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Environmental Impact Evaluation for Various Incinerator Patterns by Life Cycle Perspective: A Case Study in Taiwan

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Abstract—**Incineration technology refers to treatment methods using high-temperature combustion to transform the waste into stable substances and gases with energy or other usable resource recovery. However, the exhaust gas produced by incineration process still generates several problems threatening human's health and environment. Hence, the environmental impact of incineration technology should be discussed more comprehensively. Two type's incinerators including fluidized-bed and mechanical-grate patterns operated in Taiwan were selected to evaluate the environmental impact by life cycle perspective in this study. Through the skills of life cycle inventory and impact assessment, the environmental impacts intensity was illustrated by nine categories. It can be found that the total environmental impacts of mechanical-grate incinerator is 0.74654, which is little higher than fluidized-bed incinerator as 0.70137 in the study cases. The result also shows the heavy metal damage and global warming are the most critical environmental impact in fluidized bed incinerator and mechanical-grate incinerator respectively. The study would be helpful for improving the decision quality for choosing the municipal solid waste treatment system.**

Keywords-life cycle assessment; environmental impact evaluation; incinerator

I. INTRODUCTION

Due to the highly increasing population and economical activities, the annual amount of waste generation grows significantly in Taiwan; besides, the complicated components of municipal solid waste (MSW) also intensifies the treatment difficulties. In the past, most MSW was disposed to landfill; however, according to statistic made by EPA (Taiwan), MSW generation increased doubly from 1984 to 1994, thus making landfill become saturated. To mitigate such situation, EPA purposed a diversified treatment policy and therefore invests intensively the construction of MSW incinerator. At present, 26 incinerators were built and operating in here. Based on the sampling and analysis results of MSW, over 80% is occupied by combustible components and the lower heating values is about 1,600 kcal/kg, which is achieving the spontaneous combustion heating value. Therefore, MSW of Taiwan is suitable to regard incineration as intermediate treatment process. Due to the limited land availability for waste disposal, incineration has replaced land fill as the main waste treatment method and accommodate 96% of total municipal wastes in Taiwan [1].

Incineration is one of the most important processes in an integrated waste management system, due to the ability of destroying hazardous waste, reducing mass and volume of residues and recovering energy content from unrecyclable materials having a significant heat value [2]. Nevertheless, in spite of the evolution of technologies that have notable reduced their environmental impact in recent years, particularly due to the gaseous emissions, incinerators still create many concerns for agencies involved in the safeguarding of public health. Incinerators are still generally perceives as great pollution sources, in particular due to their gaseous emission from the stack [3].

With the increasing attention on sustainability issue, waste management systems having lower global and regional environmental impacts are desirable [4]. It must be emphasized that multiple public health, safety and environmental co-benefits accrue from effective waste management practices [5]. For this reason, standard methods for assessing the environmental impact of waste management systems are needed. One of the most useful procedures for a potential environmental impact evaluation is Life Cycle Assessment (LCA) procedure [2]. LCA is a very powerful tool can be successfully applied to MSW management systems to identify the overall environmental burdens and to assess the potential environmental impacts [6]. LCA is a methodology considering the entire life cycle of products and services from cradle to grave (from raw material acquisition through production, use, and disposal). It is thus a holistic assessment methodology of products and services [7, 8, 9]. LCA has been proved as an objective and systematic tool to measure and compare the environmental impacts of human activities [10, 11, 12]. In addition, International Organization for Standardization (ISO) states that LCA invents the input/output (I/O) information involved in producing system, subsequently assesses the impact on environment based on I/O information, and finally interpreting the results of inventory and impact assessment.

LCA applied to integrated MSW management constitutes a relatively new field of application of the methodology, and introduces great potential for development [13]. At international level LCA is being increasingly used to objectively evaluate the performances of different Municipal

Solid Waste (MSW) management solutions [14], to compare the environmental performance of different scenarios for management of mixed solid waste [7, 5, 15, 16, 17] as well as of global warming potential [6, 18]. One of the most important waste management options concerns MSW incineration [4, 8, 14, 19, 2].

The growing importance of the application of LCA to integrated Waste Management Systems is testified by many studies published in recent years [20]. In fact, when choosing the most appropriate solid waste management system for a certain territory, decision makers have to take adequately into account not only the technical aspects and implementation costs but also the environmental impacts produced by the treatment and disposal processes as well as the opinion of the local communities [16]. The results of the environmental evaluation in other areas may be different due to MSW characteristics, technology, spatial and temporal factors, and related information [8].

Hence, this study would like to discuss the I/O information involved in the waste treating process based on a life cycle assessment perceptions, realizing the potential benefits and impacts brought from various types of incinerator. Fluidized bed incinerator and mechanical-grate incinerator in Taiwan were selected as the object for the case study.

II. METODOLOGY

Life Cycle Assessment (LCA) has been defined by Society of Environmental Toxicology and Chemistry (SETAC) as an objective process to evaluate the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials used and waste released to the environment, and to evaluate and implement opportunities to effect environmental improvements [9, 5, 16]. The methodology of LCA can be described by four interrelated phases, as shown in Fig. 1, namely: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA) and (4) life cycle interpretation [12, 11, 21]. The arrows in Fig. 1 imply that the phases are continuously interrelated. If there are some unsatisfactory and missing parts in one phase, which will affect the intended application of the whole study, then the other phases must be revised and improved [7].

The objective of this study is to quantify and compare the environmental impact resulted from two different types of incinerator system: fluidized-bed incinerator and mechanical-grate incinerator. Following discusses the advantage and barrier of the two type's incineration technology, and establishes local LCA related information for domestic incineration technology.

In LCA, the functional unit is the definition of the functional outputs of the product system. The main purpose of the functional unit is to provide a reference to which the inputs and outputs can be related [11]. However, for waste management, the functional unit must be defined in terms of systems input [5]. Therefore, one tones of MSW is chosen as the functional unit for each treatment method during the life cycle assessment in this study.

In the comparison of waste treatment technologies, the LCA system boundary considered needs to be sufficiently broad to take into account all the elements of interest [18]. The system boundaries are comprised from the waste input into the plant to the emission in the environment of flue gas, bottom and fly ash. Consequently, processes of waste feeding, treating (incineration), exhaust treatment and ash disposal have been considered as shown in Fig. 2. However, the impact of the collection and transfer of solid waste is not considered since the transportation was assumed to be identical in all scenarios. Besides, the wastewater impact was also omitted owing to the zero discharge technique in the MSW treatment plant.

In this study, two kinds of incinerator used for current MSW treatment in Taiwan, fluidized bed incinerator and mechanical-grate incinerator, are compared the environmental performance as two cases. Table 1 indicates the technical information of these two incinerators.

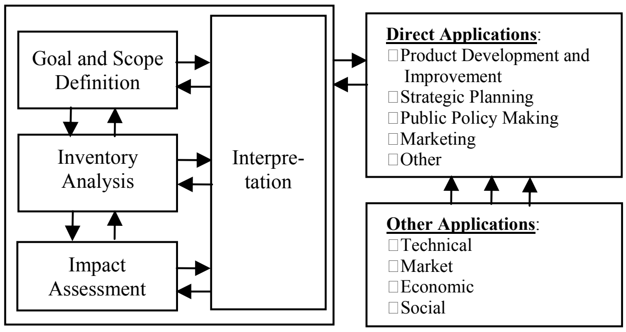

Figure 1. Life cycle assessment framework-phase of an LCA [7,22]

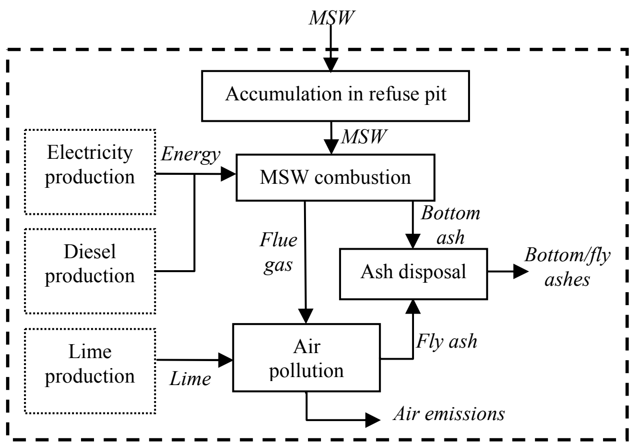

Figure 2. System boundary in this study

TABLE I. PROFILE FOR TWO TYPES OF INCINERATORS

Item		Case 1	Case 2
Designed Capacity		95 ton/day×1 plant	600 ton/day×2 plants
Designed heat value		2,300 kcal/kg	2,400 kcal/kg
Furnace		Fluidized-bed	Mechanical-grate
Exhaust treatment	Dust collector	Baghouse collector	Baghouse collector
	Scrubber	Dry scrubber	Semi-dry scrubber
	Denitrification system	N/A	SNCR
	Dioxin removal	Carbon injection (dry)	Carbon injection (dry)

The following assumptions were considered in this study:

1. The system boundary only includes incineration process and the treatment of fly ash or other solid residues; transportation, services construction and maintenance emissions are not included in this study.
2. Pollutant emission is based on the monthly average value of monitor data.
3. The category indicator considered in impact assessment mainly focus on environmental benefit; cost and energy benefits are not estimated in this study.
4. The generation and emission of electricity and fuel oil are based on built-in information of Gabi®.

III. RESULTS AND DISCUSSIONS

A. Life cycle inventory (LCI)

The procedure employed in life cycle inventory is based on the four steps defined in system boundaries mentioned above. The practical operation and regular monitoring data was used preferentially. Parts information of lacking measurement data was estimated by mass balance method, simulation software, and related references. The inventory results of resources input for treatment and output of pollutant emission are shown in Table 2 and Table 3 respectively.

B. Impact assessment

1) Normalized analysis

Normalized analysis means the conversion from actual content of each output matter to dimensionless quantity for indicating the relative significance of the various environmental impacts during a period of time. In this study, the normalization factor provided from Eco-indicator 95 model was used to accomplish the task. Nine categories of environmental impact include acidification potential, carcinogenic substances, eutrophication potential, global warming potential, heavy metals, ozone depletion potential, pesticide, summer smog and winter smog were evaluated in this process. Analysis result shows the impact of heavy metal damage and global warming potential are relatively high in all 9 impact categories, 0.0822 and 0.06 respectively for the fluidized-bed incinerator. This is due to the emission of Lead and its compound, which is significant higher than other heavy metals.

TABLE II. INPUT INVENTORY INFORMATION FOR WASTE TREATMENT

Case	Case 1 Fluidized-bed incinerator		Case 2 Mechanical-grate incinerator	
Lower heating value	1,588.9	kcal/kg	1,886	kcal/kg
Higher heating value	95	ton/day	23.63	ton/hr
Electricity consumption	700.4	kwh/hr	3,126.48	kwh/hr
Oil consumption for hot start-up	1.3	ton/time	-	
Sand consumption	45	kg/hr	-	
Water consumption for exhaust gas cooler	8,065	kg/hr	-	
Water consumption for wetting fly ash	2,800	kg/hr	-	
5% Urea water consumption for boiler	-		116	kg/hr
Water consumption for boiler	-		27,220	kg/hr
Hydrated lime consumption for attemperator	-		144	kg/hr
Cooling water consumption for attemperator	-		569	kg/hr
Activated carbon consumption for dust collector	-		3	kg/hr
Auxiliary fuel oil consumption for hot blast stove	-		259	kg/hr

On the other hand, although the consumption of fuel oil and electricity while treating waste in case 2 (mechanical-grate incinerator) is lesser than case 1 (fluidized-bed incinerator), the global warming potential contribution is the most sever one within all impact categories generated by mechanical-grate incinerator. It is caused by its high flue gas generation, 6.153 Nm^3/kg; thus it will generate 1,395.59 kg CO_2 while treating per unit waste, which is almost doubly higher than fluidized-bed incinerator. The detailed results of evaluation are shown in Table 4 and Fig. 3.

TABLE III. POLLUTION EMISSION RESULTS

Case	Case 1		Case 2	
Displacement of flue gas	2.877	Nm^3/kg	6.153	Nm^3/kg
Ash from economizer	-		12	kg/hr
Ash from attemperator	-		63	kg/hr
Ash from dust collector	200	kg/hr	251	kg/hr
CO_2	656.33	kg/ton	1395.5	kg/ton
NOx	74.433	ppm	1.909	kg/ton
SOx	30.033	ppm	0.137	kg/ton
CO	54.7	ppm	0.117	kg/ton
HCl	16.518	ppm	0.22	kg/ton
Particulate pollutants	22.975	mg/Nm^3	0.0636	kg/ton
Lead and its compounds	0.0534	mg/Nm^3	0.0000225	kg/ton
Cadmium and its compounds	0.0099	mg/Nm^3	0.0000006	kg/ton
Mercury and its compounds	0.0136	mg/Nm^3	0.0000254	kg/ton
Dioxin	0.1313	ng I-TEQ/ Nm^3	0.0369	ng I-TEQ/ Nm^3

TABLE IV. RESULTS OF NORMALIZED ENVIRONMENTAL IMPACTS EVALUATION BY ECO-INDICATOR 95

Impact category	Case 1	Case 2
Acidification potential	0.00665	0.01613
Carcinogenic substances	0.00000	0.00008
Eutrophication potential	0.00194	0.00698
Global warming potential	0.06009	0.11481
Heavy metals	0.08223	0.04164
Ozone depletion potential	0.00000	0.00002
Pesticide	0.00000	0.00000
Summer smog	0.01924	0.01664
Winter smog	0.00315	0.00213

2) Weighted evaluation

Weighted evaluation sums up the environmental impacts for each matter. It follows two steps: (1) The total scores of each impact category for each pollutant are firstly estimated during evaluating process (2) The scores for each impact category are summed to represent the contribution to whole environmental impacts for each matter. The result of weighted evaluation is displayed in Table 5.

It can be observed that the environmental impact indicator of case 2 is 0.74654, which is little higher than case 1, 0.70137. It can be concluded that the fluidized bed incinerator is relatively environment friendly. It is also worth to note that the weights of acidification impact and heavy metal damage are both higher than global warming, hence the impacts of acidification potential and heavy metal damage are increased in total evaluation, and the global warming potential is relatively decreased. Accordingly, it can be concluded that the incinerator in case 1 has to reduce the emission of heavy metal for improving the environmental benefit. Furthermore, owing to the incinerator of case 1 existed activated carbon injection equipment for controlling the heavy metal in exhaust gas, it is worth to recheck the design capability and operation efficiency for improving the pollution prevention effects. As for the Mechanical-grate incinerator, it has to reduce generation of flue gas for mitigating the environmental impacts. The results of weighted environmental impacts evaluation for two types of incinerators are displayed in Fig. 4.

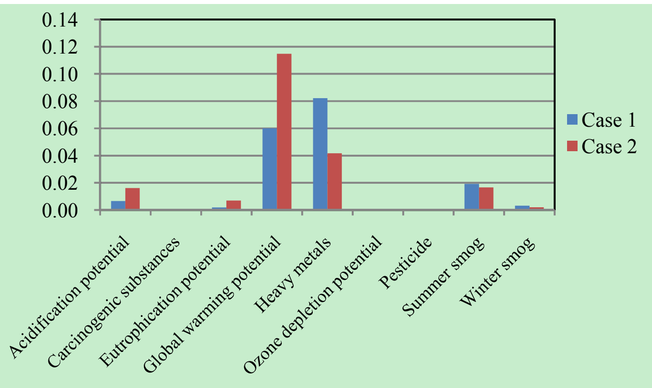

Figure 3. Normalization results for various incinerators

TABLE V. WEIGHTED EVALUATION BY ECO-INDICATOR 95

Impact category	unit	Case 1	Case 2
Total	Pt	0.70137	0.74654
Acidification potential	Pt	0.06645	0.16126
Carcinogenic substances	Pt	0.00000	0.00077
Eutrophication potential	Pt	0.00971	0.03492
Global warming potential	Pt	0.15021	0.28701
Heavy metals	Pt	0.41114	0.20818
Ozone depletion potential	Pt	0.00000	0.00214
Pesticide	Pt	0.00000	0.00000
Summer smog	Pt	0.04811	0.04161
Winter smog	Pt	0.01575	0.01065

IV. CONCLUSIONS

The conclusions of this study can be summarized as follows:

1. In this study, the total environmental impact evaluation of case 2 is 0.74654, which is little higher than case 1, 0.70137; it shows that the fluidized bed incinerator is more environmental friendly compared to mechanical-grate incinerator.
2. In fluidized bed incinerator, heavy metal damage occupies the highest proportion, about 58%, within all environmental impact categories. The major reason is the poor end-of-pipe treatment leading to the emission concentration of Lead and its compound.
3. In Mechanical-grate incinerator, the most critical environmental impact category is global warming, it is resulted from high flue gas generation during the treatment process and the CO_2 emission is almost doubly higher than the other types of incinerator.

However, the benefit brought from energy recovery is not included in this study, hence the replacement of fuel and electricity input after energy recovery are not discussed. To reflect practical application situation, the benefit resulted from energy recovery should be taken into account. Besides, the reliability of assessment result relies on the quality, precision, completeness and representativeness of collected data. It is expected to enhance reliability of LCA while a comprehensively local database is established in the future.

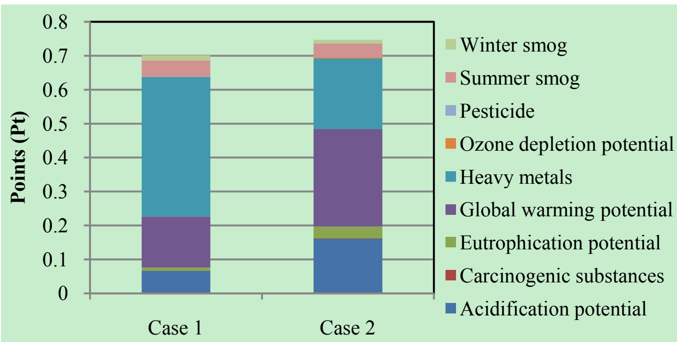

Figure 4. Weighted environmental impact evaluation for two cases

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