0016	0.0023
13) 2,3,4,6,7,8-HxCDF	0.1	<0.0010	<0.0001	<0.0002	0.0013	0.0001	0.0002	0.0089	0.0009	0.0012
14) 1,2,3,7,8,9-HxCDF	0.1	<0.0010	<0.0001	<0.0002	<0.0012	<0.0001	<0.0002	0.0029	0.0003	0.0004
15) 1,2,3,4,6,7,8-HpCDF	0.01	0.0100	0.0001	0.0002	0.0115	0.0001	0.0002	0.1573	0.0016	0.0022
16) 1,2,3,4,7,8,9-HpCDF	0.01	0.0047	0.00005	0.0001	0.0064	0.0001	0.0002	0.0506	0.0005	0.0007
17) OCDF	0.001	0.0486	0.00005	0.0001	0.0494	0.00005	0.0001	0.3436	0.0003	0.0005
PCDD/PCDFs-TEQ			**0.0009**	**0.0013**		**0.0038**	**0.0053**		**0.0093**	**0.0130**

Remarks :
- Rm^3 = Reference cubic meter for gas condition means at temperature of 25 °C, pressure of 1 atm and dry basis. (Canada Region)
- I-TEQ (International Toxicity Equivalence) = the value is calculated by using the toxicity equivalence factors (TEF).

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- Soil residues and ashes from the multicyclone and bottom ashes from the burning chamber. The soil residues of stack were monitored during August 15–17, 2012. TEQ of dioxins and furans in ashes of the multicyclone ranged from 0.0025 (OCDF) to 2.5 (OCDD) ng l-TEQ/kg.

4 Discussion

To assess the health risks associated with the occupational exposure to PM_{10}, organic and elemental carbon of outdoor workers, the incremental lifetime particulate matter exposure (*ILPE*) model was employed and defined as,

$$ILPE = C \times IR \times t \times EF \times ED \tag{1}$$

ILPE = Incremental lifetime particulate matter exposure (pg);
C = PCDD/PCDF concentrations (pg m^{-3});
IR = Inhalation rate (m^3 h^{-1});
t = Daily exposure time span (6 h d^{-1}, for two shifts);
EF = Exposure frequency (250 d $year^{-1}$ [a], upper-bound value);
ED = Exposure duration (25 years [a], upper-bound value);
Note: [a]Adapted from Human Health Evaluation Manual (US EPA, 1991).

According to the methods for derivation of inhalation dosimetry (US EPA, 1994), the inhalation rate of male and female outdoor workers were estimated as 0.89 and 0.49 m^3 h^{-1} respectively. The *ILPE* model was adapted from the probabilistic incremental lifetime cancer risk (*ILCR*) model, which was used to assess traffic policemen exposure to PAHs during their work time in China (Hu *et al.*, [13]). The average values of predicted *ILPE* of total dioxin (i.e. sum of TCDDs, PeCDDs, HxCDDs, OCDD, TCDFs, PeCDFs, HxCDFs, HpCDFs, OCDF) at a whisky factory (Red Bull) were 24.4 ± 17.3 pg and 13.5 ± 9.54 pg for male and female workers over exposure duration of 25 years respectively. Similarly, the average values of estimated *ILPE* of total dioxin observed at vegetable oil factory (Oleen) were 25.0 ± 5.03 pg and 13.8 ± 2.77 pg for male and female workers over exposure duration of 25 years respectively.

5 Conclusion

Emissions of dioxins from stacks of two boilers were investigated at a whisky factory and vegetable oil factory in Samutsakorn Province, Thailand. In the case of the vegetable oil factory, the dioxins and furans (TEQ) were 0.0038–0.0089 ng l-TEQ/m^3. For stack condition measurement, the percent of O_2 was 14.73–16.08%. In the case of the whisky factory, the dioxins and furans (TEQ) were 0.0010–0.0142 ng l-TEQ/m^3. For stack condition measurement, the percent of O_2 was 13.40–15.52%. Despite there being different types of fuels, boilers, burners and operational conditions, the estimated ILPE values of total dioxin of both factories are surprisingly similar to each other.

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