



Air Pollution Characteristics of Reclamation of Refuse Derived Fuel (RDF) Recovered from Cutting Oil Waste

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ABSTRACT

The object of this study is to investigate the emission characteristics of reclamation of refuse-derived fuel (RDF) to evaluate the feasibility of substitution of RDF for current fuels. The cutting oil collected from a canned-food factory was pretreated, mixed with wood dust and bentonite, and was remolded into pellet RDF. Input materials, including coal, wood dust, and remolded RDF, were reclaimed in a steam generation plant. The pollutant characteristics of bottom ash, fly ash, and flue gas were analyzed to evaluate the combustion performance of the tested fuels. The PCDD/F concentration of the flue gas in the runs without coal (19.6 and 21.9 ng I-TEQ Nm⁻³) was two orders higher than those in the runs with coal (0.226 and 0.017 ng I-TEQ Nm⁻³) due to partial smoldering. Except for coal, the substitution of RDF for wood dust also reduced the formation of PCDD/Fs. According to the monitoring data for CO, O₂, and combustion efficiency, RDF further improved the combustion condition with the aid of coal. The results show that reclamation of RDF is a promising method to take both waste treatment and energy regeneration into consideration.

Keywords: Combustion efficiency; Ash; RDF; Wood dust; Coal.

INTRODUCTION

Due to the current economic growth, the amount of waste generated has increased rapidly during the last several decades. The treatment of waste has thus become a worldwide issue. Therefore, a European strategy for waste management imposed a regulation on the following waste hierarchy to apply as a priority in waste management and treatment: prevention, reuse, recycling, recovery of energy or resources, and disposal (Directive 2008/98/EC). Among the management and treatment strategies, the recovery of energy from waste has been investigated for the last few decades (Chang *et al.*, 1999). There are three available processes, including combustion, gasification, and pyrolysis, to convert biowaste into energy.

Among them, the combustion process, generally called incineration, is the most commonly used treatment technology for solid waste (Lombardi *et al.*, 2015).

The incineration process converts waste into different forms of energy, such as electricity, steam, and process heat for the utilization of industrial facilities (Murer *et al.*, 2011; Vermeulen *et al.*, 2011). Incineration allows efficient treatment of different types of waste, including municipal solid waste, organic sludge, refuse-derived fuels (RDFs), and even unsorted residual waste (Arena, 2012; Myrin *et al.*, 2014; Leme *et al.*, 2014). In addition, incineration at a high temperature is an efficient technology by which to convert waste into energy and has several advantages.

First, incineration greatly reduces the mass (about 70–80%) and the volume (about 80–90%) of the waste and preserves landfill space (Consonni *et al.*, 2005). It can destroy organic contaminants (Buekens and Cen, 2011) and reduce greenhouse gas emissions in comparison with anaerobic decomposition (Psomopoulos *et al.*, 2009). According to life cycle assessment studies, it alleviates environmental burdens due to the generation of energy from various kinds of wastes (Arena *et al.*, 2003; Azapagic *et al.*, 2004).

From a sustainable development perspective, the production

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of refuse-derived fuel (RDF) is a promising waste-to-energy technology which has been utilized in the past few decades to solve both waste and energy problems simultaneously (Rada and Andreottola, 2012). Processed waste with high calorific value was segregated, mixed, and remolded into RDF (Nasrullah *et al.*, 2015). The reclamation of RDF using thermal processes has received worldwide attention due to its effective recovery of energy from the solid waste (Zhou *et al.*, 2013; Gug *et al.*, 2015). However, persistent organic pollutants are inevitably generated because the RDF is reclaimed using a thermal process (Myrin *et al.*, 2014; Nam-Chol and Kim, 2017). Therefore, the pollutant characteristics of RDF during incineration deserve more detailed investigation.

In the can manufacturing process, cutting oil is used to lubricate cutting tools and dissipate the heat. After operation for a period of time, the quality of the cutting oil deteriorates and must be renewed. The spent cutting oil waste has water, heavy metals and impurities and, thus, requires further disposal. The main component in cutting oil is palm oil, due to its high heating value and the fact that it is suitable to recover as a fuel. Water, heavy metals, and impurities must be removed before remolding spent cutting oil waste into RDF to avoid secondary pollution. However, palm oil is in the form of an ointment at room temperature and has to be heated for the purpose of being melted before the separation process.

In this study, spent cutting oil waste collected from a canned-food factory was pretreated, mixed with wood dust, and remolded into RDF. The pollutant characteristics during the reclamation of RDF in a steam generation plant were investigated. The pollutant characteristics of the flue gas, fly ash, and bottom ash were evaluated under various combustion conditions to assess the RDF reclamation performance.

METHODS

Preparation of RDF and Input-materials of Tests

The spent cutting oil waste was collected from a canned-food factory located in Southern Taiwan. The oil waste under consideration was stored in 55-gallon oil drums and transported to Shi-Chang Co., Ltd. for further treatment. Fig. 1 shows a flow chart of the RDF manufacturing process. Because it is in a solid form at room temperature, the spent cutting oil waste had to be heated to above 70°C and melted to reduce its viscosity. The fluidized oil waste was spun at a

rotation speed of 11,000 rpm using a centrifugation unit to remove its water content, heavy metals, and impurities. Before being cooled down, the treated oil waste was mixed with wood dust and bentonite. The wood dust served as an additive to adjust the heat value and increase the physical strength of the RDF. Bentonite is an absorbent aluminium phyllosilicate clay consisting mostly of montmorillonite that serves as a binder for ointment and wood dust. The ingredients of the RDF in this study included treated ointment (65.5 wt%), wood dust (34 wt%), and bentonite (0.5 wt%). The mixed materials were compressed at a pressure of 20 kg cm⁻² to form pellet RDF with a diameter of approximately 5 cm.

There were three fuels, coal, RDF, and wood dust, used in the combustion tests for which the properties are shown in Table 1. The coal, classified as sub-bituminous coal, comprised 78.5% combustibles and was mainly composed of C (77.3%). It provides 5,230 kcal kg⁻¹ of energy, 16.3% of which is bottom ash during the combustion process. In the case of the wood dust, the ternary components were moisture (11.1%), combustibles (88.4%), and ash (0.5%). The element composition of the combustibles included C (58.6%), O (20.6%), and H (7.28%), with a trace of N (0.05%), S (0.27%), and Cl (< 0.01%). The wood dust had a low heating value of 3,370 kcal kg⁻¹, and the metal content was non-detectable.

The RDF had 86.8% combustibles and low heating value of 5,800 kcal kg⁻¹. The combustibles were mainly composed of C (58.6%), O (20.6%), and H (7.28%), with a trace of N (0.05%), S (0.27%), Cl (< 0.01%), Cu (490 mg kg⁻¹), and Cr (262 mg kg⁻¹).

Reclamation of RDF in Steam Generation Plant

The remolded RDF was transported to a steam generation plant located in Northern Taiwan. The plant operating processes are shown in Fig. 2. Input materials, including RDF, coal, and wood dust were mixed in advance and fed into the combustion chamber via a chain-driven feeding unit. Table 2 shows the ingredients of the input materials in the four runs. To clarify the role of coal in the combustion process, the four runs were divided into Group I (without coal) and Group II (with coal). For Group I, 100% wood dust and half-and-half RDF and wood dust served as the input materials in runs 1 and 2, respectively, to evaluate the combustion performance when RDF was substituted for the wood dust. In Group II, 50% coal was used, and wood dust

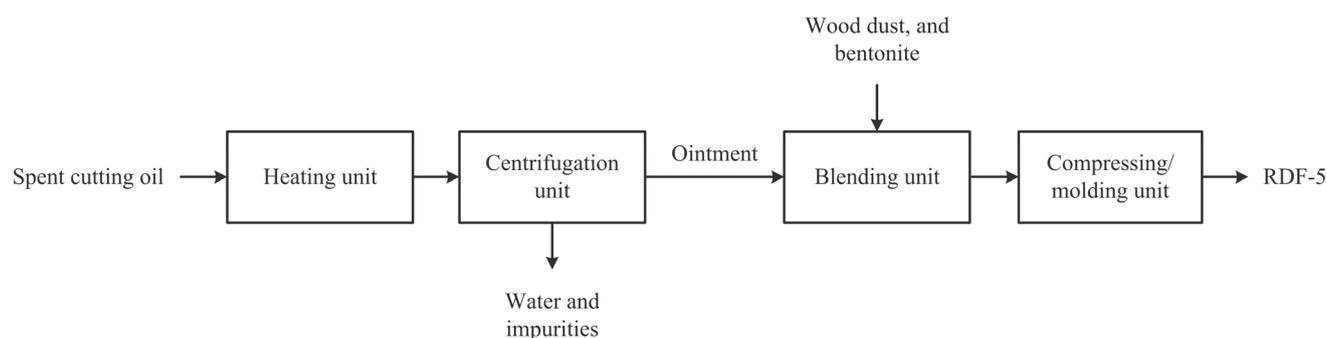
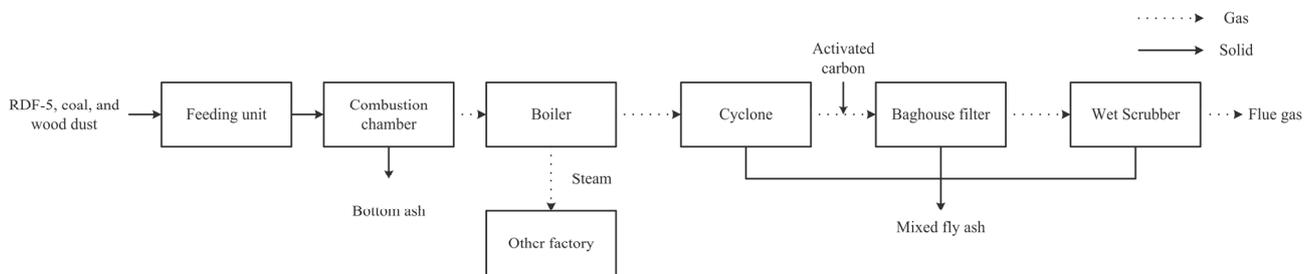


Fig. 1. RDF preparation process.

Table 1. Properties of coal, wood dust, and RDF.

	Item	Coal	Wood dust	RDF
Ternary component	Moisture (%)	5.2	11.1	5.9
	Combustibles (%)	78.5	88.4	86.8
	Ash (%)	16.3	0.50	7.3
Combustibles (%)	C	77.3	51.6	58.6
	H	0.3	6.82	7.28
	O	0.8	41.5	20.6
	N	< 0.01	0.06	0.05
	S	0.05	0.02	0.27
	Cl	< 0.01	< 0.01	< 0.01
	Heavy metals (mg kg ⁻¹)	Cd	3.82	N.D.
	Cr	5.32	N.D.	262
	Cu	25.0	N.D.	490
	Hg	0.56	N.D.	0.22
	Ni	0.75	N.D.	129
	Pb	3.38	N.D.	4.54
Low heating value (kcal kg ⁻¹)		5,230	3,370	5,800

**Fig. 2.** RDF reclamation plant process flow diagram.**Table 2.** The input materials in the RDF reclamation process.

Input-materials	Group I (without coal)		Group II (with coal)	
	Run-1	Run-2	Run-3	Run-4
Coal	0	0	50%	50%
RDF	0%	50%	0	50%
Wood dust	100%	50%	50%	0

and RDF accounted for the residual 50% in runs 3 and 4, respectively, to evaluate the effect of a similar substitution of RDF in the case with coal.

The capacity of the input materials in the combustion chamber was 2 ton hr⁻¹. The bottom ash was discharged into an ash pit and cooled using water. The flue gas emitted from the top of the combustion chamber passed through a boiler (LC-12, SZL) which generated steam sold to a nearby factory. The amount generated, the rated working pressure, and the rated steam temperature of the steam were 12 ton hr⁻¹, 10–16 kg cm⁻², and 183–203°C, respectively. The flue gas was cooled to approximately 300°C and was treated with a series of air pollution control devices, including a cyclone, a baghouse filter, and a wet scrubber. Coarse particulate (> 10 μm) was removed by the cyclone. After the cyclone removal, powdery activated carbon was injected to adsorb PCDD/Fs, and the particulates were filtered using the baghouse filter. Next, the wet scrubber was set to wash acid gas (HCl and SO₂) and then emitted to ambient air. The fly ashes emitted from the

cyclone, semidry scrubber, and baghouse filter were collected together as mixed fly ash.

Sampling of Flue Gas and Solid Specimens

The stack flue gas was sampled at the point after APCDs (air pollution control devices) which was set up to remove air pollutants in the flue gas. Before the sampling of the PCDD/Fs, known amounts of surrogate standards pre-labeled with isotopes (including ³⁷C₁₄-2,3,7,8-TeCDD, ¹³C₁₂-1,2,3,4,7,8-HxCDD, ¹³C₁₂-2,3,4,7,8-PeCDF, ¹³C₁₂-1,2,3,4,7,8-HxCDF and ¹³C₁₂-1,2,3,4,7,8,9-HpCDF) were spiked to measure the collection efficiency of the sampling train. The sampling work followed the standard sampling procedure of PCDD/Fs in stack flue gas (TEPA, 2010) for which the detailed procedure was given in a previous study. The sampling and analysis of metals followed the standard method given in National Institute of Environmental Analysis A302.72C (TEPA, 2006). A flue gas sampler equipped with a cooling device, a holder with a fiberglass filter, a series of impingers,

a pump, and a flow meter was used to sample flue gas isokinetically at an average flow rate of 5 L min⁻¹. The detail sampling and analysis procedure of metals in flue gas were given in a previous study (Tsai *et al.*, 2018; Chen *et al.*, 2019).

A flue gas analyzer (E Instruments Combustion Analyzers, E6000) was used to continuously measure the gas concentrations of O₂, CO₂, CO, NO_x, and SO_x in the flue gas after the use of the APCDs. In addition, bottom ash and mixed fly ash were collected from the ash pits for further analysis.

Analysis for PCDD/F, Metal Content, and Metal Leaching Behavior

The solid specimens were pretreated using a series of steps as follows: extraction with a mixed solvent (half-and-half *n*-hexane and dichloromethane), determination of the nitrogen-blowing concentration, cleanup using silica gel, and nitrogen-blowing re-concentration for the PCDD/F analysis. The solutions were then analyzed using a high-resolution gas chromatograph (Hewlett-Packard 6970 Series gas, CA) and high-resolution mass spectrometer (Micromass Autospec Ultima, Manchester, UK) to identify seventeen PCDD/F congeners. The procedure for the PCDD/F analysis was conducted following a procedure given in a previous study (Han *et al.*, 2017; Tsai *et al.*, 2018).

To analyze the metal content, the solid specimens were all pulverized and digested using concentrated mixed acid following a digestion procedure, modified from the standard method provided in NIEA R317.10C (TEPA, 2002). The pulverized solid specimens (~0.1 g) were added to a mixed acid composed of 3 mL HCl (32 wt%) and 3 mL HNO₃ (67 wt%). The mixture was held in sealed Teflon vessels and heated using a microwave digester (MARS Xpress, CEM). The specimens were all heated to 200°C at a rate of 6°C min⁻¹, held isothermally for 20 min, and cooled down to room temperature with forced ventilation. The digested solutions were diluted with deionized water to 50 mL and filtrated using mixed cellulose ester filters for further analysis.

The hazardous metal mobility of the bottom ash and mixed fly ash was evaluated using a toxicity characteristic leaching procedure (TCLP). An acid solution (pH = 4.93 ± 0.05) was prepared as follows: 5.7 mL glacial acetic acid and 64.3 mL NaOH solution (1 N) were added to 500 mL deionized water and were diluted using deionized water to 1000 mL. The solid specimen and prepared solution were mixed with a mass ratio of solid:liquid = 1:20. The mixture was shaken overhead at 30 ± 2 turn min⁻¹ for 18 hrs. The leachate was

digested using concentrated HNO₃ and filtered for further analysis. The detail procedure, including solution preparation, leaching conditions, dilution, digestion, and filtration, all followed the standard method stated in TEPA, 2003. The metal concentrations, including Cd, Cr, Cu, Hg, Ni, and Pb, in solution and digests were measured using atomic absorption spectroscopy (AAS, Agilent technologies 50AA).

RESULTS AND DISCUSSION

Pollutants Characteristics of Flue Gas

The concentrations of the air pollutants in the flue gas are shown in Table 3 and Fig. 2. In the case of the heavy metals, the concentrations in the flue gas in all four runs were much lower than those specified in the regulated standard. In Group I, the PCDD/F concentrations in the flue gas (19.6 and 21.9 ng I-TEQ Nm⁻³) were obviously higher than those (0.017 and 0.226 ng I-TEQ Nm⁻³) in Group II. An extremely high concentration of PCDD/Fs has been proven to be harmful to public health (Heiesh *et al.*, 2018; Hung *et al.*, 2018). Fig. 3 shows the PCDD/F patterns of the flue gas. The PCDD/F patterns of Figs. 3(a) and 3(b) were alike, and the PCDD/F mass mainly distributed in 2,3,7,8-TeCDF, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 2,3,4,6,7,8-HxCDF, and 1,2,3,4,6,7,8-HpCDF. As shown in Figs. 3(c) and 3(d), the patterns were somewhat similar, where the predominant PCDD/F congeners were OCDF, OCDD, and 1,2,3,4,6,7,8 HpCDF. The PCDD/F mass in the runs without coal was mainly distributed in 4-Cl to 6-Cl PCDD/Fs, while that in the runs with coal mainly existed as 7-Cl and 8-Cl PCDD/Fs.

The continuous monitoring results and the regulated standard of the flue gas are shown in Fig. 4 and Table 4 (TEPA, 2018). Similar to the results for the PCDD/F patterns, the [CO] and [O₂] results in the same group were similar. In Fig. 4(a), many sharp peaks of [CO], probably resulting from partial smoldering, could be observed in the deep trough of [O₂] at the same time. Obviously, CO was largely generated during the condition of low [O₂]. The replacement of 50% wood dust by RDF slightly reduced the averaged [CO] from 1240 to 886 ppm, and the averaged combustion efficiency (= ([CO₂]/([CO₂] + [CO]) × 100%) was improved from 96.98% to 97.59%. In addition, the [O₂] slightly increased, and the fluctuations in [O₂] were also abated. For runs 3 and 4, the coal addition improved the combustion efficiency to > 98%, and the [O₂] went up to >16%. Thus, a great reduction of [CO] was observed in the two runs. This indicated that the

Table 3. Concentration of pollutants in the flue gas.

Item	Group I (without coal)		Group II (with coal)	
	Run-1	Run-2	Run-3	Run-4
PCDD/Fs (ng I-TEQ Nm ⁻³)	19.6	21.9	0.226	0.017
Cd (mg Nm ⁻³)	0.0172	0.0032	0.0264	0.0029
Cr (mg Nm ⁻³)	0.0183	0.0143	0.0152	0.0153
Cu (mg Nm ⁻³)	0.0546	0.0458	0.0347	0.0332
Hg (mg Nm ⁻³)	0.0001	0.0017	0.0004	> 0.0001
Ni (mg Nm ⁻³)	0.0079	0.0068	0.0057	0.0056
Pb (mg Nm ⁻³)	0.331	0.0824	0.0261	0.0751

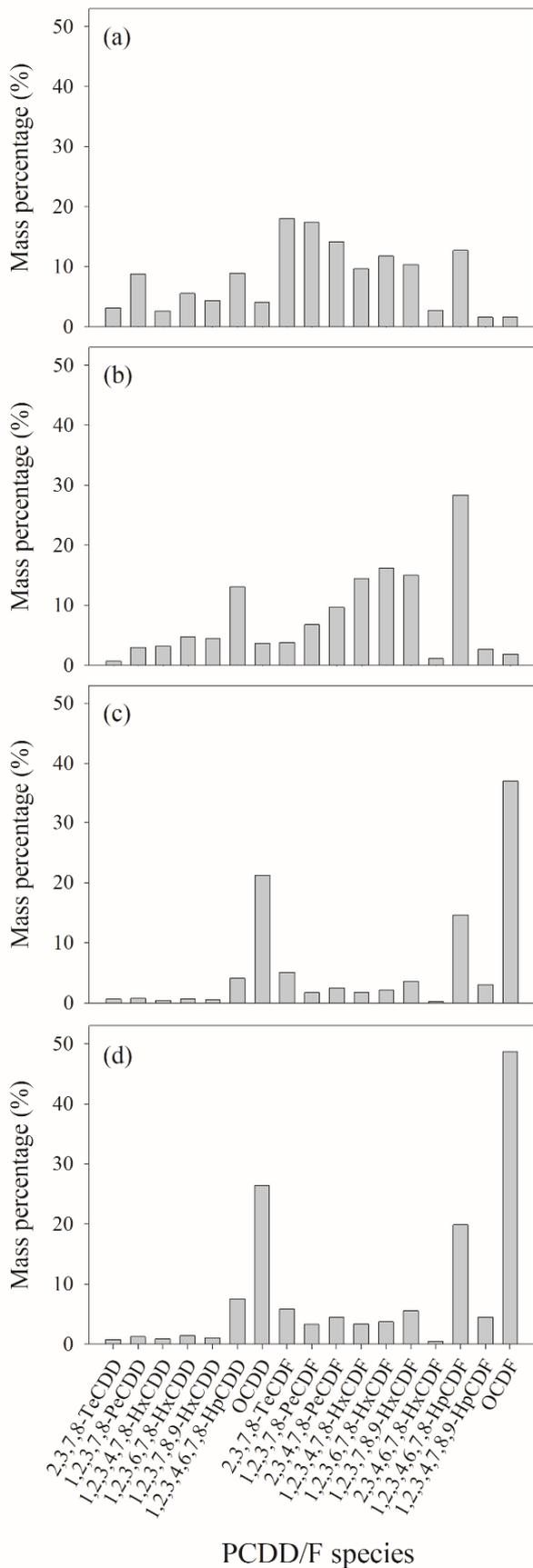


Fig. 3. PCDD/F profile of the flue gas in all runs: (a) Run-1; (b) Run-2; (c) Run-3; (d) Run-4.

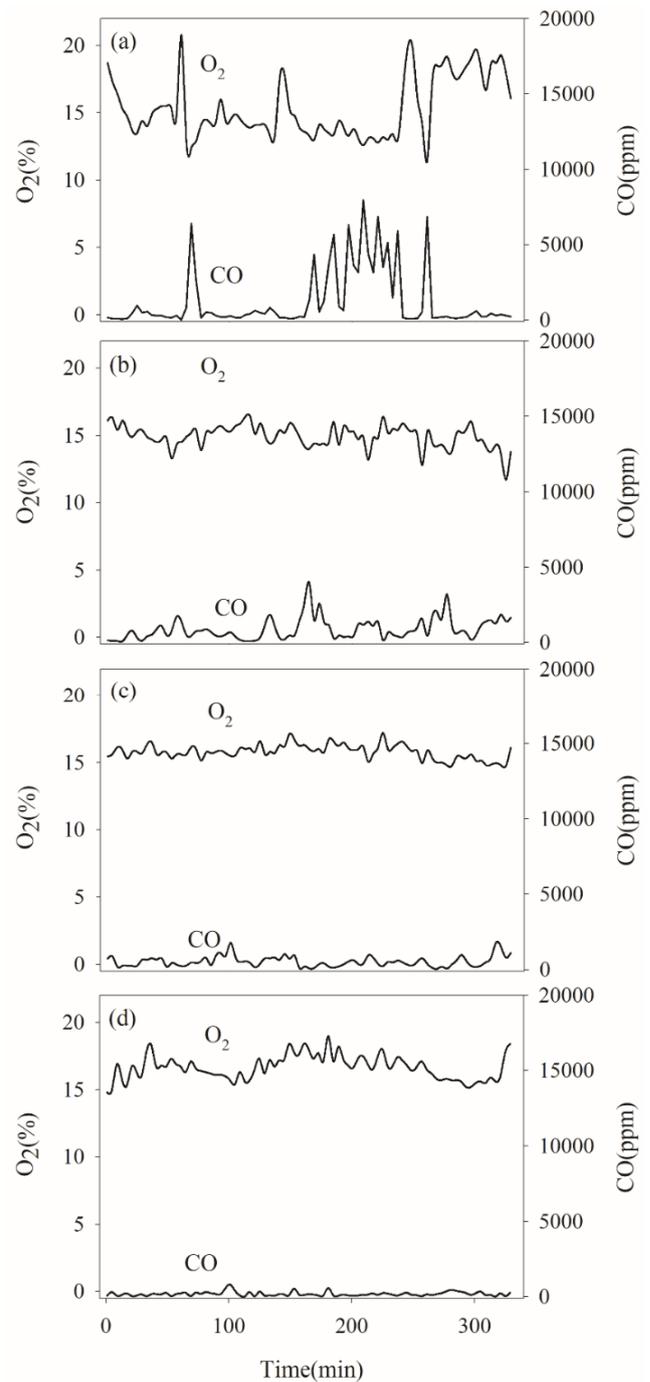


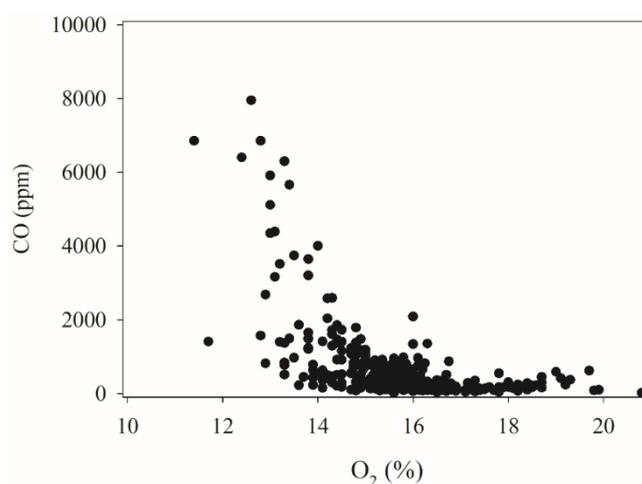
Fig. 4. Time sequence of [CO] and [O₂]: (a) Run-1; (b) Run-2; (c) Run-3; (d) Run-4.

combustion with coal was more stable than that without coal, revealing that coal improves combustion conditions.

The substitution of RDF for wood dust further reduced the [CO] from 365 ppm to 192 ppm and improved the combustion efficiency from 98.65% to 99.18%. Fig. 5 illustrates the [CO] versus [O₂] in the flue gas, which shows that the [CO] suddenly went up to an extremely high level while the O₂ concentration went down to > 14%. On the contrary, the [CO] was notably reduced when the [O₂] was higher than 16%.

Table 4. Concentration of pollutants in the flue gas.

Item	Group I (without coal)				Group II (with coal)				Regulated standard
	Run-1		Run-2		Run-3		Run-4		
	Average	RSD(%)	Average	RSD(%)	Average	RSD(%)	Average	RSD(%)	
O ₂ (%)	15.3	14.3	15.0	5.7	16.1	8.6	16.7	5.4	--
CO ₂ (%)	3.16	38.6	3.35	3.34	4.17	3.65	2.37	21.32	--
CO(ppm)	1240	157	886	82.6	365	76.8	192	74.3	--
NO _x (ppm)	90.2	15.9	60.5	78.1	117	38.5	42.0	25.4	100
SO _x (ppm)	45.0	109	7.0	14.3	22.0	35.1	6.7	81.5	50
Combustion efficiency (%)	96.98	3.8	97.59	1.76	98.65	0.54	99.18	0.65	--

**Fig. 5.** [CO] vs. [O₂] in the flue gas.

Pollutants Characteristics of Mixed Fly Ashes

Table 5 shows the level of PCDD/Fs and heavy metals in all runs. Due to partial smoldering, the fly ashes in Group I had much higher levels of PCDD/Fs than those in Group II. The replacement of 50% wood dust with RDF noticeably reduced the PCDD/F levels in the fly ash from 196 to 24.5 ng I-TEQ g⁻¹. However, the PCDD/F levels in the fly ash were still extremely high compared with those from the municipal solid waste incinerator due to poor combustion conditions (Wang *et al.*, 2010). According to Fig. 4, the combustion in Group II was improved by coal, and thus the PCDD/F content in the fly ash was reduced to 4.95 ng I-TEQ g⁻¹ in run 3. With the substitution of RDF for 50% wood dust, the PCDD/F content was further reduced to 0.03 ng I-TEQ g⁻¹. For the bottom

ash, the PCDD/F level was much lower than that of the fly ash in the same run. The substitution of RDF for the wood dust also helped reduced PCDD/F levels from 0.348 to 0.007 and from 0.002 to 0.001 ng I-TEQ g⁻¹ in groups I and II, respectively.

The PCDD/F levels in the fly ash were two to four orders higher than those in the bottom ash. Therefore, the PCDD/F profiles of fly ash deserve investigation and are shown in Fig. 6. The PCDD/F profiles in Figs. 6(a) and 6(b) are similar and the similarity is consistent to the result of combustion condition (Figs. 4(a) and 4(b)). The consistence indicates that the RDF did not have significant effects leading to improvement in the combustion conditions in the case without coal as input materials.

Table 5. Content of pollutants in the fly ashes.

Item	Group I (without coal)				Group II (with coal)			
	Run-1		Run-2		Run-3		Run-4	
	FA	BA	FA	BA	FA	BA	FA	BA
PCDD/Fs (ng I-TEQ g ⁻¹)	196	0.348	24.5	0.007	4.95	0.017	0.03	< 0.001
Cd (mg kg ⁻¹)	180	4.88	294	1.22	0.52	0.03	0.74	0.31
Cr (mg kg ⁻¹)	113	156	104	870	130	250	118	201
Cu (mg kg ⁻¹)	747	2,960	874	970	440	750	293	536
Hg (mg kg ⁻¹)	6.83	1.14	2.3	0.28	0.335	0.158	0.267	N.D.
Ni (mg kg ⁻¹)	14.9	46.1	65.6	370	210	450	190	230
Pb (mg kg ⁻¹)	4,740	87.0	6,050	23.8	125	45.5	24.7	5.43

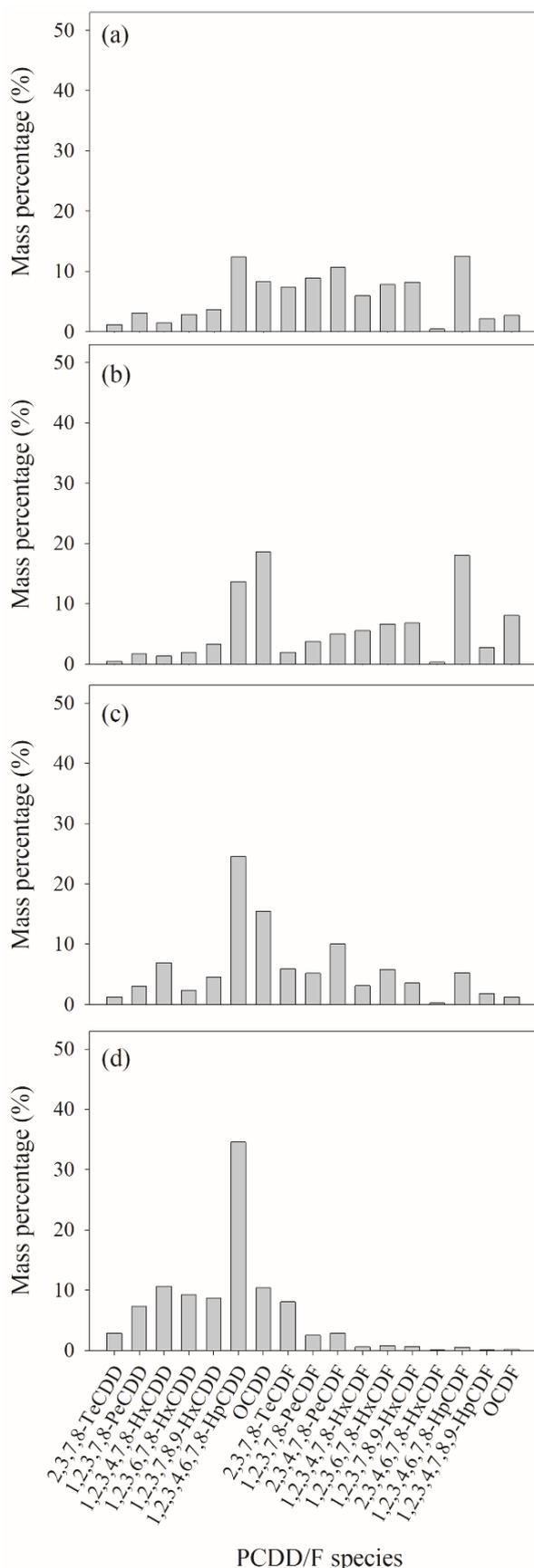


Fig. 6. PCDD/F profile of fly ashes in the runs with RDF: (a) Run-1; (b) Run-2; (c) Run-3; (d) Run-4.

For run 2, the fly ash and bottom ash had similar profiles. The predominant PCDD/F congeners were OCDD, 1,2,3,4,6,7,8-HpCDF, and 1,2,3,4,6,7,8-HpCDD, for which their mass fractions were all roughly 20%. For run 4, 1,2,3,4,6,7,8-HpCDD (34.6%) was the major PCDD/F species in the fly ash, and 1,2,3,7,8-PeCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, OCDD, 2,3,7,8-TeCDF all accounted for approximately 10% of the PCDD/F mass. In the bottom ash, the major PCDD/F congener was OCDD (38.9%), and the mass fractions of other congeners, including 1,2,3,4,6,7,8-HpCDD, 2,3,7,8-TeCDF, 1,2,3,4,6,7,8-HpCDF, and OCDF, were all roughly 10%.

In Group I, the fly ashes had much higher levels of Pb (4,740 mg kg⁻¹ in Run 1 and 6,050 mg kg⁻¹ in Run 2). With the exception of these, the heavy metal levels in the ashes were all much lower than 5000 mg kg⁻¹. The ashes in Group I had slightly higher levels of Cu than those in Group II, and BA had higher Cu levels than FA in the same run. The Pb and Cu might have come from the wood dust. Overall, heavy metals (Cd, Hg, and Pb) with low boiling points mainly were present in the fly ash, while those with high boiling points (Cr, Cu, and Ni) tended to stay in the bottom ash.

Table 6 shows the TCLP results for the ashes. For the fly ashes in Group II, the leaching concentration of the metals were all under the regulated standard. The Cd leaching concentration of fly ashes in Group I exceeded the regulated standard (TEPA, 2012). Therefore, the fly ash was declared to be a hazardous material and had to be solidified with cementation or vitrification before being transported to a landfill (Kuo *et al.*, 2003). The bottom ashes were declared to be non-hazardous materials and could be directly recycled as building materials. Overall, the TCLP concentrations in the ash for the runs in Group I were slightly higher than those in Group II.

CONCLUSIONS

This study investigated the combustion performance of RDF, wood dust, and coal. For Group I, the PCDD/F concentrations of flue gas (19.6 ng I-TEQ Nm⁻³ in run-1 and 21.9 ng I-TEQ Nm⁻³ in run-2) were two orders higher than those (0.017 ng I-TEQ Nm⁻³ in run-3 and 0.226 ng I-TEQ Nm⁻³ in run-4) for Group II, indicating that smoldering might occur under combustion conditions without coal. The substitution of RDF for wood dust by 50% slightly reduced the averaged CO concentration from 1240 to 886 ppm, and the averaged combustion efficiency was improved from 96.98% to 97.59%. With coal, the combustion condition was more stable, and the combustion efficiency was improved to approximately 99%. The results show that substitution of RDF for wood dust improved the combustion efficiency regardless of whether the combustion scenario included coal.

In the analysis of the [CO] versus [O₂] in the flue gas, the [CO] was greatly reduced while the [O₂] was higher than 16%. Smoldering often occurred in the [O₂] < 14% scenario, and [CO] peaks appeared. The TCLP results showed that bottom ash could be considered a non-hazardous material and could be directly recycled as a building material. Overall, the involved RDF was proven to be a suitable substitute for wood dust, especially in the combustion scenario with coal.

Table 6. TCLP results for the ashes.

Item	Group I (with coal)				Group II (without coal)				Regulated standard
	Run-1		Run-2		Run-3		Run-4		
	FA	BA	FA	BA	FA	BA	FA	BA	
Cd (mg L ⁻¹)	1.43	0.09	2.21	0.01	0.35	0.01	N.D.	N.D.	1.0
Cr (mg L ⁻¹)	0.62	0.40	0.44	0.13	0.36	0.15	0.011	< 0.010	5.0
Cu (mg L ⁻¹)	0.14	1.31	0.07	0.49	0.05	0.33	N.D.	N.D.	15
Hg (mg L ⁻¹)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.2
Pb (mg L ⁻¹)	0.4	0.15	0.21	0.11	0.2	0.17	N.D.	N.D.	5.0

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