Environmental levels and human health risks of metals and PCDD/Fs near cement plants co-processing alternative fuels in Catalonia, NE Spain: A mini-review

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This paper was aimed at reviewing recent studies related with the impact on environment and human health of metals and PCDD/Fs near cement plants. It has been particularly focused on the impact of cement plants located in Catalonia, Spain, which have been monitored by our research for more than ten years. Environmental monitoring studies were performed under different cement plant conditions. While some of our studies examined temporal trends of the levels of the above indicated pollutants, the main goal of other surveys was to assess the impact of implementing alternative fuels in the facilities. Even one of the studies was performed before and after the cement plant temporally ceased its industrial activity. The impact of cement plants burning alternative fuels on the emissions of metals and PCDD/Fs elsewhere was also reviewed. Regarding the cement plants in Catalonia, no significant differences were found, neither in the long-term follow-up studies, nor when alternative fuels are used, nor when a cement plant temporally stopped its activity. These results are in agreement with those reported for several stack emissions of other cement plants working under different conditions. We conclude that emissions of metals and PCDD/Fs by cement plants working with the best available techniques (BAT), should not cause a significant negative impact neither on the surrounding environment, nor on the human health of the population living in the neighbourhood.

Keywords: Cement plants; alternative fuel; environmental impact; human health risks; Catalonia (Spain)

Introduction

World cement production in 2018 was 3,900 million of tonnes, being China the main producer with 54.5% of the world's total cement production, and the European Union (EU) only produced about a 4.4% of the total. [1] Although cement production has remained relatively flat over the last five years, without efforts to reduce demand, the annual cement production is expected to grow moderately by 2030. While production is probably going to decline in China in the long term, it is expected to increase in India and other developing Asian countries, as well as in Africa. [2]

Cement is produced of clinker, gypsum and other additives. Furthermore, clinker is obtained by means of different crushed and homogenized raw materials, including limestone, clay and sands, which are calcinated at 1450ºC in a rotatory kiln. Inside the kiln, calcium carbonates ($CaCO_3$), dissociate into carbon dioxide (CO_2) and calcium oxide (CaO), which reacts with silicates (SiO_2) to form calcium silicates (Ca_2SiO_5/Ca_3SiO_4). [3] Cement production process releases large amounts of CO_2 to the atmosphere due the decarboxylation of raw material, as well as the consumption of fossil fuels in the kilns. The emission factors are between 0.9 and 1.2 tonnes of CO_2 per tonne of clinker produced, approximately 50% of contribution of each emission (fuel and decarboxylation of raw material). [4]

To reduce the great amounts of CO_2 released to the atmosphere, the cement industry has been/is using -among other strategies- alternative fuels in cement kilns. These alternative fuels are solid or liquid wastes, which are used as substitutes of the conventional fossil fuels. [5] The CO_2 emissions of these as alternative fuels do not compute in the total amounts of CO_2, since if they are not used in cement plants (for example) they should have been incinerated or landfilled, with the corresponding release of greenhouse gases. Other advantages of using alternative fuels are: (1) saving fossil fuels, (2) cheaper costs -in fuel- for the cement plants, and (3) solving an important problem of waste management. In 2014, in the EU, the average percentage calorific substitution of traditional fuels (coal and coke) by alternative fuels was 41%. [6] It should be noticed that there are important differences in calorific substitution between countries. For example, in Germany or in the Czech Republic, it was above 60%, while in Greece and Italy it was 7% and 13%, respectively. In the same way, in UK, Hungary and France, the calorific substitutions were around 40%. [6] According to the Waste Framework Directive (2008/98/EC), [7] an efficient energy recovery is classified as "other recovery" instead of "disposal" (landfill) in the waste hierarchy; that is to say: prevention, preparing for reuse, recycling, other recoveries and disposal.

The atmospheric emissions by a cement plant -like those of other fuel combustion facilities- include macro contaminants such as particles, nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon oxides, HF and HCl, as well as micro contaminants such as metals and organic compounds like polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and polycyclic aromatic hydrocarbons (PAHs). In addition to stack emissions, diffuse emissions of particulate matter (PM) are also notable sources of environmental contaminants around the cement plants. [8] Additionally, cement dust can cause important environmental problems and human health risks for the population living nearby these facilities. [9]

The present paper was aimed at reviewing recent studies dealing with the emission of metals and PCDD/Fs by cement plants co-processing alternative fuels and their impact on human health. We carefully revised and summarized the impact of cement plants located in Catalonia (NE, Spain). Environmental monitoring studies were used to evaluate the temporal trends of those pollutants around cement plants before and after alternative fuel implementation, with the exception of one of the studies, which was performed before and after the cement plant temporally ceased its industrial activity. In addition, we also reviewed the potential emission changes and environmental impact of other cement plants using alternative fuels elsewhere in the world.

Cement plants in Catalonia, Spain

Since 2000 our laboratory has conducted a number of studies in order to evaluate the impact on the environment and human health of cement plants of Catalonia (Spain). In recent years, all these plants have replaced a part of the traditional fuel (fossil fuels) for alternative fuels (sewage sludge (SS) and refuse derived fuel (RDF), mainly). Furthermore, one of the assessed cement plants ceased its activity. In our studies, which were divided in various campaigns, samples of environmental monitors such as soil, herbage and air were collected nearby the facilities and the concentrations of PCDD/Fs and a number of metals (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Sn, Tl, V and Zn) were analyzed. Non-carcinogenic and carcinogenic risks due to exposure to these pollutants for the population living in the neighborhood of the cement plants were subsequently evaluated. To assess the health risks (carcinogenic and non-carcinogenic) due to exposure to metals and PCDD/Fs for the population living around the cement plants, air inhalation, soil ingestion and dermal contact were considered as pathways of exposure. Numerical expressions and parameters used for assessing human health risks were taken from Vilavert et al. [10] In brief, the non-carcinogenic risks were calculated by using the Hazard Quotient (HQ), which is defined as the quotient between the predicted exposure and the respective reference dose (RfD). Therefore, HQ values lower than 1 ($HQ < 1.0$) are considered not being of concern. Furthermore, cancer risks were calculated by multiplying the predicted exposure and the respective slope factor (SF). In Spain, 10^{-5} is the recommended carcinogenic risk threshold for adult populations. [11] Likewise, international standards establish that risks in the range between 10^{-6} and 10^{-4} can be considered as acceptable on the basis of the highly variable characteristics of the individuals. [12]

The main characteristics of the studies performed in cement plants from Catalonia are shown in Table 1. Plants 1, 2 and 3 co-incinerate sewage sludge (between 20-25% of replacement) as alternative fuel, while plant 4 uses RDF (15-30% of replacement). In the same way, plant 5 burns SS and RDF (up to 24% of replacement). Finally, plant 6 stopped operations during the monitoring.

Cement plant 1 (Vallcarca, Barcelona) was the first of the evaluated plants to start co-incinerating alternative fuels. [13,14] In 2005, the facility began to use sewage sludge as alternative fuel in quantities between 15% and 20% of the petroleum coke's energy value. In 2008, sewage sludge was continuously used, with a permanent replacement of approximately 20% of the petroleum coke's energy value. The monitoring around cement plant 1 was divided in three surveys, which were conducted in 2003 (before co-incineration), 2006 and 2009. Samples of soils, herbage and air (only in 2009) were collected. No significant ($p<0.05$) differences were found for individual congeners, and/or the total concentrations of PCDD/Fs, between the three campaigns, neither in soils, nor in herbage samples. With regard to metals, although a clear tendency was not observed, fluctuations with time were noted. The concentrations of metals in air, measured when a 20% (calorific value) of SS was co-incinerated, were similar to those found in other industrial areas worldwide. The human health risks for the population living around the cement plant were comparable to those obtained in previous studies, when petroleum coke was exclusively used as combustible, being in both cases tolerable according to the international standards.

Cement plant 2 (Montcada i Reixac, Barcelona), is located in an area with many industries, as well as two highways with a heavy traffic. Three campaigns were carried out when the cement plant was only using traditional fuels (November 2008, May 2009 and November 2009), while three additional campaigns (December 2010, April 2013 and November 2014) were conducted after the replacement of 20% of calorific value by sewage sludge. [15,16] The levels of metals and PCDD/Fs nearby this facility were higher than those found around other cements plants, especially those located in rural sites. However, in general terms, a non-significant decrease in metal and PCDD/F concentrations was found in all environmental matrices after fuel replacement implementation, indicating a slight reduction of the human exposure to those toxic elements. Non-carcinogenic risks of PCDD/Fs and metals were still at the safety level (HQ < 1). In addition, carcinogenic risks were in the acceptable range of 10^{-6}-10^{-4}.

Cement plant 3 is located in the metropolitan area of Barcelona (Sant Vicenç dels Horts, Barcelona) close to cement plant 6. In 2010, a new production line started its activity equipped with the best available techniques (BATs). Two (January and July 2011) and three (January 2012, June 2013 and 2015) sampling campaigns were performed before and after, respectively, sewage sludge started to be used as alternative fuel. The facility can reach a fuel substitution around 25% of total thermal energy requirement. [17,18] Soils, vegetation and air samples were collected in order to measure potential environmental changes. Regarding PCDD/Fs, in almost all congeners, a seasonal pattern with statistically significant higher levels in winter than in summer campaigns, was noted. However, considering the fuel implementation, no significant differences were observed between the periods before (January 2011 and 2012) and after fuel implementation (July

2011 and June 2013), for both the PCDD/Fs total amount and the congener profiles. Results indicated that immission levels of metals and PCDD/Fs were not influenced by fuel replacement. In addition, there were no changes in risks (carcinogenic and non-carcinogenic) regardless of the fuel used, being those risks acceptable according to international standards (HQ<1, and 10^{-4}< cancer risk <10^{-6}).

The replacement of fossil fuels by RDF in Cement plant 4 (Alcanar, Tarragona) started in August 2009, with an average of 15% of substitution, reaching around 30% in 2017. The study was divided into four annual campaigns (October 2008 and 2009 and April 2014 and 2017). [19,20] Soil, herbage and air samples were collected around the cement plant in all campaigns. The concentrations of PCDD/Fs and metals were analyzed in the three environmental monitors. In general terms, no significant differences were found in the environmental levels of those pollutants after 8 years of refuse derived fuel (RDF) use. In this case, the concentrations of metals and PCDD/Fs in soil, vegetation and air were in the low part of the ranges found around other cement plants in Catalonia (in general, below 50th percentile). HQs for all metals and PCDD/Fs were below the safety limit (HQ< 1) in all the sampling points, before and after using alternative fuels. With respect to the carcinogenic risks, for all metals and also for PCDD/Fs, they were again below 10^{-5}, independently of which was the type of fuel used. The only exception was once more As, that slightly exceeded the 10^{-5} value, but being in the range 10^{-6}-10^{-4}.

In 2000 and 2001, we started our first and longest environmental study around cement plants in Santa Margarida i els Monjos (Barcelona) (Cement plant 5). [21,22] Initially, the study was focused on assessing the potential environmental impact of the cement plant on its influence area. The results of the environmental campaigns in soils and herbage did not show any relevant impact on the area under direct influence of the emissions of this facility. In March 2011, the cement plant started to use some alternative fuels (in this case a mixture of sewage sludge, RDF, animal meals, and agriculture by-products) to find the energetic requirements of the production process, in substitution of fossil fuels. In 2012, the accumulated energy replacement was approximately 24%. To evaluate long temporal trends, in 2011 and 2012 (10 years after the initial studies), two new sampling campaigns were conducted. [23] The sampling points were located at the same sites, nearby populated nuclei, which had been already evaluated in 2000 and 2001. The sampling methodology was the same used in the previous surveys. However, air samples were now included. In general terms, no significant differences were found between the 2000 and 2001 campaigns, and the last surveys (2011 and 2012). Notwithstanding, vanadium levels showed a significant increase in the three monitors. This increase could be related to the influence of traffic since vanadium is a metal associated to the refinement and burning of oil and also to traffic. In relation to carcinogenic risks, they were below 10^{-5} for all sampling points, and for PCDD/Fs and metals, with the exception of As which slightly exceeded the 10^{-5} value.

Three semi-annual surveys (September 2008, March 2009 and September 2009) were performed around cement plant 6 (Sant Feliu del Llobregat, Barcelona). [24] The relevance of this study relies on the fact that this cement plant stopped the kilns just six months before our last campaign, making this study an assessment of the real impact of the plant activity in the area under its direct influence. PCDD/Fs and metals were again analyzed in the three environmental monitors: soils, herbage and air. In soils, the differences in PCDD/F concentrations did not reach the level of statistical significance, what could be expected since soil is a long-term environmental monitor. High standard deviations were observed in some cases (e.g., 1,2,3,4,6,7,8-HpCDD in soils, OCDF in herbage, etc.). However, decreases in concentrations of metals and PCDD/Fs between the 3 surveys were not significant, suggesting a low impact of the emissions of this cement plant. In some cases, the pollutant concentrations were even higher (e.g., As, Co, Mn, Ni, Pb and V in air) after the plant stopped its regular operations. Hazard quotients were in the safety level (HQ < 1) in all the sampling points, for all metals and PCDD/Fs, when the plant was operating or stopped. With respect to the carcinogenic risks, they were acceptable for all metals and PCDD/Fs, regardless the plant was working or not.

In general terms, for almost all sampling points used in these studies, the levels of metals in soils were below the generic reference level for the protection of human health in Catalonia, according to the soil's uses established by the Catalonia Waste Agency. [25] Regarding As, it is important to note that, in our studies, this element was measured as total arsenic. However, the toxicological data to assess human health risks are defined only for inorganic As, which is the most toxic form. For that reason, although in all sampling points, As concentrations were below its generic reference level (30 mg/kg for all land uses), the As carcinogenic risks slightly exceeded -irrespectively the plants were co-incinerating or not- the 10^{-5} value. In consequence, the As risks were overestimated in both cases, either co-incinerating or not. Likewise, all PCDD/Fs levels in soils were under the reference levels established in countries such as Canada (4 ng I-TEQ/kg), or Finland, Sweden and Austria (10 ng I-TEQ/kg). [26] In air, As, Cd, Ni and Pb levels were quite below the annual limits established by the EU (Directives 2004/107/EC and 2008/50/EC). However, no reference levels are established for PCDD/Fs in air, or for metals and PCDD/Fs in vegetation.

Based on the above, some general conclusions can be drawn. Firstly, no long environmental increases in the concentrations of metals and PCDD/Fs were observed around the cement plants of Catalonia. Secondly, no differences were observed in the environmental levels of these pollutants depending on the kind of fuel used. Thirdly, cement plant emissions of metals and PCDD/Fs do not seem to have significant influences on the environmental concentrations of these contaminants around the facilities, which is supported by the results obtained when the cement plant 6 stopped its industrial activities. Lastly, human health risks due to exposure to metals and PCDD/Fs around the cement plants here reviewed would be considered as acceptable, according to national and international standards regarding health risks of these environmental pollutants.

Airborne emissions

In addition to the specific data of the studies in Catalonia, we have also reviewed airborne emissions of other cement plants. Potential changes of using alternative fuels in cement kilns were expected in stack emissions and not in other emissions, such as diffuse emissions of grinding or extraction activities. For that reason, and in order to corroborate the results of immission levels of Catalonia, discussed above, we here summarize data from studies published between 2003 and 2019 focused to assess the effects of pollutant emissions, mainly PCDD/Fs and metals, of cement kilns that were using alternative fuels. Prisciandaro et al. [27] reported data of one of the first studies aimed at comparing stack emissions of a cement plant burning traditional and alternative fuels. They observed that stack emissions of NO_x, SO_2 and CO, were slightly increased when using co-combustion of tyres. In contrast, in the case of fuel replacement by waste oils, emissions of the same pollutants resulted even decreased. Notwithstanding, the emission levels were, in general terms, below those established by the EU legislation. Likewise, Karstensen et al. [28] evaluated more than 2000 PCDD/Fs stack emission measurements representing different technologies and burning scenarios. Their results indicated that well operated modern cement kilns may clearly work with emissions below the current legal level of 0.1 ng I-TEQ/Nm^3. The authors concluded that the modern cement kilns have lower emissions than older, which worked with wet and long dry process without preheating. The availability of organics and precursors in raw materials, as well as the temperature of the air pollution control devices, are the principal parameters influencing the formation of PCDD/Fs. In this line, Conesa et. al. [29] measured continuously during one year the emissions of PCDD/Fs and other pollutants of a cement plant using petroleum coke as primary fuel. Alternative fuels such as solid recovered fuel (SRF), automotive shredder residue (ASR), sewage sludge, waste tires, and meat and bone meal (MBM) wastes, with an energy substitution level of about 40%, were also included. The emission levels were much lower than the legal limits set in the case of PCDD/Fs. Other two studies had been previously performed in that same plant. [30,31] In one of these studies, solid recovered fuel (SRF) from municipal waste on different proportions, with a maximum feed rate of 15,000 kg SRF/h, was used. In this case, the legal emission limits of PCDD/Fs and heavy metals, among other pollutants, were not reached. [30] In the second study, when tires and two types of sewage sludge were used as secondary fuels, an increase of PCDD/Fs was noted with the amount of tires fed to the kiln. However, it was concluded that the increase was probably due to the fed point used for this waste. [31] On the other hand, in 2004 Abad et al. [32] measured PCDD/Fs emissions in three Spanish cement plants using meat meal (4.8-6% calorific value), tires (9.4% calorific value), and a combination of both (13-14% calorific value), respectively. In all cases, PCDD/F emissions were below the limits established by the EU legislation. No significant differences were observed between the emissions of these cement plants using alternative fuels, and other cement plants using traditional fuels. Kara et al. [33] measured the effects of using different ratios (from 0% to 15%) of RDF in cement plants of Turkey. All measured pollutants were below the legislation limits, being similar, independently of the RDF fed ratios, with the exceptions of a NO_x decrease and a CO increase, which were observed in parallel to the increase of the RDF ratio. A similar effect was also reported in other studies. [19,34] It was probably due to the lower flame temperature, or the lower air excess. Nevertheless, other studies [34] did not find differences (increases or decreases) in the levels of NO_x. In Hong Kong, a cement plant conducted a test with an alternative fuel (20%) derived from wood waste, showing similar values in emissions of NO_x, SO_2, PCDD/Fs and heavy metals, before and after this test, fulfilling legislative requirements in both cases. [35] In another study, [36] after monitoring 10 cement kilns working under different conditions in Australia, the authors concluded that alternative fuels used in cement kilns operating in optimal conditions, should not cause an increase of air emissions of NO_x, SO_2, hydrogen halides, halogens, and total VOCs. The same authors also concluded that, processing varied substitution rates of waste oil, solvents, chipped wood, refuse waste, carbon dust, shredded tyres and black sand waste, as secondary fuels in cement plants, reduced the stack emissions of the more toxic PCDD/Fs and dl-PCBs congeners. [37,38] It was found that, in general terms, the combustion of alternative fuels do not suppose significant influences on the emissions of PMs, metals, PAHs, PCBs and PCDD/Fs. However, in some specific cases, it caused an increase of certain pollutants (e.g., co-combustion of carbon dust and wood chips increased total PAHs emission; waste solvents increased chromium and dioxin emissions, or tire derived fuels increased metals and PCBs levels). [35] Ames et al. [39] and Zembra et al. [40] examined stack emissions of two Portuguese cement plants fed with diverse fuel types, some of them classified as hazardous wastes. It was concluded that the congener profile was significantly different when coal or petroleum coke were used as primary fuel in cement kilns, being the concentrations of PCDD/Fs and metals higher when coal was used as primary fuel. Nevertheless, the implementation of hazardous waste as secondary fuels did not change significantly the congener profiles of PCDD/Fs. Moreover, it was also observed that the PCDD/Fs congener profile of the kiln emissions was significantly different from that measured in ambient air. [36] Although all pollutants emitted during these tests were within the levels established by the EU legislation, the variability in the pollutant concentrations was considerable. In two Serbian cement plants, [41] a part of the fuels (coke and coal) was replaced by tires. The monitoring carried out during five years, showed that clinker characteristics were similar, being stack emissions (mainly NO_x, SO_2 and CO) slightly increased, but remaining at the legal limits and resulting in some cases even reduced. In turn, in a study conducted in 22 Italian cement kilns during 2006, [40] it was concluded that the use of alternative fuels did not influence negatively the emission of pollutants such as total dust, SO_2, NO_x, CO, TOC, HCl, HF, metals, PAHs and PCDD/Fs. Furthermore, Zabaniotou and Theofilou [42] studied the utilization of sewage sludge as secondary fuel, in a cement plant in Cyprus. It was observed that the emission levels of metals and PCDD/Fs were far below the EU legal limits.

According to the above, it seems evident that modern cement plants working with the best available technology (BAT) can accomplish the current EU legislation on airborne emissions (Table 2). [43] The use of alternative fuels (sewage sludge or RDF, among others) does not modify the stack emission of pollutants by the cement plants, being in some cases even reduced. The results obtained in a number of countries corroborate the data of the studies conducted in Catalonia, which show that the replacement of fossil fuels by alternative fuels (sewage sludge, RDF or others) does not cause an increment of health risks for the population living nearby the cement plants.

Conclusions

Based on the above studies conducted in Catalonia, some conclusions can be drawn: (1)

no increasing trends in the concentrations of metals and PCDD/Fs were observed in any of the environmental monitors (air, plants and soils) evaluated around the cement plants, (2) no significant differences were observed in the environmental levels of these contaminants depending on the fuel used, (3) cement plant emissions did not show a significant influence on the environmental levels of metals and PCDD/Fs, which was specifically corroborated when cement plant 6 stopped its industrial activity, and (4) health risks due to exposure to metals and PCDD/Fs for the population living nearby the facilities are acceptable according to most national and international standards. These results are in agreement with data from stack emission studies reported in the scientific literature, studies, which in general terms, conclude that: (1) modern cement plant working with the best available technology (BAT) can comply with the current EU legislation on airborne emissions, and (2) the use of alternative fuels (sewage sludge, RDF, among others) does not modify substantially the pollutant emission of cement plants, being even reduced in some cases.

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Table 1. Principal characteristics of the studies conducted in cement plants from Catalonia (Spain)

Study	Site	Campaigns	Environmental monitors (nº of samples/campaign)	Fuel type and % of substitution	Reference
1	R	April 2003	Soil (16) and herbage (16)	FF	[13]
		April 2006	Soil (16) and herbage (16)	FF + SS (test-15%)	[13]
		April 2009	Soil (16), herbage (16)	FF + SS (20%)	[14]
2	U	November 2008	Soil (7), herbage (7) and air (4)	FF	[15]
		May 2009	Soil (7), herbage (7) and air (4)	FF	[15]
		November 2009	Soil (7), herbage (7) and air (4)	FF	[15]
		December 2010	Soil (7), herbage (7) and air (4)	FF+SS (20%)	[16]
		April 2013	Soil (7), herbage (7) and air (4)	FF+SS (20%)	[16]
		November 2014	Soil (7), herbage (7) and air (4)	FF+SS (20%)	[16]
3	U	January 2011	Soil (7), herbage (7) and air (4)	FF	[17]
		July 2011	Soil (7), herbage (7) and air (4)	FF	[17]
		January 2012	Soil (7), herbage (7) and air (4)	FF+SS (25%)	[17]
		June 2013	Soil (7), herbage (7) and air (4)	FF+SS (25%)	[17]
		June 2015	Soil (7), herbage (7) and air (4)	FF+SS (25%)	[17]
		January 2011	Soil (7), herbage (7) and air (4)	FF	[18]
4	R	October 2008	Soil (7), herbage (7) and air (4)	FF	[19]
		October 2009	Soil (7), herbage (7) and air (4)	FF + RDF (15%)	[19]
		April 2014	Soil (5), herbage (5) and air (5)	FF + RDF (20%)	[20]
		April 2017	Soil (5), herbage (5) and air (5)	FF + RDF (30%)	[20]
5	R	May 2000	Soil (16), herbage (16)	FF	[21]
		May 2001	Soil (16), herbage (16)	FF	[22]
		May 2011	Soil (16), herbage (16) and air (3)	FF+SS/RDF (tests)	[22]
		May 2012	Soil (16), herbage (16) and air (3)	FF+SS/RDF (24%)	[23]
6	U	September 2008	Soil (7), herbage (7) and air (4)	FF	[24]
		March 2009	Soil (7), herbage (7) and air (4)	FF	[24]
		September 2009	Soil (7), herbage (7) and air (4)	Stopped	[24]

FF: fossil fuel; SS: sewage sludge, RDF: refuse derived fuel; R: rural, U: urban.

Table 2. Limits of air emissions for cement kilns co-incinerating waste [43]

Pollutant	**Limit value**
Total dust	30 mg/Nm^3
HCl	10 mg/Nm^3
HF	1 mg/Nm^3
NO_x for new plants	500 mg/Nm^3
Cd+Tl	0.05 mg/Nm^3
Hg	0.05 mg/Nm^3
Sb+As+Pb+Cr+Co+Cu+Mn+Ni +V	0.5 mg/Nm^3
PCDD/Fs	0.1 ng/Nm^3
SO_2	50 mg/Nm^3
TOC	10 mg/Nm^3
Measurements must be standardized at the following conditions: Temperature 273 ºK, pressure 101.3 kPa, 10% oxygen, dry gas.	