# QUANTIFICATION OF AIR EMISSIONS FROM CO-INCINERATION OF WASTE DERIVED FUELS IN CEMENT KILNS

Kim J-D[1], Park J-S[2], Phae C-G[3], Kim D[3]*

[1] Department of Health and Environmental, Hallym Polytechnic University, Chuncheon, Republic of Korea;
[2] Department of Environmental Engineering, Kangwon National University, Samcheok, Republic of Korea;
[3] Department of Environmental Engineering, Seoul National University of Science and Technology, Seoul, Republic of Korea

**Introduction**

Cement manufacturing is one of the largest mineral commodity industries in Korea, with a production capacity of greater than 50 million metric tons in 2009. Cement production is an energy intensive process, accounting for 3,000-5,000 kJ/kg of produced clinker[1]. Coal has been traditionally used in the kilns, but recently many alternative fuels have been applied for energy sources. Use of alternative fuels increases national energy security and may potentially lead to reductions in costs through energy recovery from materials that would have otherwise been disposed of[2].

The types of waste that cement plants try to burn include used solvents, spent tires, waste oil, paint residue, biomass such as wood chips, treated wood and paper, municipal solid waste, and sewage sludge. The cement industry uses these materials because they are generally cheaper than coal, and expects reductions in greenhouse gases emissions from the substitution of conventional mineral fuels. In considering the net benefit of the use of alternative energy sources, several concerns must be taken into account, such as energetic valorization, economic viability, and potential environmental and health impacts. Particularly, the acceptability and compatibility of the technological solutions are involved from the point of view of the atmospheric impact.

Since the kilns are typically operated in the conditions of the very high temperature and long residency time, high incineration efficiency and low emissions may be expected. However, the kilns are not simply designed for burning wastes. The kilns generally avoid having to meet incinerator emission regulations because they are not regarded as incinerators.

The objective of this study is to identify air toxics emissions from the cement kilns burning wastes as alternative fuels, which were tested under normal operating conditions and using a variety of fuels. Particle air pollutants, gas phase air pollutants, and 17 PCDD/Fs emissions were characterized as a function of the feeding of alternative fuels.

**Materials and methods**

This study was carried out at four commercially-operating Portland cement kilns which are located at two different sites (namely as A and B) in Korea. All kilns tested consist in a rotary kiln where the flow type between the gas and solid phases in countercurrent. The existing air pollution control systems for three kilns (namely as CK1, CK2, and CK3) in site A consisted of an electrostatic precipitator and a bag filter arranged in a series. The other kiln (CK4) had the integrated air pollution control system of a spray tower and a bag filter as presented in Figure 1. The primary fuel used to the kilns was coal. Special supplemental fuels include waste-derived fuels such as refuse plastic fuel, fluff waste plastics, and waste tire chip. Table 1 shows fuel compositions and consumption in each kiln. Total suspended particles, metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), gas phase air pollutants (inorganic and organic compounds), and 17 PCDD/Fs were carefully sampled from the stack each kilns, and analyzed in the laboratory.

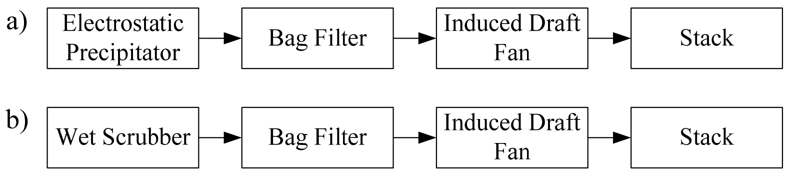


Figure 1. Emission control process in cement kilns at site A (a) and site B (b)

Table 1. Fuel types and consumption in cement kilns

| Site | Plant | Fuel | | |
|---|---|---|---|---|
| | | Type | Consumption, $10^3$kg/hr | Composition, % |
| A | CK 1 | Coal | 17.5 | 100.0 |
| | CK 2 | Coal | 11.5 | 69.7 |
| | | Refuse plastic fuel | 5.0 | 30.3 |
| | | Total | 16.5 | 100.0 |
| | CK 3 | Coal | 11.5 | 59.0 |
| | | Fluff waste plastics | 8.0 | 41.0 |
| | | Total | 19.5 | 100.0 |
| B | CK 4 | Coal | 17.8 | 91.3 |
| | | Waste tire chip | 1.7 | 8.7 |
| | | Total | 19.5 | 100.0 |

**Results and discussion**

The chemical composition of fuels as the mixtures of coal and wastes is presented in Table 2. In CK 1, coal as primary fuel was fed as sole energy sources. Other kilns burnt coal with wastes as alternative fuels, which included refuse plastic fuels, fluff waste plastics, waste oil, waste tires, and waste tire chip. All fuels were found to satisfy the Korean criteria as RPF(refuse plastic fuel) and TDF(tire derived fuel). Energetic valorization of coal (CK 1) was analyzed to be 6,476 kcal/kg, while others were more than 6,500 kcal/kg. For CK 3, lower heating value reached up to 7,583 kcal/kg. This indicates that use of the alternative fuels were attractively suitable for the energy needs in the cement kiln if burnt with the primary fuel.

Table 2. Characteristics of experimental samples utilized for fuels in cement kilns

| Experiment | LHV[a] | Water | Ash | Cl | S | Pb | Cd | T-Cr | Hg | As |
|---|---|---|---|---|---|---|---|---|---|---|
| | kcal/kg | wt% | | | | mg/kg | | | | |
| CK 1 | 6,476 | 2.80 | 9.94 | ND[b] | 1.32 | 2.05 | ND | 10.21 | ND | ND |
| CK 2 | 6,504 | 5.72 | 9.26 | 0.11 | 0.93 | 1.98 | ND | 8.31 | ND | ND |
| CK 3 | 7,583 | 6.02 | 8.46 | 0.11 | 0.79 | 35.03 | ND | 14.59 | ND | ND |
| CK 4 | 6,675 | 2.57 | 8.96 | 0.01 | 1.27 | 3.72 | ND | 9.52 | ND | ND |
| Criteria for RPF[c] | 6,000 | 10.0 | 20.0 | 2.0 | 0.6 | 200 | 9.0 | - | 1.2 | 13.0 |
| Criteria for TDF[d] | 6,000 | 10.0 | 4.0 | 2.0 | 2.0 | 200 | 9.0 | - | 1.2 | 13.0 |

[a] Lower Heating Value
[b] Not Detected
[c] Criteria for Refuse Plastic Fuel, act on the promotion of saving and recycling of resources of Korea
[d] Criteria for Tire Derived Fuel, act on the promotion of saving and recycling of resources of Korea

Table 3. Emission characteristics of particle air pollutants in stack gases (unit: mg/m$^3$)

| | | This study | | | | Other studies[c] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CK 1 | CK 2 | CK 3 | CK 4 | Coal + fluff waste | Coal | Coal + RDF | Coke + waste tire |
| TSP | | 1.65 | 2.7 | 2.26 | 3.22 | -[d] | - | - | - |
| Metal | As[a] | ND[b] | ND | ND | ND | ND | 0.0004 | 0.0003 | 0.0012 |
| | Cd | ND | ND | ND | ND | ND | 0.0056 | 0.0093 | 0.0002 |
| | Cr | ND | ND | ND | ND | 0.021 | 0.0007 | 0.0022 | 0.0031 |
| | Cu | ND | ND | ND | ND | 0.003 | 0.0015 | 0.0140 | 0.0124 |
| | Hg | ND | ND | ND | ND | - | 0.0291 | 0.0388 | <0.005 |
| | Ni | ND | ND | ND | ND | - | 0.0007 | 0.0027 | 0.0045 |
| | Pb | ND | ND | ND | ND | 0.002 | 0.1005 | 0.1758 | 0.0504 |
| | Zn | ND | ND | ND | ND | - | - | - | 0.0153 |

[a.] Gas phase concentration in this study, but particle phase in others
[b.] Not detected
[c.] In previously reported studies, fuels fed into the kilns are presented.
[d.] Not reported

Table 3 shows the concentrations of particle air pollutants in each stack gas. Total suspended particles were found to range from 1.65 $mg/m^3$ to 4.31 $mg/m^3$. Metals in each stack gas were below detection limits. Particle metals are typically generated from raw materials used to produce the clinker and fuels as the energy sources, and emission levels depend on volatilization of metals[3]. The kilns tested already have air pollution control devices such as an electrostatic precipitator, a bag filter, and a wet scrubber, which would be mostly appropriate for removals of particle pollutants.

Gas phase pollutants in the stack gas are summarized in Table 4. Ten inorganic compounds and three volatile organic compounds were analyzed. As compared to other studies, emission levels were not quite different. Since the kilns are operated at over 1,450$^{o}$C for 5 sec of gas retention time, most compounds may be oxidized, and resulted in low emissions. Particularly, organic compounds such formaldehyde, phenol, and benzene were found to be extremely low levels. Note that combustion products such as CO and $NO_2$ were detected to be relatively high level. The concentration of CO in the stack gas reached up to 816 $mg/m^3$ in CK 2. It is also worthwhile that $NO_2$ was emitted at a similar level from all kilns tested, even for CK 1, in which coal was burnt as the sole energy.

Figure 1 displays the PCDD/Fs profiles for each kiln as distinguished by primary fuel (coal), and by whether wastes as alternative fuel were used in conjunction with the use of coal. Overall, the profiles for CK 1 appear different with other kilns (CK 2, 3, and 4) having a more pronounced enrichment in PCDD/Fs. Visually, the profiles for the three kilns (CK 2, 3, and 4) are similar, with two PCDD/Fs, namely 2,3,4,7,8-PeCDF and 1,2,3,7,8-PeCDD almost always being measured at the highest concentrations. For a stack gas in CK 1, one furan, namely 1,2,3,4,6,7,8-HpCDF, was only detected. Note that the concentration profiles of PCDD/Fs are independent on hazardous waste combustion, but reflect individual facility characteristics including the performance of air pollution control devices[4]. In this study, waste combustion may affect PCDD/Fs emissions in any regard, and chloride content in coal was below detection limit in this study. Plant characteristics and emission control device performances differed among the kilns, resulting in systematically different profiles of PCDD/Fs. This reveals that air toxic emissions should be carefully recognized and air pollution control devices be properly designed and operated. In a point of view of sustainable growth of cement industry and environmental friendly waste management, cement kiln co-burning of waste can be appropriate choice, and the selection of waste to burn in kiln should be made to guarantee the valorization and hazardous air pollutants emissions.

Table 4. Emission characteristics of gas phase air pollutants in stack gases (unit: $mg/m^3$)

| | | This study | | | | Other studies[b] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CK 1 | CK 2 | CK 3 | CK 4 | Coke + waste tire | Coke + sludge | Coke | Coke + waste oil |
| Inorganic Compounds | CO | 206 | 816 | 743 | 417 | -[c] | - | 237 | 234 |
| | $CS_2$ | ND[a] | ND | ND | ND | - | - | - | - |
| | HCl | 0.70 | 0.13 | 1.44 | 0.71 | 0.96 | 1.29 | 4.3 | 4.1 |
| | HCN | ND | ND | 1.2 | 6.98 | - | - | <0.4 | <0.4 |
| | $H_2S$ | 0.79 | 0.21 | 0.18 | 0.44 | - | - | - | - |
| | $NH_3$ | 0.41 | 0.79 | 1.43 | 0.77 | - | - | - | - |
| | $SO_2$ | ND | ND | ND | ND | - | - | 119 | 90 |
| | $NO_2$ | 457 | 334 | 398 | 444 | - | - | 1,103 | 953 |
| | HBr | ND | ND | ND | ND | - | - | <0.1 | <0.1 |
| | HF | ND | ND | ND | ND | <0.1 | <0.1 | <0.1 | <0.1 |
| Volatile Compounds | $CH_2O$ | 0.19 | 0.20 | 0.09 | 0.05 | - | - | | |
| | $C_6H_5OH$ | ND | ND | ND | ND | 0.23 | ND | 1.1[d] | 1.1 |
| | $C_6H_6$ | 0.09 | 0.06 | 0.15 | 10.18 | 1.17 | ND | | |

[a] Not detected

[b] In previously reported studies, fuels fed into the kilns are presented.

[c] Not reported

[d] Total hydrocarbons

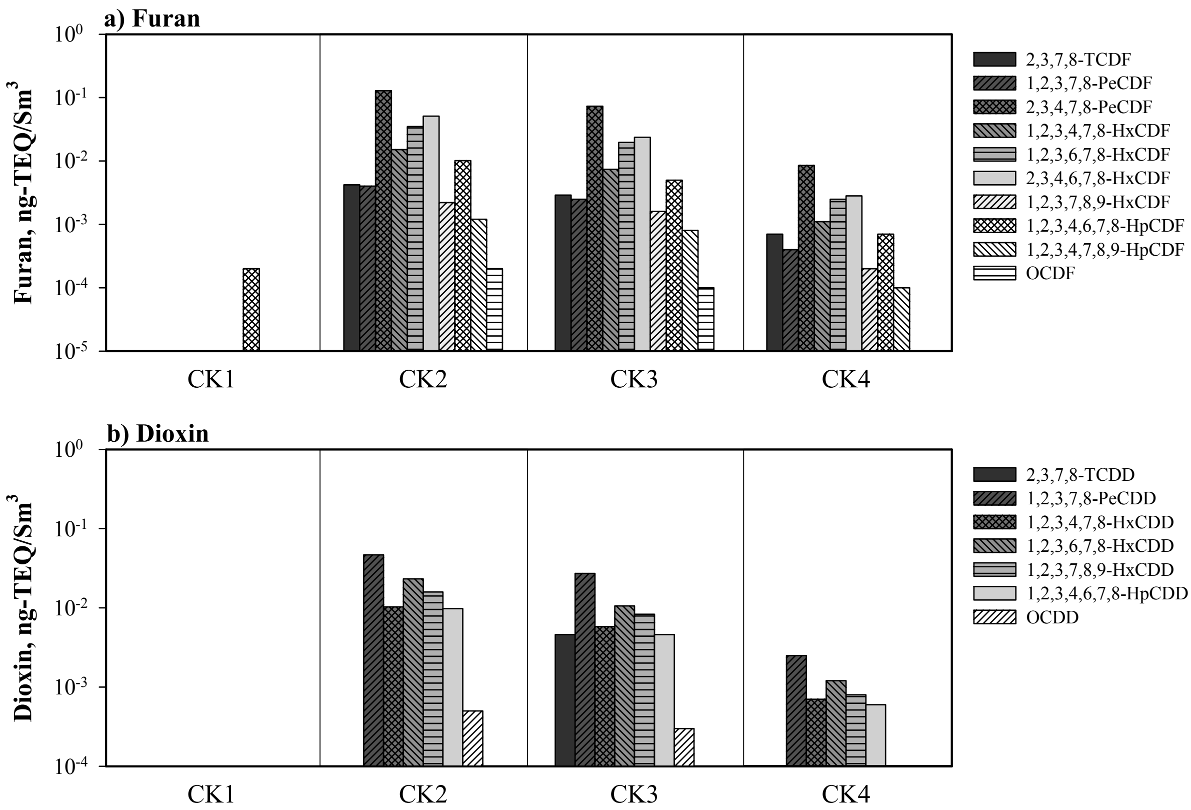


Figure 2. Concentration profiles of the 17 PCDD/Fs in the stack gases: Energy sources for kilns were 100% coal for CK 1; 69.7% coal and 30.3% refuse plastic fuel for CK 2; 59% coal and 41% fluff waste plastics for CK 3; 91.3% coal and 8.7% waste tire chip for CK 4.

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