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Characteristics of fly ash from the municipal solid waste incineration plant in Can Tho

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Abstract. In this study, 16 seasonal fly ash samples of municipal solid waste incinerator (MSWI) were collected from waste-to energy power plant in Can Tho city to analyze the physical properties and heavy metals content. The results showed that the fly ash samples are very alkaline with porous and spherical shape, and the particle size of 1 - 100 µm. The analytical results disclosed that in these fly ash samples, the Zn, Pb, Al, Fe and Cr metals were found at high content ranging from 0.36 - 19.05 mg/kg; while the toxic metals Ni and Hg are also found in fly ash, with the content from 0.141 to 0.51 mg/kg. The analysis results by SEM/EDX and XRF were quite similar to each other (with a difference of below 5 %), indicating that both techniques can be applied to research heavy metals. In addition, the content of heavy metal elements in fly ash is not affected by weather conditions due to the closed exhaust gas treatment system. The findings in this study can guide the management, treatment and reuse of fly ash from MSWI incineration plants in Viet Nam.

Keywords: Fly ash, municipal solid waste, heavy metals, MSWI incineration plant

Classification numbers: 3.3.2

1. INTRODUCTION

In Asian developing countries, including Viet Nam, trash incinerators seldom remove any dangerous substances, endanger the health of plant workers and nearby residents, and do not generate any energy. Moreover, the incineration process is not a final waste treatment stage; the emission of toxic flue gas and the release of incineration residues must be treated subsequently, especially for municipal solid waste incineration (MSWI) fly ash. Fly ash has been classified as hazardous waste because it contains toxic dioxins and various heavy metals such as Cr, Cd, Pb, Hg, and As [1, 2]. The disposal of fly ash has caused growing concerns regarding the severe negative impact on the environment and human health [3 - 5].

With the characteristics of spherical structure and superfine particle size, fly ash can disperse very far. Many studies suggested that fly ash could be dispersed up to several tens of kilometers [6, 7]. Therefore, several methods have been developed to treat and reduce the hazard of fly ash, such as glass solidification/stabilization (S/S) technology [8, 9], cementitious [10 - 12], chemical S/S technology [13, 14], and acid extraction technology [15]. For example, Fan *et al*. compared the difference between the disposals of MSWI fly ash solidified by cement, phosphate cement, aluminate cement, and alkaline-activated cement to conclude the solidification/stabilization mechanism [8]. Fly ash is a hazardous waste that must be stabilized and then landfilled [16, 17]. This stabilization and landfills are costly and unstraightforward tasks with complex operations [18, 19]. Hence, identifying the overall characteristics of fly ash before choosing an adequate solidification or stabilization treatment has great significance. The general factors must also be considered by researchers who can utilize exploring forward resource improvement of valuables for MSWI fly ash.

In Viet Nam, the overloaded domestic landfills and outdated technology incinerators lead to a high risk of environmental pollution and affect public health. The fly ash content of the Can Tho plant is currently about 3 - 5 %, which is stabilized, collected, and then covered with tarpaulins and temporarily stored in the warehouse area of the plant [20, 21]. The fly ash, after harmless treatment, is ultimately transported to the landfill site, leading to an environmental impact [22].

In Viet Nam, the proportion of metal components in solid waste varies significantly between localities, from 0.1 - 5.5 % and tends to increase gradually with the increase of industries [23]. Metals are inorganic substances that are only oxidized without decomposition during combustion. Therefore, most of the burned metals remains in the form of oxides, and the heavy parts by weight are dropped to the bottom of the furnace (bottom ash). In contrast, volatile metals, such as As, Cd and Hg, are evaporated at furnace temperature (> 850 ºC), so they often appear in flue gas [18].

Studies have found 20 metals in the composition of collected fly ash with mainly heavy metals such as Cd, Cr, Cu, Pb, Zn and dioxin/furan [8]. Therefore, evaluative, appropriate and efficient treatment of fly ash for the recycling process is being demanded urgently. This study aimed to determine the characteristics of fly ash and evaluate its heavy metals content. In addition, the accuracy and detection of heavy metal content in MSWI fly ash play a vital role in realizing a high-efficiency treatment process.

2. MATERIALS AND METHODS

2.1. Sample collection

The study focused on sampling fly ash at Can Tho waste power plant for study. Can Tho plant is located in an area about 500 m from Can Tho river and 110 km from the East Sea [24].

The 16 fly ash samples are denoted as follows: In the dry season, two samples were taken in December 2021 and January 2022, with symbols from FA1-FA8, in the rainy season, two samples were taken in May 2022 and June 2022, with symbols from FA9-FA16. Depending on the frequency of vibration of the bag dust filter system, fly ash is not continually produced. For each factory, four samples of ash will be collected per month during the two months of rainy and dry seasons. The period from December to February is the peak of the dry season, characterized by low humidity and high calorific value. In contrast, during the rainy season of June and July, municipal waste has high moisture and low calorific value, which significantly impacts the combustion and exhaust gas treatment processes and can change the composition of fly ash. The raw fly ash was preliminarily dried in an oven at 80 °C overnight and then tested for physical and chemical analysis, leaching toxicity of heavy metals. The sampling method was carried out according to TCVN 7538-2:2005 - Soil quality - sampling - Technical guidance on sampling.

2.2. Physicochemical characterizations

The morphology of the fly ash was shown by scanning electron microscope (SEM), using a Hitachi Model 8100 SEM electron microscope with high resolution and low aberration: 0.7 nm resolution for secondary electrons (Vacc: 15 kV) 0.8 nm (Target voltage: 1 kV) (Target voltage: 1 kV) *3, acceleration voltage 0.530 kV, target voltage*3' 0.12 kV, magnification 20 – 1,000,000 times, gain with Bruker SDD detector (EDX). The fly ash composition was analyzed using Energy Dispersive X-ray Spectroscopy (EDX) (model: Hitachi S-4800). Control samples were analyzed by X-ray fluorescence equipment (XRF - model: Element Eye JSX-1000S EDXRF/JEOL-US).

2.3. Leaching test of heavy metal

Heavy metals in fly ash, including Pb, Zn, Fe, Mg, Al, Cr, Cu and Ni, were also analyzed by SEM/EDX equipment. Control samples were analyzed by the XRF technique. The control comparison aims to check the measurement’s accuracy and limit technical errors in the analysis process. The analysis results of 16 fly ash samples in Can Tho plant were compared with QCVN 07:2009/BTNMT (National technical standard for hazardous waste) to assess the hazard of fly ash. The steps of the analysis process are shown in the following diagram (Figure 1):

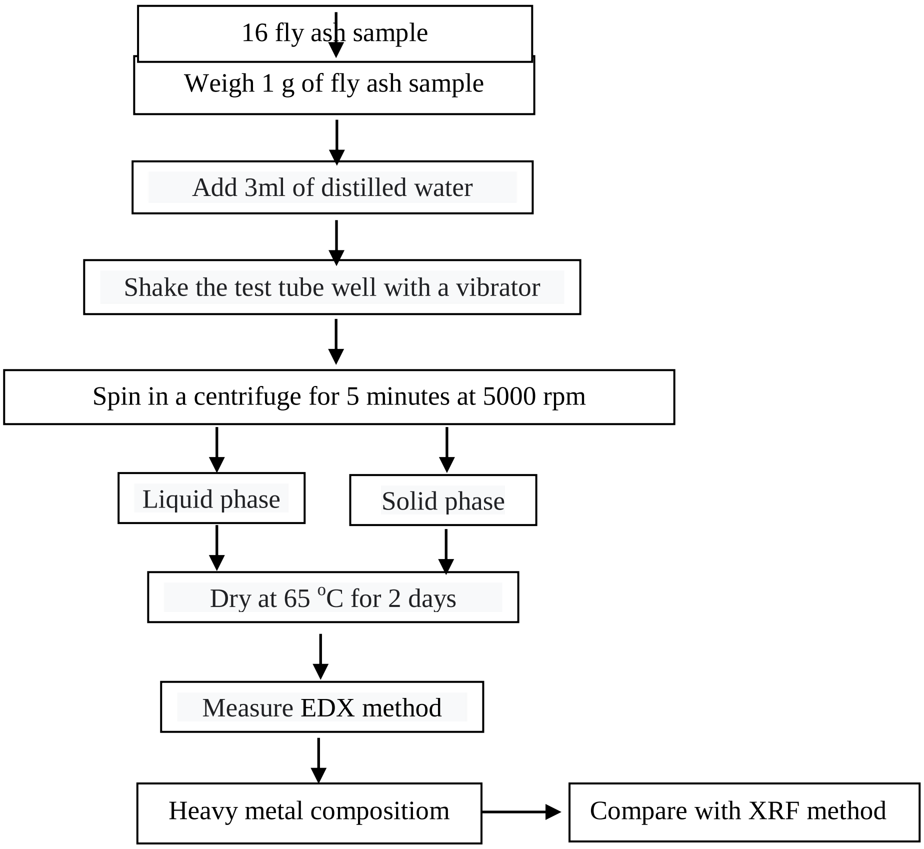

Figure 1. Diagram of fly ash analysis by SEM/EDX method.

3. RESULTS AND DISCUSSION

3.1. Characteristics of MSWI fly ash

MSWI fly ash is a type of irregular substance converged by particulates, de-acid reactant, and unreacted substance as well as condensate, with a rough surface, high porosities, and a large specific area, which makes it easy for heavy metals formed by waste incineration to condense on its surface [18, 23]. Figure 2 illustrates images of the microstructure and morphology of fly ash.

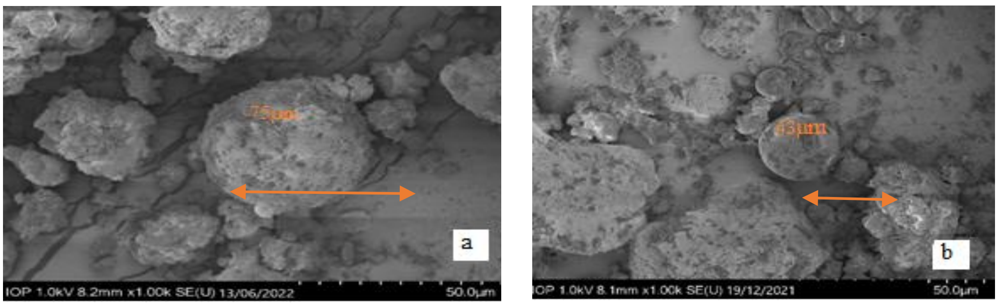

Figure 2. SEM micrographs of fly ash samples in the rainy season (a) and dry season (b).

The data showed that the fly ash of 04 sampling batches is uniform in shape with the size of 1 - 100 µm. The observed homogeneity of fly ash might be due to the low flue gas velocity left out from the furnace. Generally, there were particles with porous structures in all fly ashes from both factories. The sheet, block, and spherical forms were observed as well.

The physical properties are listed in Table 1, which shows that the obtained humidity (0.8 - 1.0 %) and pH value (11.9 - 12.3) were much higher than other reported fly ash samples.

Table 1. The physical properties of fly ash.

Parameters	Value (average)	References
Humidity	0.8 - 1.0 %	0.5 - 0.7 % [21]
pH value	11.9 - 12.3	6.1 [25]
Particle size	1 - 100 µm	7.5 µm
Temperature	71 - 80 ^{o}C	75 ^{o}C [24]

The moisture content of all samples is determined below 1.0 %, assigned to the absorption of moisture from the air during shaking and temporary storage. The humidity value is as low as 0.8 % in the dry season. In contrast, the humidity increased in the rainy season but not significantly, and the difference in moisture content of the ash between the two plants could not be determined.

Table 1 demonstrates that the alkalinity of fly ash with a high pH can be addressed to enhance acidic soil with a low pH or soil contaminated with salinity and infertile owing to shrimp cultivation. Because the coastal area of Can Tho possesses a large area of shrimp farming land, fly ash helps neutralize pH and clean the soil. However, it is necessary to check the content of organic compounds to consider the danger of fly ash. This is a rather sensitive location because fly ash can disperse far, which can cause problems of sea and ocean pollution when entering the aquatic environment. The Can Tho factory has been in operation since 2019 with a capacity of 400 tons/day and emits about 6-8 tons of fly ash per day. The plant uses a combination of "SNCR furnace denitrification + deacidification by semi-dry method + dry lime spray + activated carbon adsorption + cloth bag dust filter" [25].

Moreover, the compositions of fly ash were variable in various cases with high alkali contents (pH 11.9 - 12.3) because the hydrated lime or sodium carbonate were usually used for acid gas neutralization in the treatment processing of gas from power plants [12, 26]. Fly ashes exist in micron-scale particles, with more than 90 % of the particles below 100 µm [27]. The number of particles with a size of 50 µm is estimated to be about 50 % of particles in fly ash, which can induce easy dispersion of fly ash into the air and significantly impact human health because it can go directly into the lungs when inhaled. 20 % of particles have a size of 50-80 µm and the remaining 30 % are asymmetric or large-sized particles. The particle size of fly ash is influenced by the operational conditions of municipal solid waste and the units in which the particulates are collected [9, 28].

The analysis data from Table 1 shows that the fly ash of MSWI incinerators has a spherical, cylindrical structure with high pH and alkaline and non-hazardous waste. Therefore, it is expected that fly ash from MSWI incinerator can be used to improve soil quality in Can Tho province in particular and Mekong Delta in general. However, fly ash is a relatively new type of waste in Viet Nam, so more in-depth studies are needed before it can be put into practice.

3.2. Heavy metal contents of incineration fly ash

Although fly ashes have significant differences in the types and contents of heavy metals, eight metals including Pb, Zn, Fe, Mg, Al, Cr, Cu and Ni were mainly found in the tested samples. Table 2 shows the heavy metal content of MSWI fly ash, indicating relatively high Zn and Pb levels in incineration fly ash. However, the heavy metal contents of 16 fly ash samples are lower than the acceptable standard of QCVN 07:2009/BTNMT.

Table 2. The heavy metal content of incineration fly ash (mg/L).

	Sample No.	Fe	Cr	Al	Ni	Zn	Hg	Pb	Cu
Sampling batches 1	FA1	0.54	0.51	1.39	0.46	15.04	0.152	10.1	0.78
	FA2	0.46	0.49	1.55	0.45	19.9	0.141	9.5	0.81
	FA3	0.52	0.77	1.49	0.48	16.09	0.143	9.67	0.98
	FA4	0.36	0.6	1.24	0.51	19.05	0.15	10.2	0.85
	Average	0.47 ± 0.070	0.5925 ± 0.110	1.418 ± 0.117	0.475 ± 0.023	17.52 ± 2.012	0.1465 ± 0.004	9.867 ± 0.290	0.245 ± 0.076
Sampling batches 2	FA5	0.5	0.76	1.41	0.63	17.78	0.142	10.65	0.86
	FA6	0.51	0.87	1.31	0.24	16.54	0.152	9.8	0.85
	FA7	0.59	0.73	1.83	0.35	18.98	0.147	9.3	0.98
	FA8	0.57	0.81	1.76	0.76	16.6	0.146	10.4	1.01
	Average	0.542 ± 0.038	0.7925 ± 0.053	1.577 ± 0.221	0.495 ± 0.208	17.475 ± 0.999	0.146 ± 0.003	10.037 ± 0.526	0.925 ± 0.070
Sampling batches 3	FA9	0.86	0.89	2.45	0.24	15.37	0.187	12.7	0.45
	FA10	0.84	1.03	3.24	0.35	17.94	0.18	14.5	0.49
	FA11	0.81	1.43	3.03	0.2	15.35	0.179	14.5	0.68
	FA12	0.8	1.49	3.23	0.31	18.04	0.177	13.8	0.59
	Average	0.827 ± 0.023	1.21 ± 0.255	2.987 ± 0.321	0.275 ± 0.058	16.675 ± 1.315	0.1807 ± 0.003	13.875 ± 0.736	0.552 ± 0.089
Sampling batches 4	FA13	0.76	0.97	3.09	0.31	16.64	0.185	13.7	0.45
	FA14	0.69	1.04	5.42	0.30	17.71	0.19	14.8	0.48
	FA15	0.73	1.21	4.89	0.38	15	0.183	14.6	0.42
	FA16	0.75	1.59	4.52	0.39	15.39	0.188	13.9	0.39
	Average	0.732 ± 0.026	1.205 ± 0.240	4.48 ± 0.863	0.345 ± 0.040	16.185 ± 1.068	0.1865 ± 0.002	14.25 ± 0.460	0.435 ± 0.033
QCVN 07:2009/BTNMT		-	5	-	70	250	0.2	15	-

(-): no specified

To evaluate fly ash properties according to the regular seasons in the region, 16 samples were taken in the wet and dry seasons. The results show that the compositions of fly ash collected in the two seasons are quite similar, and not significantly different from each other. Therefore, it can be concluded that the metal composition in fly ash is not affected by weather and climate characteristics.

All fly ash samples showed the highest Zn content from 15 - 19.05 mg/L, followed by Pb, Al, Fe and Cr ranging from 9.3 to 14.8 mg/L, 1.24 to 5.42 mg/L, 0.36 to 0.86 mg/L and 0.49 – 0.86 mg/L, respectively. Meanwhile, Cu only appeared in samples ranging from 0.39 to 0.98 mg/L. Some highly toxic metals, such as Ni and Hg, were found in all fly ash samples ranging from 0.2 to 0.51 mg/L and 0.141 to 0.19 mg/L, respectively.

Table 2 shows that there are two indicators, Hg and Pb in the fly ash sample, which may be due to input solid waste including industrial solid waste. These two metals were absorbed during exhaust gas treatment and existed in fly ash. Other metals with low toxicity, such as Al, Fe and Cu, were also found in the fly ash samples. However, there is no limit for these metals in the regulation on the limit of hazardous waste of the Ministry of Natural Resources and Environment of Viet Nam. Although different analysis methods were used and the waste composition was different, the results of the heavy metal analysis in this study were quite similar to data from previous studies in China and Portugal [2, 27, 29].

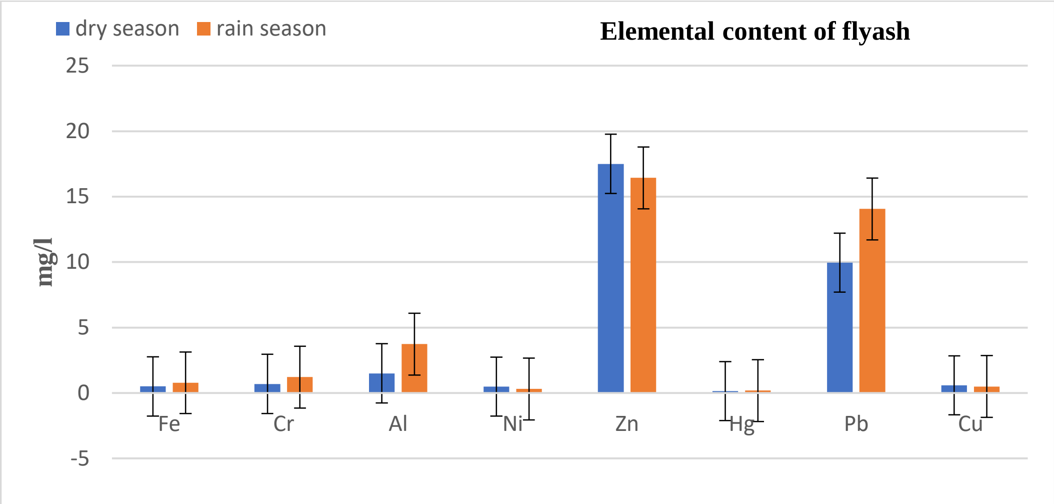

Figure 3. Elemental content of fly ash in the dry and rainy season.

Total heavy metals in incineration fly ash are estimated at 1.5 - 1.8 % by weight of ash, which is higher than the value in previous studies [2]. This can be explained by the fact that the solid waste in Viet Nam has not been classified, and the combustion components contain heavy metals. The magnitude of heavy metal toxicity in incineration fly ash is not only related to its total amount but also closely related to its chemical form. The bioavailability and toxicity of heavy metals in the environment could not be fully characterized by the total amount of heavy metals in the environment [30]. The finding showed that, with the above metal content, fly ash is not harmful to the living environment, especially the river/sea system.

3.3. SEM/EDX and XRF analysis

Two samples of fly ash representing two seasons: FA1 (dry season), and FA9 (rainy season), were randomly taken and analyzed by XRF, the results are given in Table 3.

The results of measurements made on the same ash sample carried out in two separate laboratories are compared (Table 3). The data shows no significant difference in heavy metal content in fly ash composition using SEM/EDX and XRF. The error between the two measurement techniques is as low as 1 - 2 % for heavy metals with high content, such as Zn and Pb. The error is about 3 - 5 % higher for metals with low content. However, the error between the two measurement methods is < 5 % and within the acceptable range.

Table 3. Heavy metal content in fly ash measured by EDX and XRF (mg/L).

Sample no.	Fe	Cr	Al	Ni	Zn	Hg	Pb	Cu
FA1 (XRF)	0.6	0.55	1.46	0.48	18.09	0.2	13.2	0.81
FA1 (EDX)	0.54	0.51	1.39	0.46	15.04	0.152	10.1	0.78
FA9 (XRF)	1.1	0.92	3.56	0.32	16.15	0.21	13.1	0.54
FA9 (EDX)	0.86	0.89	2.45	0.24	15.37	0.187	12.7	0.45

4. CONCLUSIONS

This study was carried out on 16 fly ash samples collected at Can Tho waste power plant, according to two regional characteristics, rainy and dry seasons between 2021 and 2022, to examine the structural morphology and heavy metal composition in fly ash. The results indicated that fly ash is spherical particles with porous and relatively smooth surfaces with particle sizes ranging from 1-100 µm, low moisture content, and high pH. Fly ash composition includes some heavy metals: Pb, Zn, Fe, Hg, Al, Cr, Cu and Ni, which are metals with relatively high content. There was a similarity in the composition and concentration of elements between samples in 2 different seasons, corresponding to not being affected by weather factors. The contents of heavy metals are below the values at QCVN 07:2009/BTNMT, which deduce that the fly ash is not hazardous waste. Moreover, the results from two SEM/EDX and XRF measurements are similar to 02 randomly selected control samples, indicating that the reliability of the SEM/EDX method and can be further applied to other studies on heavy metals.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Yao S., Zhang L., Zhu Y., Wu J., Lu Z., Lu. - Evaluation of heavy metal element detection in municipal solid waste incineration fly ash based on LIBS sensor, Waste Management **102** (2020) 492-498. Doi: 10.1016 / j.wasman.2019.11.010.

2. Haiying Z., Youcai Z., Jingyu Q. - Characterization of heavy metals in fly ash from municipal solid waste incinerators in Shanghai, Process Safety and Environmental Protection **88** (2010) 114-124. Doi: 10.1016 / j.psep.2010.01.001.
3. Dwivedi A., Jain M. K. - Fly ash waste management and overview: A Review, Recent Research in Science and Technology **6** (1) (2014) 30-35. Doi.org/10.1016/ j.proenv.2016.02.079
4. Jambhulkar H. P., Shaikh S. M. S., Kumar M. S. - Fly ash toxicity, emerging issues and possible implications for its exploitation in agriculture; Indian scenario: A review, Chemosphere **213** (2018) 333-344. Doi: 10.1016/j.chemosphere.2018.09.045.
5. Pandey V. C., Singh J. S., Singh R. P., Singh N., Yunus M. - Arsenic hazards in coal fly ash and its fate in the Indian scenario, Resources Conservation and Recycling **55** (9-10) (2011) 819-835. Doi: 10.1016 / J.Resconrec.2011.04.005.
6. Karakaş, G., James, A. & Al-Barakati, A. - Prediction of Fly-Ash Dispersion in the Southern Black Sea: A Preliminary Modelling Study, Environmental Modeling & Assessment **9** (2005) 137-145. Doi.org/10.1023/B:ENMO.0000049390.23801.81.
7. Maria de Lurdes Dinis., Antonio Fiuza., Joaquim Gois., Jose Soeiro de Carvalho., Ana C. Meira Castro. - Assessment of Natural Radioactivity, Heavy Metals and Particulate Matter in Air and Soil around a Coal-Fired Power Plant—An Integrated Approach, Atmosphere **12** (11) (2021) 1433. Doi: 10.3390 /atmos12111433.
8. Fan C., Wang B., Zhang T. - Review on Cement Stabilization/Solidification of Municipal Solid Waste Incineration Fly Ash, in: Ling B. Kong (Eds.), Advances in Materials Science and Engineering, Hindawi, 2018, pp. 1-7.
9. Zhang B., Zhou W., Zhao H., Tian Z., Li F., Wu Y. - Stabilization/solidification of lead in MSWI fly ash with mercapto functionalized dendrimer Chelator, Waste Management. **50** (2016) 105-112. Doi: 10.1016 / j.wasman.2016.02.001.
10. Van der Sloot H., Kosson D., Hjelmar O. - Characteristics, treatment, and utilization of residues from municipal waste incineration, Waste Management **21** (8) (2001) 753-765. Doi: 10.1016/s0956-053x (01) 00009-5.
11. Cristelo N., Segadães L., Coelho J., Chaves B., Sousa N. R., de Lurdes Lopes M. - Recycling municipal solid waste incineration slag and fly ash as precursors in low-range alkaline cements, Waste Management **104** (2020) 60-73. doi:10.1016/j.wasman. 2020.01.013.
12. Yakubu Y, Zhou J, Ping D, Shu Z, Chen Y. - Effects of pH dynamics on solidification/ stabilization of municipal solid waste incineration fly ash, Journal of Environmental Management **207** (10) (2017) 243-248. Doi: 10.1016/j.jenvman.2017.11.042
13. Ren P., Mo K. H., Ling T.C. – Chapter 10: Stabilization/solidification of municipal solid waste incineration fly ash, in: Daniel C. W and Tsang, Lei Wang (Eds.), Low Carbon Stabilization and Solidification of Hazardous Wastes, Elsevier, Amsterdam, 2022, pp. 141-156.
14. Wu C.y., Yu H.f., Zhang H.f. - Extraction of aluminum by pressure acid-leaching method from coal fly ash, Transactions of Nonferrous Metals Society of China **22** (9) (2012) 2282-2288. Doi.org/10.1016/S1003-6326(11)61461-1.
15. Long L., Jiang X., Lv G., Chen Q., Liu X., Chi Y., Yan J., Zhao X., Kong L. - Characteristics of fly ash from waste-to-energy plants adopting grate-type or circulating

fluidized bed incinerators: a comparative study, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2020, 1-17. Doi.org/10.1080/15567036. 2020.1796851.

16. Joseph A. M., Snellings R., Van den Heede P., Matthys S., De Belie N. - The use of municipal solid waste incineration ash in various building materials: a Belgian point of view, Materials **11** (1) (2018) 141. Doi.org/10.3390/ma11010141.
17. Kanhar A. H., Chen S., Wang F. - Incineration fly ash and its treatment to possible utilization: A review, Energies **13** (24) (2020) 6681. Doi.org/10.3390/vi13246681.
18. Ferone C., Colangelo F., Messina F., Santoro L., Cioffi R. - Recycling of pre-washed municipal solid waste incinerator fly ash in the manufacturing of low temperature setting geopolymer materials, Materials **6** (8) (2013) 3420-3437. Doi.org/10.3390/ma6083420.
19. Hue N. T and Mai N. T. P. - Emission characterization of PCB, HCB and their correlation in fly and bottom ashes from various thermal industrial processes in Northern Vietnam, Human and Ecological Risk Assessment **27** (2) (2021) 378-391. Doi.org/10.1080/ 10807039.2020.1718486.
20. Van Thuong, N., Hung, N.X., Mo, N.T. *et al.* - Transport and bioaccumulation of polychlorinated dibenzo-p-dioxins and dibenzofurans at the Bien Hoa Agent Orange hotspot in Vietnam, Environ Sci Pollut Res. **22** (19) (2015) 14431-14441. Doi.org/10.1007/s11356-014-3946-9.
21. Huang T., Chuieh P. - Life cycle assessment of reusing fly ash from municipal solid waste incineration, Procedia Engineering **118** (2015) 984-991. doi:10.1016/j.proeng. 2015.08.539.
22. EB Can Tho Environmental Energy Company Limited. - Report on Completion of environmental protection works, Can Tho waste incineration plant, Can Tho, 2020, (in Vietnamese).
23. Rau S. – People’s Republic of China: Sustainable Management of Fly Ash from Municipal Solid Waste Incineration, Technical Assistance Consultant’s Report ADB, 2015.
24. Zhang Y., Wang L., Chen L., Ma B., Zhang Y., Ni W., Tsang D. C. - Treatment of municipal solid waste incineration fly ash: State-of-the-art technologies and future perspectives, J Hazad Mater. **411** (2021) 125-132. Doi: 10.1016 / j.jhazmat.2021.125132.
25. Ministry of Natural Resources and Environment. - Special Topic on Domestic Solid Waste Management, Report on the State of the National Environment 2019, Dan Tri Publisher, Ha Noi, 2020, (in Vietnamese).
26. Quina M. J., Bontempi E., Bogush A., Schlumberger S., Weibel G., Braga R., Funari V., Hyks J., Rasmussen E., Lederer J. - Technologies for the management of MSW incineration ashes from gas cleaning: New perspectives on recovery of secondary raw materials and circular economy, Science of The Total Environment. **635** (2018) 526-542. Doi.org/10.1016/ j.scitotenv.2018.04.150.
27. C. Ferreira , A. Ribeiro, L. Ottosen. - Heavy Metals in MSW Incineration Fly Ashes, Journal de Physique IV **107** (2003) 463–466. Doi.org/10.1051/jp4:20030341.
28. Phua, Z., Giannis, A., Dong, ZL. *et al.* - Characteristics of incineration ash for sustainable treatment and reutilization, Enviroment Science and Pollution Research **26** (2019) 16974-16997. Doi: 10.1007 / s11356-019-05217-8.

29. Zhu J., Hao Q., Chen J., Hu M., Tu T., Jiang C. - Distribution characteristics and comparison of chemical stabilization ways of heavy metals from MSW incineration fly ashes, Waste Management **113** (2020) 488-496. Doi: 10.1016 / j.wasman.2020.06.032.
30. Tchounwou P. B., Yedjou C. G., Patlolla A. K., Sutton D. J. - Heavy metal toxicity and the environment, in: Luch, A. (Eds.), Molecular, Clinical and Environmental Toxicology, Springer, Basel, 2012, pp. 133-164.