



Research Paper

Evaluation of power generation efficiency increment by applying element technologies to industrial waste incineration facility in South Korea

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ABSTRACT

It has been an important topic to talk about commercialization of waste-to-energy technology and the establishment of relevant policies as alternatives for waste treatment to prevent environmental pollution, securing energy resources to replace fossil fuels, and realizing zero reclamation of waste. In particular, the domestic and international waste policies have been shifted from the 3R system (Reduction, Recycle and Reuse) to the 4R with the addition of Energy Recovery. In South Korea, the Resource Circulation Basic Act has been newly established in order to utilize energy from waste and promote the use of such energy. This has been the law and system to recycle collected energy from waste. However, the generation efficiency of Korean waste incineration facilities is within 10%, which is not satisfactory to meet the standard of energy recovery on the current laws. Industrial waste incineration facilities, in particular, has their limits to only utilize the steam, that is, the created heat energy. This suggests that there should be more measures to realize high efficiency of waste-to-energy and energy diversification. This study analyzes greenhouse gas reduction effects as well as the steam power generation efficiency increment by applying element technologies to industrial waste incineration facilities under the purpose of efficiency increment from waste to energy. To calculate the increment effects of generation efficiency, 5 element technologies (e.g. low-temperature economizer, low temperature catalyst denitrification) that have been suggested by the Japan's Ministry of Environment are applied to the operation status of Korea's industrial waste incineration facilities (lower heating value of waste: 3,300~4,100 kcal/kg, volume of emission gas: 9,500~11,500 m³/ton, emission gas temperature from boiler outlet: 190~250°C, combustion air ratio: 1.4~2.0). As a result, it is expected to increase 36.47 % in energy recovery rate depending on element technology application at incineration facilities based on the average value of the current facilities. In the case that all of this energy would be used for power generation, it is likely to have efficiency increment of 0.62% on average in power generation. In terms of strengthening heat recovery ability and efficient usage of steam, energy reduction volume would be 155.97 Mcal/ton per input waste if element technologies are applied. This is the equivalent result to crude oil replacement volume of 60.12×10³ m³ (annual), which amounts to USD 20.13 million. Also, it is expected to reduce greenhouse gas reduction of 301,421 ton CO₂/yr if element technologies are applied within incineration process.

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Key words: Waste-to-energy, industrial waste incineration, element technology, waste energy recovery, waste heat power generation.

Abbreviation: WtE, Waste-to-energy; MSW, municipal solid waste; TOE, tonnage of oil equivalent.

INTRODUCTION

As the world population continuously increases and the industrialization is ever accelerated, there have been

perspective changes to view waste. Waste is no longer regarded as something to get rid of; rather, waste is now

recognized as a source of renewable energy. Energy recovery from waste is important as a counter measure of global warming and resource depletion. As of 2018, the South Korean government established and declared 'Resource Circulation Basic Act' (Ministry of Environment, 2018). This act introduces policy approach to establish Korean style WtE scheme (Park, 2016) while including details such as zero reclamation of waste and imposing charges to proceed with waste for incineration. In particular, the act encourages incineration facilities for flammable waste to realize a certain level of energy recovery or utilize such energy (Ministry of Environment, 2018). To meet the standards, operators of waste treatment facilities and local governments voluntarily cooperate.

According to the New and Renewable Energy Statistics 2016 (Renewable Energy Center of Korea Energy Agency, 2017), renewable energy created from industrial waste discharging facilities was estimated to be 944,486 TOE/yr, which is 10.80 % of the total. Meanwhile, the power generation volume was 174,950 MWh/yr, which is 0.77 % of electric energy emanating from waste. These figures demonstrate the Korea's discrepant waste-to energy (WtE) status as compared with the potential energy volume from waste of 13,977,173 TOE/yr (Ministry of Trade, Industry and Energy, Renewable Energy Center of Korea Energy Agency, 2016) in theory. Recovery of potential energy from waste energy has not been properly done because the facility efficiency of steam power generation is within 10%. As compared with that of Germany and other overseas countries, the efficiency is very low (Ministry of Trade, Industry and Energy, 2013; Choi, 2002a, b). Due to low efficiency of steam generation system, waste incineration facilities have been showing passive stances for steam generation. In addition, most of these industrial waste incineration facilities have smaller-sized capacity to proceed with incineration and have been focusing on waste discharging rather than energy recovery and utilization (Yoon et al., 2017; Yoon et al., 2015; Yu, 2015). Therefore, it is required to have measures to improve steam generation efficiency for those incineration facilities in order to pursue high efficiency for WtE and secure the economic foundation of resource circulation society.

The present study conducts a comprehensive analysis of Korean industrial waste incineration facilities regarding efficiency increment from waste to energy. The research also includes analysis of long-term operation data of waste incineration facilities in operation at the moment in Korea as well as the status analysis of utilizing energy that is recovered from those facilities. Accordingly, this study is designed to provide basic data that are needed to invigorate the power generation market from waste incineration by calculating improved effects of steam generation efficiency and greenhouse gas reduction volume if element technologies are applied within incineration process.

MATERIALS AND METHODS

Selection of incineration facilities for municipal solid waste

Table 1 shows the summary of the selected 30 facilities (62 incinerators) for this research. Among industrial waste incineration facilities in operation in South Korea, 30 facilities of 43 that are registered with the Korea Resource Recycling Energy Mutual Aid Association (KREMA). Depending on facility capacity, those facilities are divided into: 100 ton/day or less (15 places), between 100 and 200 ton/day (9), between 200 and 300 ton/day (4), and 300 ton/day or more (2) in order to review recovery and utilization status of energy from incineration heat. Depending on incinerator type, there were 38 incinerators in stoker type, 18 in rotary kiln & stoker type, 5 in rotary kiln type, and 1 in circulating fluidized bed type, which were designed and are in operation. The process volume is relatively small with the on-average waste process capacity per hour of 2.78 ton/hr as compared with the process capacity of incineration facilities for municipal solid waste (MSW).

Survey on operation status of industrial waste incineration facilities

The study conducted a survey for the operation status to review the status of heat energy generation and utilization from the selected 30 industrial waste incineration facilities mentioned above. The survey was carried out by site visit in order to collect the operation data that are necessary to calculate generation efficiency. The collected data were from the year 2016 to 2017 in order to exclude the period for maintenance and inspection for the selected facilities. Details of the survey are under the categories of: waste input volume; generation part (steam generation volume from boiler, electric energy generation from steam generation); utilization part (e.g. steam utilization within incineration process, external steam sales); and others (e.g. received power volume from Korea's national power station or Korea Electric Power Corporation (KEPCO), usage volume of auxiliary fuel).

How to calculate generation efficiency and energy reduction if applying element technologies

To maximize the collection of energy from emission gas created when incinerating waste as electricity, steam calorie, temperature and pressure increment, and increased volume of steam play as important factors (Park, 2015; Korea Environmental Industry and Technology Institute, 2017). The Environmental Satellite Center of Japan (Environmental Satellite Center of Japan, 2007)

Table 1: Outline of industrial waste incineration facilities.

Facility		Incineration temperature	Incinerator type	Treatment capacity (ton/hr)	Waste input volume (ton/yr)
1	A	General(2)	Stoker(2)	1.20, 1.20	11,715, 11,724
		High temp.(2)	R/K+St, Stoker	1.27, 0.40	11,609, 4,143
2	B	High temp.	R/K+St	3.14	29,199
		General	Stoker	1.83	15,937
3	C	General(2)	Stoker(2)	3.25, 2.00	29,671, 18,716
4	D	High temp.	R/K+St	3.90	31,850
		General(2)	Stoker(2)	4.00, 4.00	36,310, 34,100
5	E	General(2)	Stoker(2)	4.00, 4.00	42,259, 42,541
		High temp.	R/K+St	3.54	35,139
6	F	General(2)	R/K+St, Stoker	1.50, 2.50	15,406, 21,186
7	G	General(2)	Stoker, R/K+St	3.00, 3.85	31,450, 37,152
		High temp.	Stoker	0.50	5,239
8	H	General	Stoker	3.35	33,718
9	I	General(2)	Stoker, R/K+St	2.00, 2.00	16,170, 16,170
10	J	General	Stoker	4.00	38,391
11	K	General(2)	Stoker(2)	3.00, 1.25	30,723, 13,232
		High temp.	R/K+St	2.00	21,117
12	L	High temp.	R/K+St	3.18	28,025
		General(2)	R/K+St, Stoker	2.00, 3.00	14,086, 28,454
13	M	General(2)	Stoker(2)	1.00, 3.00	9,021, 23,991
14	N	General(2)	Stoker(2)	1.00, 3.00	6,395, 28,801
15	O	General(2)	R/K(2)	6.25, 6.25	51,141, 41,133
16	P	High temp.(2)	Stoker, R/K+St	3.00, 2.00	18,603, 26,764
17	Q	General	Stoker	2.00	16,845
		High temp.	R/K+St	1.95	15,830
18	R	General	Stoker	3.95	24,855
19	S	High temp.(2)	R/K(2)	6.25, 6.25	53,000, 52,000
20	T	General	Stoker	1.40	11,088
		High temp.	R/K	1.90	15,048

Table 1: Continued.

21	U	General(3)	Stoker(3)	1.50, 1.50, 3.00	8,357, 8,253, 13,039
22	V	High temp. General(2)	R/K+St Stoker(2)	1.00 3.00, 3.00	11,218 33,518, 33,556
23	W	General	Stoker	3.90	34,162
24	X	General	Stoker	3.00	20,948
25	Y	General High temp.	Stoker R/K+St	3.00 1.70	27,747 16,325
26	Z	General High temp.	Fluid phase R/K+St	2.08 2.00	20,352 19,070
27	AA	General	Stoker	3.80	31,372
28	BB	High temp. General(2)	R/K+St R/K+St, Stoker	3.00 3.00, 5.00	24,440 19,008, 42,495
29	CC	General	Stoker	2.50	19,800
30	DD	General	R/K+St	2.60	20,718

* Number of incinerators unit.

** R/K+St : Rotary kiln + stoker.

suggests 9 element technologies as alternatives to improve energy transfer efficiency from steam generators at waste incineration facilities as shown in Table 2. The element technologies that contribute to the improvement of steam generation efficiency include: ① strengthening heat recovery ability (low temperature economizer, low air ration combustion); ② efficient use of steam (low temperature catalyst denitrification, high efficiency dry emission gas treatment, no application or operation suspension of white smoke reduction, no application of drainage closed system); and ③ improvement of steam turbine system efficiency (e.g. high temperature and pressure boiler, extraction condensing turbine, water-cooled condenser).

This study calculates improved effects of steam generation that is expected when applying 5 element technologies (low temperature economizer, low air ratio combustion, low temperature catalyst denitrification, high efficiency dry emission gas treatment, no application of drainage closed system) among those technologies mentioned before to industrial waste incineration facilities in Korea. To reflect the operation status of industrial waste incineration facilities in Korea, the increment volume of heat recovery volume and power generation efficiency

depending on factor changes step by step will be calculated through heat balance method while considering the average generation efficiency of 10% based on changes in boiler outlet temperature and incinerator air ratio, which are the same as theoretical comparison conditions of generation efficiency. Moreover, the energy reduction volume owing to incineration heat utilization was calculated and converted into economic alternative effect (Kim, 2009) in relation to reduction cost of crude oil import. Based on the below formula, energy reduction effects by element technology was converted to reduction cost of crude oil import by utilizing crude oil (applying standards of Dubai crude) unit cost of 378.53 USD/L as of 2017 and crude oil heating value of 9,267 kcal/L.

Reduction cost of importing crude oil = crude oil replacement volume × unit cost of crude oil

How to calculate greenhouse gas reduction volume

The reduction volume of greenhouse gas is calculated based on No. 39 (Usage type of electricity that is externally provided) shown in Table 6 of the 'Guidelines for

Table 2: Element technology for improvement the steam power generation efficiency.

Element technology		Theoretical improvement effect (%)	Comparison conditions of operating factors in incineration facility
Enhancement of heat recovery ability	Low-temp. economizer	1.0	Exhaust gas temperature of boiler outlet : 250 →190°C
	Low air ratio combustion	0.5	Based on 300 ton/day treatment capacity, combustion air ratio 1.8→1.4
Effective use of steam	Low temp. catalyst	1.0~1.5	Gas temperature in catalyst inlet : 210 →180°C
	High efficient dry-type emission gas treatment	3.0	Wet-type emission gas treatment → high efficient dry-type emission gas treatment
	No de-plumer	0.4	De-plumer condition: 5°C, 60%→no condition
	No wastewater close system	1.0	Exhaust gas temperature of boiler outlet : 250 →190°C
Efficiency improvement of steam turbine system	High-temp. and pressure boiler	1.5~2.5	Steam condition: 3 MPaG×300°C→4 MPaG×400°C
	Extraction condensing turbine	0.5	Steam heat source for deaerator heating: main steam→turbine extraction
	Water-cooled condenser	2.5	Turbine exhaust pressure: -76 kPaG→-94 kPaG

* For accurately calculation of the improvement steam power generation efficiency, it is necessary to set up the heat balance for steam turbine. However, it was assumed that the power generation efficiency is roughly proportional to the boiler efficiency.

Reporting and Certifying Emission Volume of Greenhouse Gas Emission Trading'. This is suggested by the Ministry of Land, Infrastructure and Transport. Greenhouse gas reduction volume depending on increase in generation efficiency when element technologies are applied is calculated by utilizing energy reduction volume ((MWh/ton) per a ton of waste for incineration as well as Korea's own electricity emission factor (National Law Information Center, 2017) of CO₂ 0.4653 tonCO₂/MWh (provided by the Korea Exchange), CH₄ 0.0054 kgCH₄/MWh and N₂O 0.0027 kgN₂O/MWh. Also, the unit cost of greenhouse gas emission trade (KAU17) of 21,000 won/tonCO₂ (<http://marketdata.krx.co.kr>) declared by the Korea Exchange is converted to USD in order to calculate the economic benefits that are expected to be possessed by element technology when reducing greenhouse gas.

RESULTS AND DISCUSSION

Waste to energy policy and status regarding domestic waste

Regarding energy recovery from waste incineration heat, South Korea pursues the system called 4R after revising its 3R policy (reduction, recycle and reuse) by adding one more R (Recovery). In particular, the government encourages introduction and distribution of high efficiency waste energy in order to stably secure renewable energy resources and prevent global warming. According to the Resource Circulation Basic Act that took effect as of

January 2018, there have been practical enforcement decrees in detail prepared in order to raise the value of waste as resources. 'Waste Treatment Charge System', one of the major enforcement decrees, imposes certain charges on waste that is reclaimed or incinerated by local governments and waste providers. Also, the current law encourages facility operators and local government to make voluntary effort to improve energy recovery by providing discounts on charges step by step when meeting certain standards (energy recovery rate) set by the current laws and regulations.

Based on the status evaluation report of installation and operation by Korea's Ministry of Environment (2018), a survey was conducted to determine the energy recovery rate of incineration heat from 162 waste incineration facilities in South Korea. Among those 162, the survey excluded the facilities that do not collect or reuse incineration heat. From the 82 facilities left, the energy recovery rate of incineration heat was calculated as 62.4%: Mid-to-large facilities with the daily capacity of 48 ton/day (68 places) or more collect waste energy of 63.3% and smaller facilities with the daily capacity of less than 48 ton/day (14 places) collect waste energy of 33.6%. However, this data do not include the entire waste incineration facilities that also deal with MSW. This suggests that industrial waste incineration facilities would collect less incineration heat.

Meanwhile, previous researches (Ko et al., 2017) have evaluated the status of WtE of Korea's industrial waste incineration facilities based on the calculation method of energy efficiency, which has taken effect since 2018. These

researches include facilities that are actually in operation. To calculate the energy recovery rate, the researches only include heat energy generated from waste heat boilers. Among that, the heat energy of the steam that was actually used was included in order to calculate energy recovery efficiency. As a result, based on usage volume, the final energy recover rate was 56.6% for (boiler-built-type incineration facilities) and 41.3% for (incineration facilities with separate boiler). This does not satisfy discount standards of Waste Treatment Charge System (75.0%), which is suggested by the current laws and regulations.

Taking geographical and environmental conditions in Korea into account, it is very easy to sell steam heat within the incineration facility complexes or external facilities nearby as steam heat can be provided upon generation without any specific processes. However, most of incineration facilities in Korea are in remote areas while being away from demand source of steam heat due to citizens' complaints and NIMBY (Not In My Back Yard). This disrupts utilizing waste energy. Steam generation has an advantage of such easy sales and utilization through power supply network. However, the steam turbine efficiency in Korea is very low at the level of 10.0% or lower. Also, systematic guideline that needs to satisfy energy recovery efficiency that the current laws and regulations suggest results in passive power generation, which makes it hard to increase energy recovery rate in a short period of time. To enhance energy recovery of steam turbine and utilization of waste energy, there is need to review proper element technologies as the industry starts shift towards new generation methods that are suitable for Korean incineration facilities.

Survey on operation status of industrial waste incineration facilities

Heat energy generated from waste incineration facilities creates hot water through devices such as heat exchanger, which is utilized for district heating or transferred to high pressure steam to become an energy source for power generation. Table 3 shows the status survey results of the steam power generation and utilization of industrial waste incineration facilities.

The average annual steam generation volume of the selected 30 facilities is 110,699 Gcal/yr, which is half or less of incineration heat energy as compared with that of MSW incineration facilities. For steam usage volume, 88.9% (82,143 Gcal/yr) of the whole steam usage volume (92,420 Gcal/yr) is used to provide heat to entities outside of the facilities or to the facilities themselves. The average pressure and temperature at boiler outlets are 10.7 kg/cm² and 246°C. Therefore, we need technological improvement for enhancing steam generation efficiency in order to use the steam itself, as well as generate electric

energy for easier supply and usage through power grid under the goal of energy recovery diversification and highly efficient WtE.

Calculation results of improvement effect of power generation efficiency when applying element technology

To convert waste incineration heat energy to as much electric energy as possible, application of element technologies can be realized through increase of power generation efficiency. The average efficiency of steam turbine is 10% in operation at the moment in Korea's waste incineration facilities, which is very low. Industrial waste incineration facilities focus on dealing with waste rather than energy recovery. This means, most facilities do not generate power or the generation efficiency of facilities that generate some electricity is very low.

Based on the operation status of Korea's industrial waste incineration facilities, the increment volume of generation efficiency depending on factor change by step is calculated as shown in Table 4. For this calculation, the following conditions were applied: 3,300~4,100 kcal/kg for lower heating value (LHV) of waste; 9,500~11,500 m³/ton for boiler emission gas volume; 190~250°C for emission gas temperature at boiler outlets; and 1.4~2.0 of incinerator-fed combustion gas air ratio. If 5 element technologies are applied to each incineration process based on 10.00% of steam generation efficiency at Korea's waste incineration facilities, there is 0.62% of the total generation efficiency added. This means that the existing facilities with 10.00% of steam generation efficiency can improve the efficiency up to 10.62% by having element technologies as medium.

Power generation efficiency by element technology increases 0.55% (when performing low temperature economizer combustion) and 0.40 % (low air ratio combustion) on average in terms of strengthening heat recovery ability. When it comes to efficient usage of steam, there are improvement effects of steam generation of 0.29% by low temperature catalyst denitrification, 1.31 % by the introduction of high efficiency dry emission gas system, and 0.55% by no application of drainage closed system. Among the 5 element technologies, low temperature catalyst denitrification marks the lowest efficiency of 0.11%, while high efficiency dry emission gas treatment system shows the highest efficiency of 1.93%. It is expected to see the improved effect of 0.62% when comparing the improved value of theoretical generation efficiency by the Environmental Satellite Center of Japan (Value B) with the modeling value that reflects the operation status of Korea's industrial waste incineration facilities selected for this paper (Value A) under the conditions of the same factor changes. The number 0.62% is 36.47% of 1.70%, which is the theoretical value suggested by Environmental Satellite Center of Japan.

Table 3: Results of field survey on steam production and utilization of target industrial waste incineration facilities.

Facilities	Steam production (Gcal/yr)	Steam utilization (Gcal/yr)			Steam utilization rate (%)
		Sales to third party	Self-use	Sub total	
Average	110,699	82,143	10,277	92,420	80.8
Minimum	32,616	800	-	8,051	10.8
Maximum	287,000	245,000	68,485	245,000	100.0
A	156,220	129,062	20,838	149,899	96.0
B	133,122	115,094	4,123	119,218	89.6
C	147,941	121,564	1,317	122,881	83.1
D	163,797	146,122	17,568	163,689	99.9
E	265,033	168,918	68,485	237,403	89.6
F	127,696	112,137	299	112,435	88.1
G	134,052	89,343	39,025	128,368	95.8
H	54,750	35,706	9,404	45,110	82.4
I	89,468	62,177	6,315	68,493	76.6
J	96,869	62,537	-	62,537	64.6
K	142,751	118,087	8,146	126,233	88.4
L	144,556	144,556	-	144,556	100.0
M	111,745	46,777	22,608	69,385	62.1
N	111,057	80,632	17,125	97,757	88.0
O	124,410	72,045	10,607	82,651	66.4
P	87,958	73,704	14,254	87,958	100.0
Q	101,291	98,636	2,655	101,291	100.0
R	45,712	39,655	2,251	41,906	91.7
S	287,000	245,000	-	245,000	85.4
T	63,451	42,475	20,975	63,451	100.0
U	68,446	11,715	-	11,715	17.1
V	115,392	107,526	-	107,526	93.2
W	63,069	30,156	-	30,156	47.8
X	42,419	42,419	-	42,419	100.0
Y	74,624	7,705	346	8,051	10.8
Z	69,074	45,400	11,838	57,238	82.9
AA	72,601	800	20,139	20,939	28.8
BB	138,464	127,994	10,004	137,998	99.7
CC	55,384	55,384	-	55,384	100.0
DD	32,616	30,959	-	30,959	94.9

* Steam supplement to third parties is the sum of both paid-in and free-of-charge.

** Self utilization of steam: alternative of auxiliary fuels, heating energy source in management building, etc.

Enhancing heat recovery ability

Low temperature economizer and low air ratio combustion are the element technologies to improve the ability of heat energy recovery from steam that is generated from incineration facilities. For low temperature

economizer, there's an increase of steam volume that comes to the entrance of steam turbine as the temperature of combustion emission gas at boiler outlets is lowered from 250 to 190°C. This suggests that steam generators result in much more volume of steam energy input. Considering the same combustion gas volume of 11,500

Table 4: Theoretical and actual modeling value of steam power generation efficiency improvement effect by applying each element technology.

Element technology		Steam power generation efficiency improvement effect (%)		Applied comparison conditions of operating factors in target incineration facility
		Field modeling value (A)	Theoretical value (B)	
Enhancement of heat recovery ability	Low-temp. economizer	0.55 (0.22~1.01)	1.00	· Exhaust gas temperature of boiler outlet : 250 →190°C
	Low air ratio combustion	0.40 (0.16~0.73)	0.50	· Based on 300 ton/day treatment capacity, combustion air ratio 2.0→1.4
Effective use of steam	Low temp. catalyst	0.29 (0.11~0.50)	1.00~1.50	· Gas temperature in catalyst inlet: 210 →180°C
	High efficient dry-type emission gas treatment	1.31 (0.84~1.93)	3.00	· Wet-type emission gas treatment → high efficient dry-type emission gas treatment
	No wastewater close system	0.55 (0.22~1.01)	1.00	· Exhaust gas temperature of boiler outlet : 250 →190°C
Average		0.62	1.70	(A/B) 36.47%

* Low temperature economizer: increment volume of recovery heat from boiler due to lowering temperature of boiler outlet

* Low air ratio combustion: reducing energy loss depending on air volume difference

* Low temperature catalyst denitrification: reducing reheating energy by lowering combustion gas temperature at catalytic reactor inlet

* High efficiency dry emission gas treatment: reducing energy consumed from emission gas reheating device by skipping wet scrubber

* No application of drainage closed system: For drainage closed system, emission gas temperature at boiler outlet should be set at 250°C. Therefore, increment volume of recovered heat due to lowering emission gas temperature should be reflected onto increment volume of generation efficiency.

m³/ton, generation efficiency increases by 1.01% (10.00 %→11.01 %) when waste LHV is 3,300 kcal/kg and 0.81 % (10.00 %→10.81 %) when waste LHV is 4,100 kcal/kg.

Low air ratio combustion operation can improve generation efficiency based on energy reduction volume depending on different volume of air coming through incinerators. By gradually lowering combustion air ratio from 2.0 to 1.4 through low air ratio combustion, the air consumed while waste is incinerated can be reduced to the level of theoretical air volume. Emission gas volume and discharging calorie from boilers can be also reduced. There was a comparison between the increased rate (%) of steam generation volume at steam turbine entrance when combustion air ratio is 2.0 and 1.4 based on emission gas volume of 11,500 m³/ton. As a result, based on generated steam volume under the condition of waste LHV of 3,300 kcal/kg, air ratio 1.4 turns out to improve boiler steam generation volume of 4.97% on average as compared with air ratio of 2.0. If the figure is converted as generation efficiency, there is an increase through low air ratio combustion operation in the range of minimum 0.16% (4,100 kcal/kg of waste LHV, 9,500 m³/ton of emission gas volume) and maximum 0.73% (3,300 kcal/kg of waste LHV, 11,500 m³/ton of emission gas volume). This suggests that discharging calorie relatively decreases and boiler efficiency increases accordingly as emission gas volume decreases and temperature rise due to application of element technologies.

Efficient use of steam

Low temperature catalyst denitrification, high efficiency dry emission gas treatment and no application of drainage closed system are the element technologies to reduce energy lost from steam that is generated from boilers at incineration facilities and encourage efficient use. Low temperature catalyst denitrification is a technology to increase steam turbine efficiency by reducing energy consumed to reheat combustion emission gas. There is an increase in steam generation volume at steam turbine entrances as the temperature of emission gas that comes into catalytic reactors lowers from 210 to 180°C without reheating. At the condition of waste LHV of 3,300 kcal/kg and emission gas volume of 11,500 m³/ton, there is an increase of 0.50% in generation efficiency at the catalytic reactor temperature of 180°C. Meanwhile, the catalytic reactor temperature of 210° when low temperature catalyst denitrification is not executed (reheating emission gas is executed) does not have influence on an increase of generation efficiency.

Figure 1 shows a process diagram of wet and dry emission gas process system. As compared with the wet type, the dry type emission gas process can reduce energy that is consumed for temperature rises of emission gas that comes into catalytic reactor inlets, as web scrubber process low temperature is skipped. When switching to high efficiency dry emission gas system and there is more

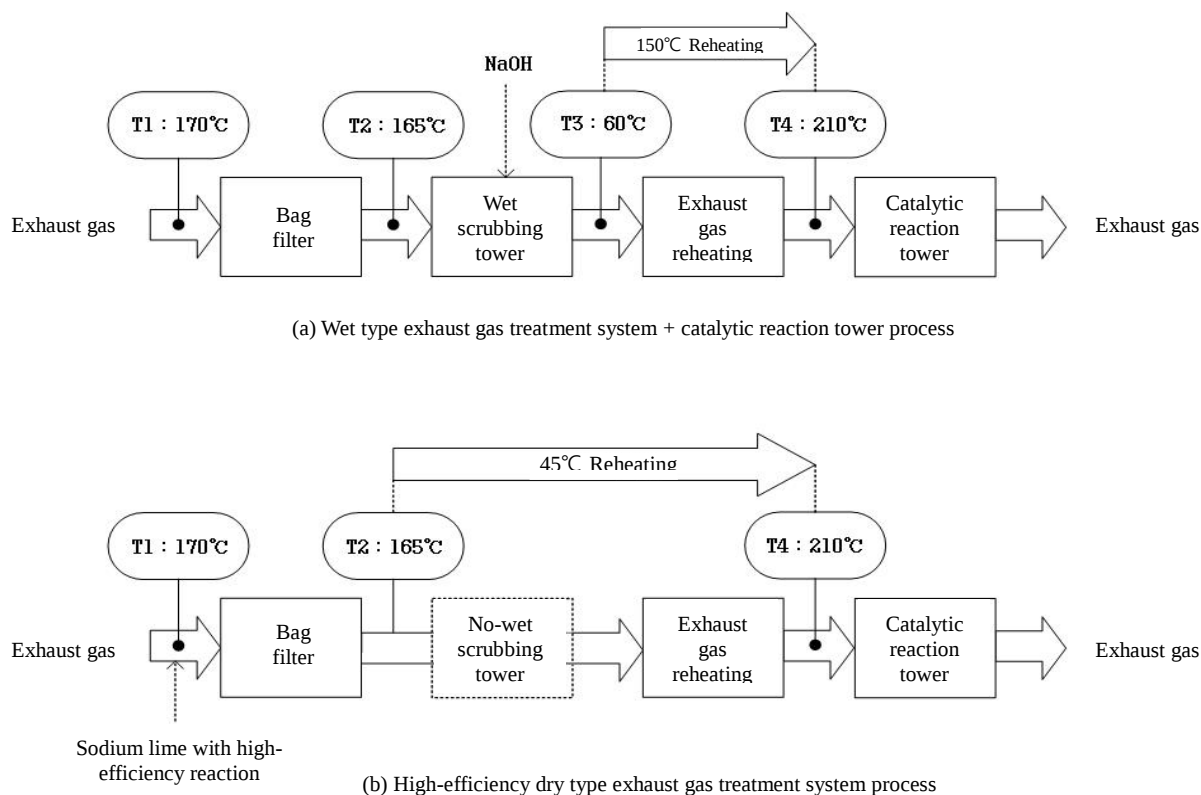


Figure 1: Comparing wet and dry exhaust gas treatment system processes.

emission gas volume and higher reheating temperature, steam generation efficiency becomes higher in the minimum range of 0.84% (4,100 kcal/kg of waste LHV, 9,500 m³/ton of emission gas volume) and maximum of 1.93% (3,300 kcal/kg of waste LHV, 11,500 m³/ton of emission gas volume).

Drainage closed system means gasifying waste water created from inside the incineration facilities by utilizing heat energy within processes. Instead of executing drainage closed system as an element technology and waste water after processes are provided to waste water treatment facilities nearby or outsourced entities to be treated; however, the heat energy consumed while gasifying can be saved. This suggests that steam turbine can transfer much more steam. According to the results of this study, at the condition of the same combustion gas volume of 11,500 m³/ton and waste LHV of 3,300 kcal/kg, generation efficiency increases by 0.00, 0.34, 0.67 and 1.01% as the temperature of emission gas discharging at boiler outlets lowers to 250, 230, 210 and 190°C, respectively.

Calculation results of energy reduction and greenhouse gas reduction volume

This study also evaluates the volume of energy reduction

and greenhouse gas reduction effects due to additional electric energy generation when applying element technologies and generation efficiency increases accordingly. Table 5 shows the effects of energy reduction and crude oil import reduction by applying element technologies at industrial waste incineration facilities. The calculation reflects the average exchange rate in 2017 (1,130.61 KRW/USD) and the average price of Dubai crude (53.2 USD/barrel) in order to compare energy reduction volume with crude oil replacement volume by applying individual element technologies at incineration processes. When applying 5 element technologies, it turns out that there's an energy reduction effect of 155.97 Mcal per a ton of waste for incineration on average if converting the volume of steam that can be additionally collected and the electricity that is consumed to reheat boiler emission gas into energy reduction effect. In terms of enhancing energy recovery ability, low temperature economizer shows 1.4 times better performance (138.60 Mcal/ton) than low air ratio combustion (99.82 Mcal/ton). As per efficient use of steam, high efficiency dry emission gas treatment performs the maximum energy reduction effect (329.18 Mcal/ton) among 5 element technology, while low temperature catalyst denitrification shows the minimum effect (73.63 Mcal/ton).

It is 60.12×10³ m³/yr on annual average when converting energy reduction volume per a ton of waste for

Table 5: Crude oil replacement volume and import reduction cost by the generation efficiency increment and energy savings by each element technology.

Element technology		Energy savings		Annual crude oil replacement volume ** (B) (10 ³ m ³ /yr)	Annual crude oil import reduction cost *** (C) (million USD/yr)
		(Mcal/ton) (A)	(Gcal/yr)*		
Enhancement of heat recovery ability	Low-temp. economizer	138.60 (62.70~227.70)	495,079 (223,964~813,344)	53.42 (24.17~87.77)	17.89 (8.09~29.38)
	Low air ratio combustion	99.82 (45.16~163.99)	356,557 (161,300~585,772)	38.48 (17.41~63.21)	12.88 (5.83~21.16)
Effective use of steam	Low temp. catalyst	73.63 (31.35~113.85)	263,011 (111,982~406,672)	28.38 (12.08~43.88)	9.50 (4.05~14.69)
	High efficient dry-type emission gas treatment	329.18 (235.13~436.43)	1,175,813 (839,867~1,558,910)	126.88 (90.63~168.22)	42.48 (30.34~56.32)
	No wastewater close system	138.60 (62.70~227.70)	495,079 (223,964~813,344)	53.42 (24.17~87.77)	17.89 (8.09~29.38)
Average		155.97	557,108	60.12	20.13

* Calculating by applying the average incineration volume at industrial waste incineration facilities in 2016 (3,572,000 ton/yr) (Ministry of Environment, 2017).

** Crude Oil replacement Volume = Energy reduction(Mcal/ton)/ Calorie value of crude oil(kcal/L), Calorie value of crude oil: 9,267 kcal/L

*** Applying Dubai crude unit cost in 2017: 378.53 USD/L.

Table 6: Cost calculation results of GHG reduction and carbon trade reduction by each element technology.

Element technology		Energy savings (MWh/ton)	Annual GHG reduction *			Annual carbon trade reduction cost ** (million USD/yr)
			CO ₂ (tonCO ₂ /yr)	CH ₄ (kgCH ₄ /yr)	N ₂ O (kgN ₂ O/yr)	
Enhancement of heat recovery ability	Low-temp. economizer	0.16 (0.07~0.26)	267,861 (121,175~440,057)	3,109 (1,406~5,107)	1,554 (703~2,554)	5.00 (2.26~8.21)
	Low air ratio combustion	0.12 (0.05~0.19)	192,914 (87,271~316,930)	2,239 (1,013~3,678)	1,119 (506~1,839)	3.60 (1.63~5.92)
Effective use of steam	Low temp. catalyst	0.09 (0.04~0.13)	142,301 (60,588~220,029)	1,651 (703~2,554)	826 (352~1,277)	2.66 (1.13~4.11)
	High efficient dry-type emission gas treatment	0.38 (0.27~0.51)	636,170 (454,407~843,443)	7,383 (5,274~9,789)	3,692 (2,637~4,894)	11.88 (8.48~15.74)
	No wastewater close system	0.16 (0.07~0.26)	267,861 (121,175~440,057)	3,109 (1,406~5,107)	1,554 (703~2,554)	5.00 (2.26~8.21)
Average		0.18	301,421	3,498	1,749	5.63

* Applying Korea's own electricity emission factor CO₂ (tonCO₂/MWh): 0.4653, CH₄ (kgCH₄/MWh): 0.0054, N₂O (kgN₂O/MWh): 0.0027.

** When applying element technologies, the CO₂ reduction was adopted as the Korea Exchange suggests (unit cost of greenhouse gas emission trade (KAU17) of 21,000 KRW/tonCO₂).

incineration by applying element technologies at incineration facilities (Value A) into annual crude oil replacement volume (Value B). It is USD 20.13 million when converting annual crude oil import volume into crude oil replacement volume by adopting standard unit cost of Dubai crude. Similar to the energy reduction results, high efficiency dry emission gas treatment performs the maximum effect of crude oil replacement (42.48 million USD/yr) among 5 element technology, while

low temperature catalyst denitrification shows the minimum effect (9.50 million USD/yr). In terms of enhancing energy recovery ability, using low temperature economizer and low air ratio combustion shows relatively low energy reduction and crude oil replacement effect as compared with the rest of 3 element technologies for efficient use of steam.

Table 6 shows greenhouse gas reduction volume by element technology and carbon trade cost reduction

volume. Here, CO₂, Methane and Nitrous Oxide that generate more greenhouse gas are selected to calculate greenhouse gas reduction volume per each gas when reducing energy. When applying element technologies, it is expected to reduce greenhouse gas as follows: 301,421 tonCO₂/yr of carbon dioxide, 3,498 kgCH₄/yr of methane, and 1,749 kgN₂O/yr of nitrous oxide. By applying the unit cost of greenhouse gas emission trade to convert CO₂ reduction volume into economic effects, it turns out to save USD 5.63 millions of carbon trade cost annually. The 5 element technologies are expected to reduce CO₂ generation volume in the range of minimum of 60,588 tonCO₂/yr and maximum of 843,443 tonCO₂/yr. At the same time, those technologies are likely to save carbon trade cost in the range of minimum of USD 1.13 million and maximum of 15.74 million annually, which would eventually reduce the operation cost of incineration facilities or create additional profits.

Conclusion

In this study, the effects of applying element technologies to increase steam generation efficiency of Korea's industrial waste incineration facilities was calculated using heat balance method. Five element technologies were applied in order to strengthen heat recovery ability and have efficient use of steam. Under the condition of the average steam generation efficiency of Korean boilers (10.00%), it turns out that 0.62% of generation efficiency when applying element technologies is obtained. In general, the generation efficiency increases to 10.62% and this result in energy reductions volume of 155.97 Mcal per a ton per a ton of waste. This can annually save the energy of 557,108 Gcal, which can also replace imported crude oil of 60.12×10³ m³ worth USD 20.13 million. The application of individual element technologies is expected to reduce greenhouse gas as follows: 301,421 tonCO₂/yr of carbon dioxide, 3,498 kgCH₄/yr of methane, and 1,749 kgN₂O/yr of nitrous oxide. Accordingly, it is expected to save USD 5.63 millions of carbon trade cost or reduce the operation cost of incineration facilities annually as generation efficiency increases and greenhouse gas reduces.

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