Chinese J. Chem. Eng., 11 (1) 102 – 105 (2003)
RESEARCH NOTES

Plant Test of Industrial Waste Disposal in a Cement Kiln

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Abstract Destruction of industrial waste in cement rotary kilns (CRKs) is an alternative technology for the treatment of certain types of industrial waste (IW). In this paper, three typical types of industrial wastes were co-incinerated in the CRK at Beijing Cement Plant to determine the effects of waste disposal (especially solid waste disposal) on the quality of clinker and the concentration of pollutants in air emission. Experimental results show that (1) waste disposal does not affect the quality of clinker and fly ash, and fly ash after the IW disposal can still be used in the cement production, (2) heavy metals from IW are immobilized and stabilized in the clinker and cement, and (3) concentration of pollutants in air emission is far below than the permitted values in the China National Standard—Air Pollutants Emission Standard (GB 16297-1996).
Keywords incineration, industrial waste, cement rotary kiln, rotary kiln incinerator, clinker

1 INTRODUCTION

Incineration today is an important component in waste management policy all over the world. Waste incineration offers the real or potential advantages[1] such as volume reduction, especially for solids with high combustible content; detoxification, especially for combustible carcinogens, pathologically contaminated material, toxic organic compounds, *etc.*; environmental impact mitigation; and energy recovery.

Rotary kiln incinerators (RKIs) with operating temperature about 1000℃ are better suited to handle all physical forms of hazardous wastes. The disposal of industrial waste (IW) in cement rotary kilns has appeared as an alternative technology for the treatment of certain types of IW. The first burning test of this kind was performed in 1970 in the United States; afterwards, this technology was applied in Europe and Asia.

Many researchers[2,3] investigated the efficiency of destruction of waste used in the cement rotary kilns. The liquid IW was used to substitute a portion of traditional fuels (*e.g.*, coal, oil and natural gas) for final disposition of the IW. However, all these experiments were conducted to treat the liquid hazardous waste such as toluene, xylene and dichlroethane, without consideration of solid waste containing heavy metals. Therefore, as for incineration of solid hazardous waste, the effect of slag and ash, which will become a constituent of the cement after co-incineration, on quality of clinker or cement has not been determined.

In recent years, the disposal of IW (especially hazardous waste) in CRK has attracted much more attention from researchers and engineers in China because of its advantages over the conventional RKI. Several years ago, Jinshan Cement Plant in Shanghai obtained the license to dispose hazardous waste by a CRK. However, there is no research publication on disposal of IW in the cement rotary kiln up to now in China. All the hazardous waste incineration is carried out in the conventional RKI. To dispose the tremendous amount of IW generated in China, a great deal of fund has to be invested to install many more RKIs in the future.

In this paper, three kinds of IW were burnt as supplemental fuel in CRK at the Beijing Cement Plant. To determine the effects of disposal of IW on environment and quality of clinker, the pollutant concentration in the air emission and the composition of the clinker were determined. The concentration of heavy metal in the lixivium of clinker and cement block (the mass ratio of clinker to water is 1/10) was analyzed.

2 EXPERIMENTAL

2.1 Operating parameters of the CRK

A flow sheet for the clinker production in the Beijing Cement Plant is presented in Fig. 1. The operating parameters are shown in Table 1.

When the kiln runs normally, it can burn 150 t of raw materials per hour. The coal-consuming rate is 11—13 $t\cdot h^{-1}$. The heat demanded for a kilogram of raw material is 3260.4 $kJ\cdot kg^{-1}$. The air runs countercurrent to the feed flow and the airflow rate is about

Received 2001-10-18, accepted 2002-08-10.
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Table 1 Characteristic parameters of CRK

Length m	Diameter m	Slope %	Rotating speed $r\cdot min^{-1}$	Gas residence time s	Solid residence time, min	Temperature ℃
60	4	3.5	2.8—3.2	7.0	30—35	1750 (gas) 1450 (solid)

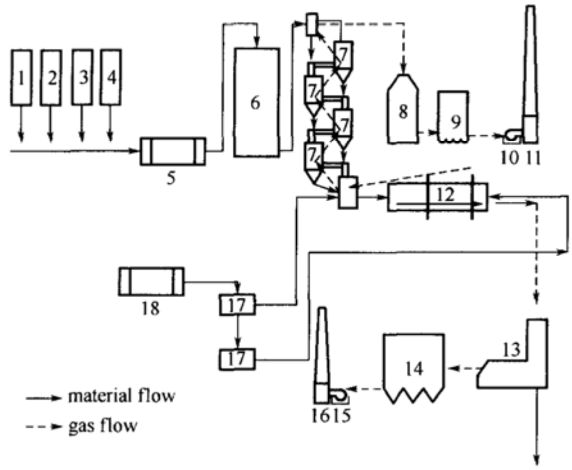

Figure 1 Technological flow sheet for the clinker preparation

1—quartzite; 2—Fe powder; 3—limestone; 4—coal ash; 5—crusher; 6—raw materials mixer; 7—preheating; 8—humidifier; 9—baghouse; 10, 15—fan blower; 11, 16—chimney; 12—rotary kiln; 13—cooling machine; 14—electro-precipitator; 17—pump for fuel coal fines; 18—ball grinder

$250000\,Nm^3\cdot h^{-1}$. The whole process is carried out safely and effectively under negative pressure (400 Pa below the normal atmosphere pressure).

2.2 Materials

Acrylic ester residue was supplied by Beijing Eastern Rohm & Haas Co., Ltd, which produces coating and paint residue was supplied by Beijing Light-duty Automobile Corporation (see Table 2). Waste oil from Beijing Langxun Optical Cable Corporation mainly consists of benzene, toluene, acetone, butanone and other organic solvents.

The supplemental fuels, acrylic ester residue (used in Exp. No. 1), paint residue (used in Exp. No. 2) and waste oil (used in Exp. No. 3), substituted almost 18% of the primary fuel. Their injection equalled $2000\,kg\cdot h^{-1}$; the primary fuel is coal from Shanxi Province. The 3 experiments continued for 6 days.

2.3 Analyses

Atomic absorption spectrometry (AAS 6 Falme, Germany) and ICP spectrophotometer (Spectro Ciroscсd, Germany) were used to analyze the chemical elements. The concentration of SO_2 in the flue gas was measured by spectrophotometry (China National Analysis Standard, GB/T 15262-94). The concentration of hydrocarbon compounds was measured by GC (TRACE GC 2000, USA).

3 RESULTS AND DISCUSSION

3.1 Effect of co-incineration on pollutant concentrations in the air emission

The pollutant concentration in the air emission (as seen in Table 3) was measured to determine the effect of industrial waste disposal on the environment. The height of the chimney is 40 m.

Table 2 Chemical analysis of the industrial wastes ($mg\cdot kg^{-1}$)

Wastes	Pb	Cu	Zn	Cd	Cr	S	Cl	P	Mineral oil	Benzene	Toluene	Dimethyl benzene
acrylic ester residue	—	5.5	102	9.52	12.8	1490	3300	1.34	—	—	—	—
paint residue	43.5	1420	65.2	0.75	—	786	3300	1.38	19900	< 0.2	< 0.2	10.3

Table 3 Pollutant concentrations in the flue gas (after the dust-collector, flue gas rate is $2.5\times10^5\,m^3\cdot h^{-1}$)

Pollutants	Exp. No. 1		Exp. No. 2		Exp. No. 3		Blank exp.		Control standards*	
	concen. $mg\cdot m^{-3}$	flow $kg\cdot h^{-1}$	concen. $mg\cdot m^{-3}$	flow $kg\cdot h^{-1}$	concen. $mg\cdot m^{-3}$	flow $kg\cdot h^{-1}$	concen. $mg\cdot m^{-3}$	flow $kg\cdot h^{-1}$	concen. $mg\cdot m^{-3}$	flow $kg\cdot h^{-1}$
hydrocar-bon	44.0	11.4	24.5	6.74	4.78	1.16	20.65 −30.50	5.45 −8.23	150	120
Cu	< 0.002 −0.013	<0.002 −0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	N.A.	N.A.
Zn	0.007 −0.064	0.002 −0.017	0.007 −0.021	0.002 −0.006	0.013 −0.033	0.003 −0.008	0.014 −0.031	0.003 −0.008	N.A.	N.A.
Cd	<0.002	<0.01	<0.002	<0.01	<0.002	<0.01	<0.002	<0.01	1.0	0.59
Ni	0.014 −0.032	0.004 −0.008	0.008 −0.013	0.002 −0.004	0.007 −0.013	0.002 −0.003	0.002 −0.010	0.002 −0.003	5.0	1.80
SO_2	<1.0	<0.26	<1.0	<0.28	<1.0	<0.35	<1.0	<0.30	700	30.0

* The height of chimney is 40 m. N.A.: not available.

Table 4 Composition of the clinker with and without IW incineration

Exp. No.	Composition, %									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_5	Cl
blank exp.*	21.77	5.18	3.15	64.54	2.39	0.84	0.21	0.30	0.09	0.013
1	21.75	5.01	3.19	64.42	2.57	0.97	0.15	0.34	0.08	0.010
2	21.78	5.03	3.25	64.63	2.59	0.81	0.16	0.28	0.08	0.010
3	21.81	5.09	3.20	64.49	2.64	0.81	0.16	0.28	0.08	0.009

* Blank exp.: experiments without injection of IW.

Table 5 Composition of the fly ash with and without IW incineration

Exp. No.	Composition, %									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_5	Cl
blank exp.*	10.52	3.97	2.42	42.44	1.81	0.96	0.08	0.09	0.10	0.062
1	10.55	3.90	2.39	43.33	1.78	0.94	0.08	0.09	0.09	0.059
2	10.61	4.00	2.41	42.89	1.82	0.97	0.07	0.09	0.10	0.061
3	10.53	3.91	2.38	42.33	1.82	0.95	0.08	0.09	0.10	0.061

* Blank exp.: experiments without injection of IW.

The concentration of pollutants in the flue gas is far below the permitted values in the China National Standard—Air Pollutants Emission Standard (GB 16297-1996) (APES). The maximum emission concentrations of the above pollutants in APES are presented in the last column of Table 3.

3.2 Effect of IW disposal on the quality of clinker

Compared with the conventional RKI, no undegradable waste remains when IW is burned in the CRK because slag and ash have become constituents of cement. Residues from a conventional RKI plant have to be pretreated (*e.g.*, immobilization and stabilization) and then be put in a landfill. However, the effect of slag and ash on the quality of clinker has to be investigated.

As can be seen in Table 4, the compositions of the clinker before and after the disposal of IW remained almost unchanged. The co-incineration of solid hazardous waste in CRK did not affect cement quality. However, the concentrations of Na_2O and Cl in the clinker decreased during the IW disposal.

Na_2O and Cl are the main components which do harm to the normal operation of cement production. In CRK, Na_2O is vaporized in the high temperature zone and can seriously corrode pipeline and equipment; also, its combination with Cl forms gaseous NaCl[4]. When the flue gas leaves from the CRK and cooled down, the gaseous NaCl may condense and attach to the pipeline, leading eventually to clogging.

3.3 Effect of IW disposal on the component of fly ash

The composition of the fly ash was measured to show the effect of IW disposal on the quality of fly ash (Table 5). The composition of the fly ash did not change obviously in the experiment with injection of IW, compared with the blank experiment. And therefore, the fly ash after IW disposal can still be used in the production of cement.

3.4 Lixiviation experiments of heavy metals containing in the clinker and fly ash

When the clinker and fly ash are made into cement, the heavy metals in them may be lixiviated by surrounding water and then transferred into environment. In order to further determine the effect of IW disposal on quality of clinker and fly ash, the lixiviation experiments were carried out in the following conditions: the weight ratio of solid (clinker or fly ash) to water was 1/10; operation temperature 25℃±0.1℃; stir at $600\,r\cdot min^{-1}$ for 18 h. The clinker and fly ash were used as obtained. The respective results are shown in Tables 6 and 7.

Table 6 Concentrations of heavy metals in the lixivium of clinker($mg\cdot L^{-1}$)

Exp. No.	Cu	Zn	Cd	Ni
blank exp.*	<0.002	0.002	<0.002	<0.01
1	<0.004—0.017	<0.004—0.001	<0.002	<0.01
2	<0.019—0.024	<0.001—0.024	<0.002	<0.01
3	0.012—0.023	0.002—0.015	<0.002	<0.01

* Blank exp.: experiments without injection of IW.

Table 7 Concentration of heavy metal in the lixivium of fly ash (in dust-collector) ($mg\cdot L^{-1}$)

Exp. No.	Cu	Zn	Cd	Ni
Blank exp.*	0.009—0.024	<0.001—0.008	<0.002	<0.01
1	0.008—0.024	<0.001—0.022	<0.002	<0.01
2	0.026—0.032	0.027—0.040	< 0.002	< 0.001
3	0.026—0.040	0.008—0.027	< 0.002	< 0.001

* Blank exp.: experiments without injection of IW.

With IW disposal, the concentrations of Cd and Ni in the lixivium of clinker or fly ash showed no change; those of Cu and Zn in the lixivium of clinker or fly ash increased a little. However, the concentrations of these heavy metals in the lixivium are less than those permitted by the National Water Quality Standard—Surface Water Environmental Quality Standard (GB

3838—88) (SWEQS). The maximum permitted concentrations of the above pollutants in SWEQS are presented in Table 8.

Table 8 Maximum permitted concentrations of the above pollutants in SWEQS

Pollutants	Concen., $mg\cdot L^{-1}$
Cu	1.0
Zn	1.0
Cd	0.01
Ni	N.A.*

* N.A.: not available.

3.5 Lixiviation experiments of heavy metals containing in cement production

To further determine the effect of IW disposal on quality of cement production, a cement block with $10\,cm\times10\,cm\times5\,cm$ (its curing time was 28 days) was dipped in the de-ionized water in 10 time mass of water at room temperature. After 15 and 30 days, the concentration of heavy metal in the lixivium was measured. However, the concentrations of Cu, Zn, Cd and Ni were below the detection limit of the instrument. Consequently, the heavy metals were much better immobilized and stabilized in cement than in clinker.

ACKNOWLEDGEMENTS

Assistance of Department of Fluorescent Analysis in Beijing Cement Plant in chemical analysis is gratefully appreciated.

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