

Environmental Performance Test of Hazardous Waste Incinerator in Indonesia

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Abstract

One of the effective ways to reduce industrial hazardous and toxic wastes is to burn them in the incinerator. Advantages of hazardous and toxic waste incineration cause incinerator business in Indonesian to evolve. Besides, it is triggered by the availability of supporting regulations, such as the Regulation of the State Minister of Environment [1] that allows business people to have licenses to treat hazardous and toxic waste through incinerator. However, the operation of the hazardous and toxic waste incinerator must meet the performance test as regulated by the Government of Indonesia [2], such as destruction removal efficiency (DRE) of principal organic hazardous constituents (POHCs), combustion efficiency, gas residence time, concentration of emitted particulates and heavy metals, HCl and other gaseous pollutants. This paper presents the procedures and results of a case study of the trial burn test (TBT) conducted for the hazardous waste rotary kiln incinerator typically done in Indonesia.

Keywords: Incinerator, Hazardous and toxic wastes, Performance test or trial burn test, Destruction Removal Efficiency (DRE), Principal Organic Hazardous Constituents (POHC)

1 Introduction

The number and varieties of hazardous and toxic wastes in Indonesia tend to increase in line with increasing development of industries. The generated hazardous and toxic wastes will degrade the environment and then affect other sectors of activities, such as tourism, economy, social and health.

Hazardous and toxic waste disposal that has so far been its primary alternative treatment in Indonesia is starting to diminish due to the land scarcity. Incineration now becomes an attractively alternative treatment to disposal method due to some advantages owned by the incinerators [3]. Therefore, they attract many hazardous waste oriented business people in Indonesia asking a permit to the Ministry of Environment and Forestry.

Incineration destroys organic compounds contained in hazardous wastes and reduces the volume of the

wastes by removing liquids. To achieve those goals, the incinerator must be able to provide controlled burning (combustion) conditions that ensure the proper mixing of air, temperature, and gas, and adequate time to allow a thorough destruction of organic constituents to take place [4], [5].

Incineration has two unique attributes. First, it permanently destroys toxic organic compounds contained in hazardous waste by breaking their chemical bonds and by converting them to their constituent elements, thereby reducing or removing their toxicity. Second, it reduces the volume of hazardous waste by converting solids and liquids to ash. [3], [4]

Regulation of the State Minister of Environment Number 18 Year 2009 [1] obligates operator of hazardous and toxic waste incineration facilities to do the performance test to have an operational permit of the incinerator. Then, the Decree of Head of Environmental

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Impact Management Agency Number 3 Year 1995 requires a permit operator to meet the standard values of his/her incinerator's performance test parameters [2]. Demonstration to show the environmental performance of the incinerator is known as trial burn test [1], [4]–[6].

Before the trial burn is executed, the waste operator has to analyse the planned hazardous wastes burned and determine chemical composition and concentration according to Appendix I of Government Regulation Number 101 Year 2014 [7]. From this analysis the operator might be able to determine principal organic hazardous constituents (POHCs) and other parameters in the wastes [3]–[6]. These POHCs are usually the constituents in the wastes (real material) or a surrogate of comparable heat content, chlorine content, and content of designated POHCs. The selection of the POHCs to use in the testing program is critical [8].

During performance test, all emission parameters mentioned above will be measured through standard sampling and analysis protocols. They must meet related standard values of emission parameters in order to get the permit [1], [2].

2 Statement of the Trial Burn Test

For incineration to be an effective method for destroying the hazardous wastes, combustion must be complete. Three critical factors ensure the completeness of combustion in an incinerator [5]:

1. The temperature in the combustion chamber.
2. The length of time when wastes are maintained at high temperatures.
3. The turbulence or degree of mixing of the wastes and the air.

The goal of trial burn test (TBT) for hazardous waste incinerators is to ensure compliance with the performance standards (i.e., for organics (DRE), HCl, PM and CE). An incinerator permit specifies operating conditions that have been shown in a trial burn to result in the incinerator meeting these performance standards.

Permit for a hazardous waste incinerator sets operating conditions that specify allowable ranges for certain critical parameters. Operation within these parameters ensures that combustion is performed in the most protective manner and the performance standards are achieved. These parameters, or operating conditions, include [4]:

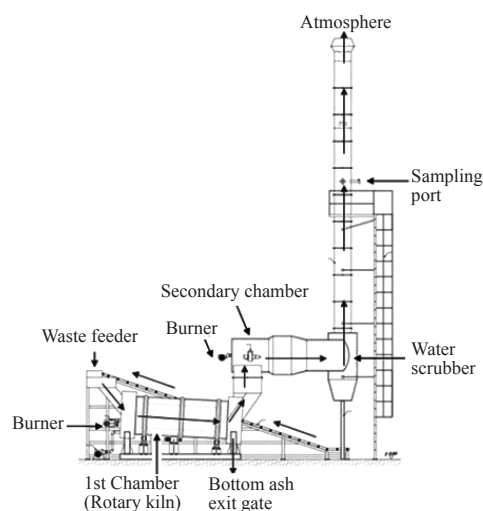


Figure 1: Process Flow of PTWI rotary kiln incinerator.

1. Maximum allowable carbon monoxide levels in stack emissions or combustion efficiency.
2. Allowable ranges for temperature.
3. Maximum waste feed rates.
4. Combustion gas velocity.
5. Limits on variations of system design and operating procedures.

2.1 Incinerator unit used

A rotary kiln type incinerator was chosen as the basis for the TBT study. The capacity of the incinerator is 600 kg of hazardous waste sludge per hour. The schematic diagram of the system is shown in Figure 1

The incinerator system consists of 2 (two) combustion chambers : the first chamber of rotary kiln and the secondary chamber of cyclonic one. Pollution control device uses a water scrubber and waste feeding device uses belt conveyor.

2.2 Equipment operation

The combustion process begins with burning gas in the 1st chamber until the temperature reaches 800°C. Gases and particles produced from burning waste in the 1st chamber will go to the 2nd chamber. In this 2nd combustion chamber, the compounds that have been burned in the 1st chamber will be completely combusted. The combustion temperature of the 2nd chamber is between 900 and 1200°C. The final result of the combustion

is water vapor and other emission gases that will be released into atmosphere, as well as residual ash (bottom ash and fly ash) that will be treated in the landfill.

Rotary kiln incinerator is used to burn sludge wastes. The feeding unit uses semi-automatic and continuous system of belt conveyor that transports the wastes to the incinerator inlet. The produced ash will fall down automatically and goes to the hydraulic door. The ash will fall into collecting tank for cooling down before further packed for shipment to the authorized residue management company.

2.3 Test conditions

The sludge waste is continuously fed into the kiln. The type and composition of waste to be burned is given Table 1 Table 2 shows typically chemical composition of waste.

Table 1: Type and composition of waste burned

No	Type of waste	Composition
1	Sludge WWT	20%
2	Sludge oil	40%
3	Paint sludge	40%
Total		100%

There are two different waste feed during the trial burn test: 480 kg of waste or 80% load, and 600 kg of waste or 100% load, per hour. The fuel used is natural gas of around 85 CFM (144 m³ per hour). POHC used as a surrogate for DRE calculation is around 33.6 kg per hour Tetrachloroethane (TCE).

Table 2: Chemical composition of wastes allowed to be burned.

Parameter of waste burned	Limit	Unit
Sulfate (SO ₃ -)	≤ 800	ppm
Nitrite (NO ₂ -)	≤ 1000	ppm
Hydrogen Fluoride (HF)	≤ 10	ppm
Hydrogen Chloride (HCl)	≤ 70	ppm
Arsenic (As)	≤ 30	ppm
Cadmium (Cd)	≤ 20	ppm
Chromium (Cr)	≤ 2500	ppm
Lead (Pb)	≤ 7500	ppm
Mercury (Hg)	≤ 5	ppm
PCBs	≤ 5	ppm
Heating Value	>1650	kcal/kg
pH	4 – 11	-
Ash content	≤ 2	%
Sediment	≤ 10	%
Density	0.6 – 1.3	g/cm ³
Boiling point	20 - 250	°C

2.4 Performance standards

Head of Environmental Management Agency Decree No. 03 Year 1995 [2] has set performance standards that limit the quantity of gaseous emissions from the hazardous waste incinerator. The regulation has set emission limits of organics (DRE), HCl, particulates, metals, the product of incomplete combustion (PIC) and, other emission gases.

2.4.1 Organics (DRE)

To obtain a permit, an owner or operator must demonstrate that emission levels set for various hazardous organic constituents are not exceeded. The principal measure of incinerator performance is its destruction and removal efficiency (DRE). This is basically a measure of how efficient the incinerator in destroying organics. Since it would be impossible to monitor the DRE results for every organic constituent contained in a waste, certain principal organic hazardous constituents (POHCs) are selected for monitoring and are designated in the permit. POHCs are selected based on high concentration in the waste feed and difficulty in burning compared with other organic compounds. [3], [4] Indonesian standards require a minimum DRE of 99.99% for POHCs, 99.9999% for dioxins/furans and PCBs [3].

2.4.2 Hydrogen chloride

HCl is an acidic gas that forms when chlorinated organic compounds in hazardous wastes are burned. An incinerator burning hazardous waste cannot emit more than 70 mg/Nm³ of the total HCl in the stack gas [2].

2.4.3 Particulate matter and metals

The incinerator regulations control particulate and metal emissions through the performance standard for particulates. A limit of 50 mg/Nm³ of gas emitted through the stack is the performance standard for particulate in the stack gas [2]. Metals regulated under the standards are arsenic, lead, mercury, thallium, cadmium and chromium.

2.4.4 Products of incomplete combustion

Poor combustion conditions result in the release of a

high concentration of organic materials formed during the combustion process. [4] In order to control the emission of products of incomplete combustion (PICs), the Government of Indonesia places limits on carbon monoxide (CO) emissions and total hydrocarbon (THC) emissions from the unit [2]. The presence of carbon monoxide is an indicator of incomplete combustion.

3 Sampling and Analysis

3.1 Stack sampling plan

Stack sampling test was conducted between May 9 and May 15, 2015 as shown in Table 3. The wastes were arranged at 80% and 100% feed load. As suggested by Decree of Head of Environmental Management Agency No. 3 Year 1995 [2], the test parameters consist of combustion efficiency (CE), gas residence time (t), organics or DRE (POHC), DRE (dioxins/furans), DRE (PCBs), particulate, metals (As, Cd, Cr, Pb, Hg, Tl), HCl, HF, Total Hydrocarbon as CH₄, CO, SO₂, NO₂, and opacity. This paper presents sampling and analysis of all those parameters but DRE (dioxins/furans), DRE (PCBs) and HF.

Table 3: Time schedule for TBT of rotary kiln

Sampled parameters	May 2015			
	9	10	11	12
A. DRE POHC:				
• 80%- Run1				
• 80%- Run2				
• 80%- Run3				
• 100%- Run1				
• 100%- Run2				
• 100%- Run3				
B. Other pollutants*):				
• 80%- Run 1				
• 80%- Run 2				
• 80%- Run 3				
• 100%- Run 1				
• 100%- Run 2				
• 100%- Run 3				

* Other pollutants: particulate, metals (As, Cd, Cr, Pb, Hg, Tl), HCl, Total Hydrocarbon as CH₄, CO, SO₂, NO₂, and opacity

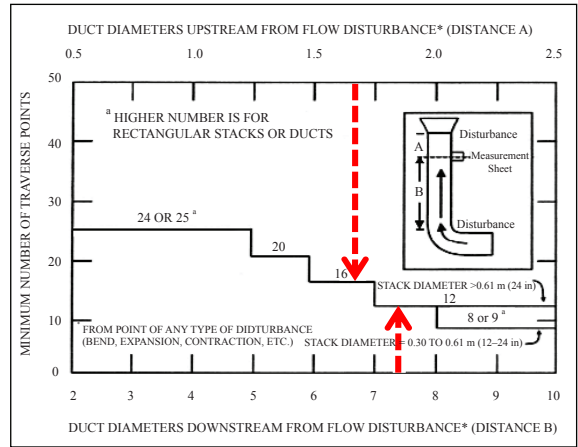


Figure 2: Minimum number of traverse points for particulate stack sampling.

3.2 Stack initial data for isokinetic sampling

Before isokinetic sampling of the targeted stack pollutants is conducted, the location of sampling holes and number of traverse points must be determined. Also, the preliminary data of stack gas velocity, moisture content and molecular weight must be collected. In this case, the targeted gaseous emissions that require isokinetic sampling are particulate and heavy metals.

3.2.1 Sampling ports and traverse points

Method of determining the location of the sampling holes and traverse points across the stack area for isokinetic sampling uses reference of SNI 7117.13: 2009, equivalent to KEP-205 / BAPEDAL / 07/1996, or US-EPA Method 1 [9].

The ideal position of stack sampling holes is at 8 (eight) times the equivalent diameter or more from the downstream disturbances and 2 (two) times the equivalent diameter or more from upstream disturbances. Minimum number of traverse points for particulate stack sampling as regulated in US-EPA Method 1 is presented in Figure 2.

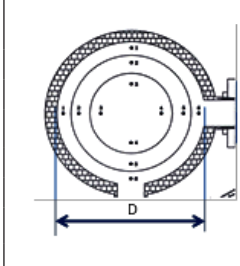
Based on the guidance as in Figure 2 [9] and stack specification as in Table 4, it is found as many as twelve traverse points for this stack. The relative distance of each traverse point to inner stack wall is presented in Table 5.

Table 4: Determination of traverse points for particulate stack sampling

Stack specification	Size
Stack height from the ground, h	17.0 m
Stack diameter, D	0.75 m
Sampling hole position from the ground	12.2 m
Disturbance free stack height, H	13,0 m
Stack height of equivalent diameter	17,3 D
Sampling hole distance from upper disturbance, HA	4.8m (6.4 D)
Sampling hole distance from lower disturbance, HB	8.2m (10.9 D)

Table 5: Distance from stack wall of each traverse point

Distance from the wall	cm	
	Distance from the wall	cm
1	3.30	
2	10.95	
3	22.20	
4	52.80	
5	64.05	
6	71.70	



3.2.2 Linier stack gas velocity

Method of determining the linear velocity of stack gas emission follows the reference method of SNI 7117.14: 2009, equivalent to KEP-205 / BAPEDAL / 07/1996, or US-EPA Method 2 [10]. The principle of determining the linear velocity of the exhaust gas is calculated from the results of measurements of the dynamic pressure, static pressure, ambient air pressure, temperature, composition and moisture content in the flue gas. Linear velocity which is a function of the gas pressure is measured by means of Type S-Pitot Tube.

3.2.3 Dry gas molecular weight

Method of determining molecular weight of dry flue gas emission from stationary sources uses a reference method of SNI 7117.15: 2009, equivalent to Kep-205/ BAPEDAL / 07/1996, or US-EPA Method 3A [11]. The sampling principle is done by sucking the exhaust gas using an electric or manual suction pump, then analyzed using a gas analyzer or other means.

3.2.4 Gas moisture content

Method of determining moisture content of the exhaust

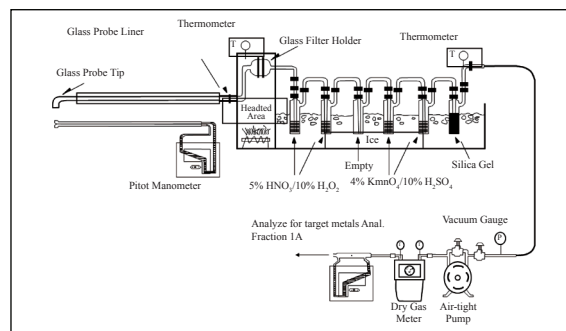


Figure 3: Isokinetic sampling train for particulates and heavy metals.

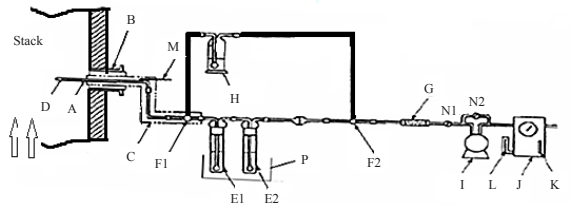
gas emission from stationary sources uses a reference method of SNI 7117.16: 2009, equivalent to KEP-205/ BAPEDAL/07/1996, or US-EPA method 4 [12]. The principle of the measurement is done by sucking the exhaust gas and condensing its water vapor in the absorbent bottles (impingers) and then measured volumetrically or gravimetrically.

3.3 Stack sampling for gaseous emission

There are two types of stack gas sampling methodology: isokinetic and non-isokinetic sampling. Isokinetic sampling is done for non-volatile and semi-volatile gaseous emissions, such as particulates including heavy metals. During isokinetic sampling, a vacuum pump that is already accurately calibrated for flow is used to withdraw flue gas sample over a period of time. Isokinetic sampling requires preliminary determination of sampling holes, traverse points, stack gas velocity, gas molecular weight and moisture content. Whereas, non-isokinetic sampling method is used to measure volatile gases, such as NO₂, SO₂, CO, O₂ and HCl.

3.3.1 Sampling of particulates and heavy metals

Isokinetic method of determining total particulates and heavy metals in the exhaust gas from stationary sources uses a US-EPA reference method 29 [13], [14]. The principle work is to withdraw the flue gas via the thin, tapered nozzle of the sampling train so that the linear velocity of the gas entering the nozzle is as close as possible to the velocity of gas flowing pass the nozzle. The USEPA Method 29 sampling train is shown in Figure 3. Particulate form emission is collected on



- Note:
- | | |
|---------------------------|---------------------------|
| A : probe | I : suction pump |
| B : flange | J : gas meter |
| C : heating element | K : thermometer |
| D : glass wool | L : manometer |
| E1, E2 : impinger, 250 ml | M : temperature regulator |
| F1, F2 : three-way valve | N1 : closing valve |
| G : dessicator | N2 : flow rate regulator |
| H : rinsed bottle | O : fluororubber pipe |
| | P : cooling bottle |

Figure 4: Typical sampling train used for HCl/HF.

a heated filter and a probe line in front of the filter for gravimetrically particulate content determination followed by digestion process for heavy metals detection. The gas form emission is collected in hydrogen peroxide acid solution contained in the impinger number 1 and 2 (for all heavy metals analysis but Hg), and in potassium permanganate acid solution contained in the impinger number 4 and 5 (for Hg analysis). All recovered sample is digested and then analyzed for Hg by CVAAS and for other heavy metals by AAS.

3.3.2 Sampling of HCl

Stack sampling method for hydrogen chloride (HCl) is carried out by the method of mercury thiocyanate and then detected using a spectrophotometer. Reference methods used is Indonesia SNI 19-7117.8-2005. The sampling principle is HCl gas from the flue gas is withdrawn by the suction pump and absorbed in the absorbent solution (Figure 4).

3.3.3 Sampling of POHC (TCE)

Sampling method for principal organic hazardous constituents (POHCs) from the incinerator flue gas uses a reference Method 30 of USEPA [15]. In this case, the compound of Trichloroethylene (TCE) is used to represent POHC. A number of TCE was added to the hazardous and toxic waste or fuel, and then fed it into the first chamber of the incinerator. Most of TCE is destructed in the combustor but some of it emits

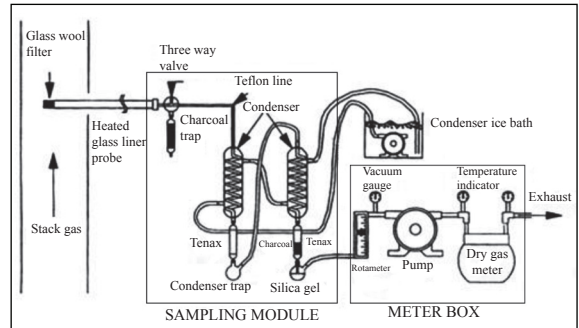


Figure 5: Volatile Organic Sampling Train (VOST) according to US-EPA Method 30.



Figure 6: Smoke opacity measurement equipment based on ASTM D 2156-2003.

out with other flue gases through a stack. This TCE emission is then captured by resin trap installed at the VOST (Volatile Organic Sampling Train) employed, and it is followed by analyzing it in the laboratory using a Gas Chromatograph/ Flame Ionization Detector (GC/FID). Figure 5 shows the schematic diagram of the US-EPA Method 30 - Volatile Organic Sampling Train (VOST).

3.3.4 Opacity measurement

The measurement method of exhaust gas opacity from stationary source uses a smoke scale tool (see Figure 6) as regulated by ASTM D 2156-2003. The principle operation of the equipment is to insert its probe into the stack gas. Then, the handle of the tool is fully pulled to suck the smoke into it. The filter paper is then removed from its place and matched the color of smoke point on the filter paper to the closest possible one of the 10 points “OIL BURNER SMOKE SCALE” references given (RR-776).



Figure 7: Gas analyzer used to measure emitted gases from the stack.

3.3.5 Measurement of emitted gases

Measurement of flue gas composition from a stationary source uses automatic portable gas analyzer as shown in Figure 7. It is based on an Indonesian reference method of SNI 19-7117.10-2005. The principle work is done by sucking the gas which is then analyzed using an automatic portable gas analyzer.

The gas analyzer is used to measure gas concentration of O_2 , CO , CO_2 , SO_2 , NO_2 , CH_4 in the flue gas to an accuracy of approximately 2% using electrochemical sensors. The instrument is calibrated before use according to the manufacturer's specifications. Data is recorded on a computer monitor and also on a log-sheet.

At least hourly or when the probe position is changed during stack sampling, relevant operational and emissions variables, such as fuel mass flow rate, temperature, pressure, gas velocity and flow rate, and water content (humidity) will be measured and recorded.

4 Results and Discussion

4.1 Number of traverse points

Based on the calculation of sampling holes position at the stack that gives more than eight stack diameters downstream and more than two diameters upstream from a flow disturbance, twelve traverse points are decided as indicated by Figure 2 above. For that, the first six traverse points are determined at the line of the first test sampling hole and the second six traverse points are determined at the line of the second test sampling hole. Since the position of stack sampling holes

meet the rule of eight diameters (8D) downstream and two diameters (2D) upstream from a flow disturbance, the gas flows at these traverse points are assumed to have a laminar gas flow. Detailed location of traverse points across the stack holes is shown in Table 5 above.

4.2 Stack gas data of particulate and heavy metals

Stack gas flow rate measurements were done simultaneously with the particulate and heavy metal sampling tests. The gas flow rate is calculated based on the gas linear velocity measured by a S-type pitot tube multiplied by the cross sectional area of the stack. During this Trial Burn Test (TBT), the other incinerator's stack gas parameters were also measured at conditions of 80% and 100% waste feed, three runs each.

Measurement of linear stack gas velocity at two waste feed conditions mentioned above results the values between 10.77 and 11.12 meters per second for 80% waste feed and between 9.67 and 10.10 meters per second for 100% waste feed. They produce the gas flow rate from 9481 to 9637 m^3 per hour for 80% waste feed and from 8422 to 8781 m^3 per hour for 100% waste feed, at standard condition. Other values of stack gas parameters are presented in Table 6.

Total particulate and heavy metals sampling test uses US-EPA Method 29. Six heavy metals as stipulated in the Decree of the Head of Environmental Control Agency (BAPEDAL) No. 03/1995 [2], namely Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg) and Thallium (Tl), were sampled and analyzed in the laboratory using atomic absorption spectrophotometry (AAS).

Based on Table 6 above, isokinetic values of the particulates and heavy metals sampling test at the rotary kiln incinerator's stack is between 102.4% and 109.7%. Thus, these all Isokinetic values have met the regulated isokinetic range values of the stack sampling method of particulates and heavy metals, which is $100\% \pm 10\%$. In other words, the concentrations of particulate and targeted heavy metals that are drawn by the sampling equipment can be considered as the representation of the particulate and heavy metals concentration in the incinerator flue gas. After the isokinetic value of the stack sampling is met, then the sampled particles and heavy metals can be further determined gravimetrically.

Table 6: Gas stack conditions during particulate and metals emission sampling

Parameter	80% Waste feed			100% Waste feed		
	Run-1	Run-2	Run-3	Run-1	Run-2	Run-3
Sampling date	12-5-15			12-5-15	13-5-15	
Sampling time	09:15	12:45	15:27	18:05	21:30	00:10
Total sampling time, min.	60	60	60	60	60	60
Vol. of sampled gas, $V_{m(STD)}$, m ³	1,466	1,522	1,512	1,419	1,532	1,281
Stack temperature, °C	231	236	217	228	217	213
Gas linear velocity, m/s	11,12	11,07	10,77	10,10	9,67	9,81
Gas flow rate, ACT. m ³ /h, db.	17676	17589	17128	16052	15371	15593
Gas flow rate, STD. m ³ /h, db.	9637	9481	9625	8770	8781	8422
O ₂ content, %	11,2	11,6	12,3	11,4	11,4	11,4
Isokinetic value, %	102,5	106,9	104,3	109,7	107,2	102,4
Fuel consumption, CFM	85	85	85	85	85	85
Waste feeding rate, kg/h	480	480	480	600	600	600
Gas retention time, second	2,38	2,35	2,25	2,43	2,42	2,75
Temperature of 1st chamber, °C	1256	1332	1315	1377	1322	1226
Temperature of 2nd chamber, °C	1109	1139	1129	1177	1198	1134

Table 7: Results of particulate and metals emission sampling

Parameter	80% Waste feed			100% Waste feed		
	Run-1	Run-2	Run-3	Run-1	Run-2	Run-3
Sampling data	12-5-15			12-5-15	13-5-15	
Sampling time	09:15	12:45	15:27	18:05	21:30	00:10
Total sampling time, min.	60	60	60	60	60	60
Particulate, mg/Nm ³	36,16	37,82	35,62	44,73	49,00	48,89
Arsenic (As), mg/Nm ³	<0,0191	<0,0191	<0,0191	<0,0191	<0,0191	<0,0191
Chromium (Cr), mg/Nm ³	0,2562	0,6905	<0,0025	0,1277	0,2840	0,2552
Lead (Pb), mg/Nm ³	0,2136	0,6077	0,1266	0,2461	0,1801	0,1478
Cadmium (Cd), mg/Nm ³	0,0204	0,0198	0,0231	0,0211	0,0228	0,0239
Thallium (Tl), mg/Nm ³	<0,0144	<0,0144	<0,0144	<0,0144	<0,0144	<0,0144
Mercury (Hg), mg/Nm ³	<0,00056	<0,00056	<0,00056	<0,00056	<0,00056	<0,00056

To compare the concentration of emitted particulates resulted from the stack gas emissions of the incinerator in accordance with the Decree of the Head of BAPEDAL No. 03 /1995, it should be corrected to normal conditions (25°C, 760 mmHg), at 10% oxygen (O₂) content and dry weight.

Six heavy metals derived from the sampled particulates were analyzed using Atomic Absorption Spectrophotometric method (AAS). Similar with the particulate concentration, the targeted these six heavy metals should also be corrected to normal conditions (25°C, 760 mm Hg), at 10% oxygen (O₂) content, and dry weight. Sampling and analysis results of incinerator flue gas emissions of particulates and six heavy metals are presented in Table 7 below.

4.3 DRE

Measurement of destruction removal efficiency (DRE) uses a reference of US-EPA Method 30. This measurement aims to determine the efficiency of the destruction of volatile Principal Organic Hazardous Constituents (POHC) through incineration. To determine the DRE of the incinerator, then a selected organic compound, namely Trichloroethylene (TCE) was chosen as a surrogate. This surrogate was added (spiked) into the hazardous waste burned in the incinerator. Then, the gas emission formed during the incineration of the mixture between waste and TCE was sampled through the stack sampling port by Volatile Organic Sampling Train (VOST) of USEPA

Method 30. The gas sampling rate was about 0.5 liters per minute for period of 40 minutes so that the total volume of drawn gas was around 20 liters per sample. The Destruction Removal Efficiency (DRE) is formulated as:

$$DRE = \frac{W_{in} - W_{out}}{W_{in}} \times 100\% \quad (1)$$

Where,

DRE = Destruction Removal Efficiency, % ;

W_{in} = Input of POHC into incinerator, ng;

W_{out} = Emission of POHC into the stack, ng

POHC surrogate compound (TCE) that was trapped in a glass made sorbent cartridges containing TenaxTM resin of the VOST was treated through thermally desorbed purge-and-trap and then analyzed by gas chromatography/mass spectrometry, GC-MS.

Table 8 shows DRE values of TCE surrogate representing the POHCs of the waste incinerated.

Table 8: DRE values of POHC represented by TCE

Capacity	Run 1	Run 2	Run3
80% (480 kg waste/h & 85 CFM fuel)			
W_{in} (ng)	3.25×10^7	3.25×10^7	3.25×10^7
W_{out} (ng)	1503.5	1403.63	1299.71
DRE (%)	99.995	99.996	99.996
100% (600 kg waste /h & 85 CFM fuel)			
W_{in} (ng)	3.25×10^7	3.25×10^7	3.25×10^7
W_{out} (ng)	989.78	942.48	894.92
DRE (%)	99.997	99.997	99.997

4.4 Hydrogen chloride (HCl)

Gas emission of hydrogen chloride (HCl) was sampled from the incinerator flue gas using Method 26 USEPA equivalent to KEP-205 Year 1996. The sample is then analyzed by a spectrophotometer at the laboratory. The test results were corrected to normal conditions (25°C, 760 mm Hg, 10% O₂, dry weight), as shown in Table 9. These HCl concentrations are compared with the standard value according to Head of BAPEDAL Decree No. 03 Year 1995 [2].

Based on test result measured at two conditions, HCl gas emissions are still far below its standard value. Thus, there is no potential pollution due to HCl gas generated by this incinerator operated at a load of 80% and 100% hazardous waste of the design capacity.

Table 9: HCl concentration of the stack gas

Run No.	80% Load, mg/ Nm ³	100% Load, mg/ Nm ³
1	19	23
2	22	24
3	21	24
Standard	70	70

4.5 Concentration of other emitted gases

Common emitted gases from incinerator are carbon dioxide (CO₂), carbon monoxide (CO), oxygen (O₂), nitrogen dioxide (NO₂), and total hydrocarbons as methane (CH₄). They were measured using a calibrated flue gas analyzer. Measurement of these gas emissions was done simultaneously while taking samples of particulates and heavy metals. Similarly, the emitted flue gas was measured by the analyzer when the POHC sampling was carried out. The results were corrected to normal conditions (25°C, 760 mm Hg and dry weight), and 10% oxygen content. These final results can then be compared with the standard value as stipulated in the Decree of the Head of BAPEDAL No.03 Year 1995. The gaseous emission sampling results are given in Table 10 that all parameters indicate compliance with the regulatory.

4.6 Combustion efficiency

The Combustion Efficiency (CE) is determined by comparing the concentration of CO₂ to the total concentration of CO₂ and CO at 10% oxygen correction. Mathematically, CE can be formulated as follows:

$$CE = \frac{[CO_2]}{[CO_2] + [CO]} \times 100\% \quad (2)$$

Where,

CE = Combustion Efficiency, %;

[CO₂] = Concentration of CO₂, mg/Nm³;

[CO] = Concentration of CO, mg/Nm³.

According to the Decree of Head of BAPEDAL No. 03/1995, the combustion efficiency of incinerator is $\geq 99.99\%$. The measured values of gaseous emissions as well as combustion efficiency of the operated incinerator with 80% and 100% hazardous waste feeding rate are shown in the Table 10.

Table 10: Gas emissions and combustion efficiency of operated rotary kiln incinerator, corrected at 10% O₂

Parameter	STD Value	Unit	80% Load Capacity				100% Load Capacity			
			Run 1	Run 2	Run 3	Average	Run 1	Run 2	Run 3	Average
NO ₂	300	mg/Nm ³	45	50	48	48	57	63	60	60
SO ₂	250	mg/Nm ³	12	13	19	14	19	3	3	8
THC (CH ₄)	35	mg/Nm ³	10	<0,6	3	5	26	7	<0,6	11
CO	100	mg/Nm ³	9.1	<1	<1	3.0	10.3	<1	6.2	5.5
CO ₂	---	%	6.8	6.7	6.9	6.8	6.8	7.0	6.5	6.8
O ₂	---	%	12.2	12.9	12.5	12.5	12.4	12.5	12.7	12.6
CE	99.99	%	99.993	100	100	99.998	99.992	100	99.995	99.996

Note: Limit of detection of THC (Total Hydrocarbons) as CH₄ = 0.6 mg/Nm³ and CO = 1 mg/Nm³

Based on the Table 10, gas emissions of the case study of the rotary kiln incinerator at 80% and 100% waste load meet the standard values according to Head of BAPEDAL Decree No. 03/ 1995. Likewise, the calculation results for the incinerator combustion efficiency at two different conditions also show the values that comply with the standard one of 99.99% or above.

4.7 Flue gas opacity

The values of the flue gas opacity were found to be less than 10 % at both load capacity and runs, as shown in the following Table 11. If these opacity measurement results are compared with the standard value stated on the Decree of the Head of Environmental Management Agency (BAPEDAL) No. 03 Year 1995, which is 10%, then they comply with the performance regulation.

Table 11: Result of the incinerator flue gas opacity measurement

Opacity at 80% Load Capacity			
Run 1	Run 2	Run 3	Average
< 10%	< 10%	< 10%	< 10%
Opacity at 100% Load Capacity			
Run 1	Run 1	Run 1	Run 1
< 10%	< 10%	< 10%	< 10%

4.8 Gas residence time

The gas residence time is defined as the time required by the gas produced by waste incineration resides in the chamber of the hazardous waste incinerator. Based on the Decree of the Head of Environmental Management Agency (BAPEDAL) No. 03 Year 1995, the gas residence time is 2 seconds or more.

Calculation of gas residence time is determined by measuring the volume of the combustion chamber (m³) divided by the gas flow rate (m³/s), and mathematically formulated as follows:

$$t = \frac{V_{ch}}{Q_{ch}} \quad (3)$$

Where,

t = Gas residence time (s);

V_{ch} = Chamber volume (m³);

Q_{ch} = Chamber flow rate (m³/s);

Using this formula, the gas residence times are found as shown in the Table 12.

Incinerator gas residence time calculation shows that it exceeds 2 (two) seconds. This means that this gas residence time complies with the performance regulation as stated by the Decree of the Head of Environmental Management Agency (BAPEDAL) No. 03 Year 1995 [3].

Table 12: Calculated result of gas residence time

Parameter	Chamber 1	Chamber 2
Volume, m ³	37,68	3,43
Gas flow rate (Q), m ³ /s	4,0601	4,2664
Temperature (T), °K	1370,65	1440,29
Gas residence time (t _R), s	9,28	0,80
Total, s	10,08	

5 Conclusions

Based on the Trial Burn Test (TBT) of the hazardous waste rotary kiln incinerator from May 9 to May 15, 2015, it is concluded as follows:

1. The rotary kiln incinerator that is facilitated with a 17 meter ground-based stack height, a 13 meter disturbance free stack height and a 0.75 meter stack diameter was fed with hazardous waste during Trial Burn Test (TBT). The position of stack sampling holes is at 8.2 meters (more than eight diameters) from downstream disturbance and at 4.8 meters (more than two diameters) from the upstream disturbance and it therefore produces 12 traverse points.

2. This TBT is conducted under 80% and 100% incineration capacity of hazardous and toxic waste. These toxic wastes burned in the incinerator consist of wastewater treatment sludge, oil sludge, and paint sludge. The summarized results of the TBT are presented in the following Table 13.

Table 13: Rotary kiln incinerator performances during TBT

Parameter	Sampling Data Value	STD Value
Isokinetic, %	101.6 – 109.7	90 – 110
Particulate, mg/Nm ³	9.16 – 49.00	50
SO ₂ , mg/Nm ³	3 – 19	250
NO ₂ , mg/Nm ³	34 – 63	300
CO, mg/Nm ³	< 1 – 10.3	100
HCl, mg/Nm ³	< 4 – 24	70
HF, mg/Nm ³	< 0.8 – 2.7	10
THC as CH ₄ , mg/Nm ³	< 0.6 – 26	35
As, mg/Nm ³	< 0.0191	1
Cd, mg/Nm ³	0.0192 – 0.0239	0.2
Cr, mg/Nm ³	<0.0025 – 0.284	1
Pb, mg/Nm ³	0.1266 – 0.607	5
Hg, mg/Nm ³	< 0.00056	0.2
Tl, mg/Nm ³	<0.0144	0.2
Opacity, %	< 10	10
CO ₂ , %	6.5 – 6.9	-
O ₂ , %	12.2 – 12.9	-
CE, %	99.992 – 100.00	99.99
DRE, %	99.994 – 99.996	99.99
t _r of gas, s	10.08	≥ 2

3. The result of TBT of the hazardous waste incinerator has all met the standard values as stated in the Decree of the Head of Environmental Management Agency (BAPEDAL) No. 3 Year 1995 regarding Technical Requirements of Hazardous and Toxic Wastes Management.

4. The measurement result of particulate emissions at the 80% hazardous waste feeding capacity gives the range values between 35.62 and 37.82 mg/Nm³ with an average of 36.53 mg/Nm³. At 100% waste feed capacity, the particulate concentration is between 44.73 and 49 mg/Nm³ with an average of 47.54 mg/Nm³. If these particulate measurement data are compared with the standard value as stated in Head of BAPEDAL Decree No. 3 Year 1995, which is 50 mg/Nm³, they meet their standard value. To avoid particulate levels exceed the standard value, it is necessary to modify the existing air pollution control device (scrubber) system in order to obtain a better efficiency.

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