OPTIMIZING OPERATION PARAMETERS FOR REDUCING PCDD/F EMISSIONS FROM THE IRON ORE SINTERING PROCESS

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Abstract

This study is set out to optimize the operation parameters to reduce PCDD/F emissions from the iron ore sintering process. A pilot scale sinter pot is used to simulate various sintering conditions. The method of the Taguchi experimental design is adopted in this study and the water content (range = 6.0–7.0 wt %), suction pressure (range = 1000–1400 mmH_2O), bed height (range = 500–600 mm) and type of hearth layer (including sinter, hematite, and limonite) are the four selected operation parameters. PCDD/F samples are collected from the sinter pot exhaust by using an isokinetic sampling system. The resultant optimal operation parameters are: water content 6.5%, bed height 500 mm, suction pressure 1000 mmH_2O, and hearth layer of 10-15 mm hematite. The amount of total PCDD/F emissions decrease up to 34.2% with the decrease of the gas-phase PCDD/Fs up to 53.2% in comparison with reference operation condition which is currently used in the real-scale sinter plant. The result ANOVA analysis indicates that the water content is the major contributor for decreasing PCDD/F emissions. In addition, the sinter productivity and sinter strength are found being slightly increased indicates that the resultant optimal operation parameters are also applicable in the real situation.

Introduction

The discovery of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) from the fly ash of a municipal solid waste incinerator (MSWI) was first reported in 1977[1]. Since then, PCDD/F emissions from various emission sources, such as MSWI, power generation, metallurgical process and chemical-industrial sources has became a significant environmental issue[2]. Among them, PCDD/F emissions from iron ore sinter plants has been recognized as a major source emitted into ambient environments[3-5]. The formations of PCDD/Fs in the sintering process are not only related to precursor reactions but also affected by combustion conditions of raw mixtures[6]. In order to comply with future PCDD/F emission standard and decrease the cost resulting from end-pipe PCDD/F control technologies, it is important to develop an effective method for directly reducing PCDD/F emissions during the sintering process. In principle, four operating parameters, including the water content, suction pressure, bed height and type of hearth layer, are factors affecting combustion conditions during the iron ore sintering process[7, 8]. However, the influences of the above mentioned operation parameters on PCDD/F emissions from the sintering process are limited and hence warrants the need for further investigation.

In this study the Taguchi experimental design is used to optimize operation parameters to reduce PCDD/F emissions from the sintering process. Two important indexes, the sinter productivity and sinter strength, widely used for characterizing the quality of the sintering process are also examined to further validate the appropriateness of the resultant operating parameters. Results obtained from this study can not only provide a useful operating combination to reduce PCDD/F emissions from the sintering process, but also can ensure its sintering quality.

Material and Methods

The Pilot Scale Sinter Pot and Its Operating Procedures- Iron ore sintering is an agglomeration process to convert iron ore fines into lumpy agglomerates. During sintering, the raw mixture of iron ore is first ignited by gas-fueled (nature gas) burns situated at the beginning of the steel belt conveyer. Then, the sinter bed is heated to temperature ~1000 ºC or above. Suction air passes through the sinter layer by means of wind legs and a fan, which moves the melting zone to the down layer to produce sintered products. In order to simulate the real-scale sintering process, a pilot scale sinter pot is used in this study (Fig. 1). The sinter pot includes a sinter pot body, an ignition hood, and a windbox which is connected to an exhaust duct. The size of the pot is 330 mm in diameter and 600 mm in height. The suction pressure is controlled by an electromagnetic valve. Six kilogram of sinter with particle diameters 10‒15 mm and 40 mm in thickness is used as the hearth layer. During sintering, the designated ignition temperature is around 1150‒1200 ºC for 1.5 minutes in ignition hood and then holds in another 1.5 minutes for keeping heat. Starting from the ignition to the removal of the ignition hood, the suction pressure is controlled at 800 mmH_2O. 3 minutes later, it is raised to 1200 mmH_2O and then keeps constant throughout the end of the sintering process. The total sintering time is around 35 minutes depending on the experimental conditions. In this study, a blending of the iron ore (52.8 wt %), coke breeze (4.0 wt %), anthracite (1.84 wt %), serpentine (0.42 wt %), marble (1.98 wt %), slurry (0.56 wt %), and return fine (31.5 wt %; including sinter plant and blast furnace return fine), and mini-pellet (1.50 wt %), which is similar to the one used in the real-scale sinter plant, is served as the raw mixture. The mean granular size range of the above raw material is 1.0‒6.3 mm.

Selected Experimental Parameters for the Taguchi Experimental Design‒ Four experimental parameters, including water content, suction pressure, bed height, and type of hearth layer, are selected variables used in this study. A specific operation condition (the water content 6.5 wt %, suction pressure 1200 mmH_2O, bed height 550 mm and sinter of hearth layer) which is used in the real-scale sinter plant is served as a reference combination. The ranges of the four selected experimental parameters are: water content (6.0 wt %–7.0 wt %), suction pressure (1000 mm H_2O‒1400 mm H_2O), bed height (500 mm–600 mm), and the type of the hearth layer (including sinter, hematite, and limonite). Table 1 shows the selected three levels for each experimental parameter. An $L9(3^4)$ orthogonal array with four columns and nine rows is used based on the Taguchi experimental design. Nine experiments representative to the three selected levels for each individual parameter are conducted. Since the experimental design is orthogonal, it is possible to discriminate the effect of each individual parameter at each designated level. Each experiment are repeated twice (n=2) in this study.

PCDD/Fs sampling and analysis‒ A Graseby Anderson stack isokinetic sampling system complying with U.S.EPA Method 23 is used in this study for sampling PCDD/Fs from the flue gas. Seventeen 2,3,7,8-substituted PCDD/F congeners are analyzed by a high-resolution gas chromatography (HRGC; Hewlett-Packard 6890 plus)/high resolution mass spectrometer (HRMS; JEOL JMS-700D). Detailed sampling, analytical procedures, and QA/QC results are described in our previous works[9].

Evaluation of sinter productivity and strength‒ The sinter productivity, expressed in tons per square meter of grate area of sintering machine per day, is calculated from the sintering time, the cross-sectional area of the pot grate, and the weight of sinter product recovered from the test (by removing the loss of the weight of hearth layer). The sinter strength is measured by using a modified ISO 3271 test method. Detailed descriptions are presented in our previous works[10].

Data analysis‒ The S/N ratio based on the concept of the-lower-the-better is used to characterize PCDD/F concentrations. The analysis of variance (ANOVA) is used to investigate the effect of each individual parameter on PCDD/F emissions, while the resultant *p*-value is less than 0.05 suggesting a statistical significance. The 2,3,7,8-TCDD toxic equivalent concentrations of air samples are calculated by using the International Toxic Equivalent Factors (I-TEFs).

Table 1. Operating parameters and the selected levels for sintering process

Symbol	Parameter	Level 1	Level 2	Level 3
A	Water content (wt %)	6.5[a]	6.0	7.0
B	Suction pressure (mmH_2O)	1200[a]	1000	1400
C	Bed Height (mm)	550[a]	500	600
D	Hearth layer type	Sinter[a]	Hematite[b]	Limonite[c]

[a]: Initial operating parameter [b]: Fe_2O_3; [c]: $FeO(OH)\cdot nH_2O$

Results and Discussion

Table 2 shows S/N ratios based on resultant total PCDD/Fs for each individual parameter in three designated levels according to its orthogonal array experimental arrangement. The total mean S/N ratio and PCDD/F concentrations are 0.989 dB and 0.942 ng I-TEQ/Nm^3, respectively. The difference between maximum S/N ratio and minimum S/N ratio (i.e., max-min) for a given parameter at the three designated levels represents the effect on the PCDD/F emissions. Results show the parameter affecting PCDD/F emissions in sequence is water content (8.35 dB), hearth layer (4.63 dB), suction pressure (3.33 dB), and bed height (2.69 dB). The analysis of variance (ANOVA) is used to investigate which design parameters significantly affect PCDD/F emissions (not shown). The result indicates that water content is the significant (p=0.035) operating parameter for PCDD/F emissions. Both water content and hearth layer are the top two dominant factors affecting PCDD/F emissions, in total accounting for 55.3% and 17.4%, respectively. Both hematite and limonite used in the hearth layer can slightly decrease PCDD/F emissions because of their oxidation catalytic function[8].

Table 2. S/N response for the total PCDD/Fs

Symbol	Parameter	Mean S/N ration (dB)				
		Level 1	Level 2	Level 3	Max-Min	Rank
A	Water content	4.89	1.53	-3.46	8.35	1
B	Suction pressure	-0.513	2.82	0.661	3.33	3
C	Bed height	0.043	2.74	0.188	2.69	4
D	Hearth layer	-1.58	3.05	1.50	4.63	2

Table 3 shows the levels, total PCDD/Fs and S/N ratios for the sintering processes under reference combination and optimal operation combination. For the former, the level, total PCDD/Fs and S/N ratio are A1B1C1D1, 0.909 ng I-TEQ/Nm^3, and -0.127 dB, respectively. Based on the S/N ratio calculation, the prediction of optimal operation combination s for reducing PCDD/F emissions are the water content at level 1 (6.5 wt %), the suction pressure at level 2 (1000 mmH$_2$O), bed height at level 2 (500 mm), and type of hearth layer at level 2 (Hematite) (i.e., A1B2C2D2 as shown in Table 3). The predicted total PCDD/F concentrations and S/N ratio for the optimal operation combinations are 0.279 ng I-TEQ/Nm^3 and 10.5 dB, respectively. The corresponding values for confirmation are 0.596 ng I-TEQ/Nm^3 and 5.48 dB, respectively. The increase of the S/N ratio from the reference operating parameters to the optimal operation parameters is 5.61 dB indicating that PCDD/F emissions are decreased by about 34.2%.

Table 3. Comparison with the initial and optimal operation parameter for the level, total PCDD/Fs, and S/N ratio.

	Reference operation parameter	Optimal operation parameter	
		Prediction	Confirmation
Level	A1B1C1D1	A1B2C2D2	A1B2C2D2
Total PCDD/Fs (ng I-TEQ/Nm^3)	0.906	0.279	0.596
S/N ratios (dB)	-0.127	10.5	5.48

Figure 2 shows the amount of PCDD/Fs decreased in the reference and confirmation experiments for gas-phase PCDD/Fs, particle-phase PCDD/Fs, gas- and particle-phase PCDDs, and gas- and particle-phase PCDFs. The amount of gas-phase PCDD/Fs is decreased up to ~53.2% in comparison with the optimal operation combination with the reference combination. On the other hand, the reduction in particle-phase PCDD/Fs can not be seen. PCDD and PCDF concentrations are consistently reduced and PCDF/PCDD ratio is increased significantly from 3.70 to 11.5. The results indicate that the operation conditions of the sintering process could affect not only amount of PCDD/F emissions but also their congener profiles.

Besides the reducing of PCDD/F emissions by using the optimal operation parameters, their impact on the sinter productivity and sinter strength are also examined. In reference operation combinations, the sinter productivity and sinter strength are 29.9 t/m^2/24hr and 72.2%, respectively. We also find that the sinter productivity and sinter strength are respectively increased slightly to 30.3 t/m^2/24hr and 72.4% for the optimal operation combinations.

It is concluded that the use of optimized operation condition for the sintering process can not only reduce its PCDD/F emissions but also slightly improve its sinter productivity and sinter strength.

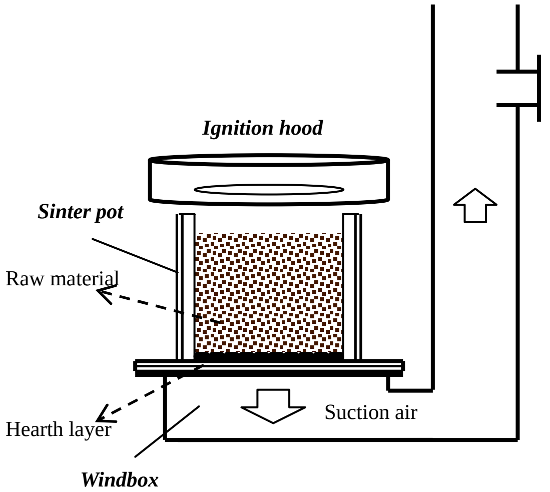

Fig. 1 Schematic diagram of experimental apparatus

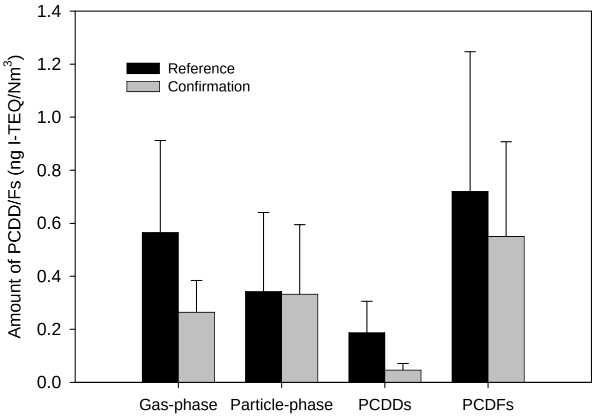

Fig. 2 The amount of PCDD/Fs decreased in the reference and confirmation experiments for gas-phase PCDD/Fs, particle-phase PCDD/Fs, gas- and particle-phase PCDDs, and gas- and particle-phase PCDFs.

Acknowledgements

We are grateful to China Steel Corporation (CSC) in Taiwan for supporting this research project.

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