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Chemical and mineralogical analyses of Cement-Kiln-Dust (CKD) and its potential impact on the environment

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Abstract

Cement-kiln-dust (CKD), a by-product of cement production, is generated and disposed off in piles at different cement factory sites in Nigeria, raising environmental concerns. About 25% of every tonne of raw materials fed into the kiln during cement production results in CKD waste. Dust recycling has been employed in the past by many cement plants in the country to curtail their environmental effects but despite this, large quantities of CKD are still being produced. The wastes are suspended in air as particulates during dry weather causing air pollution, or deposited on plants and roofs of buildings. The dusts are also washed into surface and groundwater during rains thereby polluting the water sources particularly around the factories. An intensive study is currently being conducted to find a productive use for this waste in civil engineering construction and this paper presents the results of chemical and mineralogical analyses of CKD with a view of determining their impact on the environment. Tests conducted on CKD samples collected from Lafarge Cement Plant Shagamu, Nigeria were chemical analysis using X-ray Flourescence (XRF), microstructural analysis using Scanning Electron Microscopy (SEM) and mineralogical analysis using X-ray Diffraction (XRD). From these analyses, results showed that the CKD contained lime, CaO, as the predominating elemental oxide among the major oxides present with a value of 68.44% while silica oxide, aluminium oxide and ferric oxide were 12.80%, 5.90% and 4.01% respectively. The SEM analysis showed the presence of fine and dense crystalline microstructure of mineral particles. XRD results showed that minerals present were antigorite, mordenite, chrysolite, sanidine, etc. The high lime content indicate that soil, surface and groundwater sources will have a high pH values and which may have both short-term and long-term implications on both plants and animals in the affected areas, however, further studies shall reveal the implications of these on the environment.

Keywords: Cement-kiln-dust, Chemicals, Mineralogy, Pollution, Environment

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1. Introduction

Cement-kiln-dust (CKD), a by-product of cement production, is generated in large quantities in many cement plants all over the world, and they constitute a problem to the environment due to their poor storage disposal. The CKD is generated continuously during the manufacturing processes of cement and large particulates of CKD escape into the air while the solid particles are collected in a chamber and transported to the disposal site. During generation, CKD causes air pollution of the environment and also where they are disposed off, they cause pollution of soil, surface water and groundwater.

Due to the large quantities of the waste, and the potential pollution they pose to the environment, a number of steps have been taken to reduce their impact on the environment. These steps include installation of dust recycling systems to reduce the amount of the waste disposed off. However, this step has faced with many challenges such as high cost of energy and high lime content of the waste which limit its introduction into the new cement production. An intensive research is therefore currently being conducted to find a productive use for this waste in civil engineering and thereby reduce the potential hazard of the waste on the environment.

A number of researches have shown that CKD though not classified as a harzardous material, pose significant health threats to plants, animals, and humans. According to El-Aleem et al. (2005), CKD is produced in cement plants in Egypt and constitute about 10 - 12% of the total cements production, although about 73% of it is recycled. From X-ray diffraction (XRD) analysis it contains mainly limestone and minor element such as quartz, $CaSO_4$, KCl, NaCl, K_2SO_4, $KNaCl_2$, $2(2CaO.SiO_2).CaSO_4$ and sulfospurite $\{2(2CaO.SiO_2).CaCO_3\}$.

Mostafa et al. (2005) corroborated this result by stating that about 1.0 million tons of CKD is produced annually in Egypt and that large percentage of it contains high alkali which makes the waste to be non-recyclable. Also, Hindy et al. (1990) showed that about 0.07 kg of every kilogram of cement manufactured in Egypt is released into the atmosphere causing air pollution. Jan et al. (2007) noted that large particulates air pollutants are released into the atmosphere around cement plants which are deposited on leaves, roofs and other receptacles. The CKD contains a high concentration of many metals known to have toxic effects not only on plants and animals but also on humans (Branquinho et al., 2008; Hirano et al., 1995; Shukla et al., 1990).

CKD contaminated soils around some cement plants in Al-Hasa Oasis, Saudi Arabia has been shown to contain heavy metals such as As, Cd, Pb and Ni with the heavily contaminated metal of Cr especially on soil samples taken from 0 to 2km from the cement plant. El-Abssawy et al. (2011) tested for heavy metals in CKD obtained from three cement plants in Cairo area, Egypt using Atomic Absorption Spectrometry techniques, and it was found that Cr had the highest concentration of 35.95% with zinc having a value of 30.17%. Other elements found were Ni, Pb, As, and Cd having values of 15.44%, 12.49, 1.27 and 1.02% respectively.

CKD also has been found to affect plants growth in the vicinity of cement plants in India (Al-Omran et al., 2011). Apricot trees planted between distances of 0.5km to 2km was shown to be adversely affected physiologically with a reduced photosynthetic ability (Rafiq and Kumawat, 2016). Darley (1966) had earlier shown that comparison of carbon dioxide (CO_2) exchange between CKD dusted leaves and undusted leaves showed that fine particles of CKD affected the plants leaves and in some cases caused damages to the leaf's tissues. But however, the chemical composition, particle size and deposition rates of CKD may also be factors that can influence the damages to CKD infected environments. Ade-Ademilua and Obalola (2008) showed results of tests conducted on the effect of cement dust on Lagos spinach plants with significant accumulations of heavy metals such as aluminium, copper and zinc in the plants tested. Prassad et al. (1991) also reported on damages to plants and other vegetations by CKD.

Akinola et al. (2008) have shown that the health of animals are affected by CKD environment when chemical analysis of the lung tissues of some albino rats was tested. It was found that high percentages of calcium, silicon, zinc, aluminium and iron were detected. And this further confirms the toxicity and carcinogenic character of CKD. Gupta and Mishra (1994) stated that air pollution presents a severe threat to plants and animals in the vicinity of industrial plants. Aribigbola et al. (2012) reported that in Ewekoro area diseases associated with inhalation of silica containing dust have been noted among the people in the area and these include silicosis, chronic airways obstruction and bronchitis, tuberculosis and lung cancer.

Surface waters have also been found to be affected by CKD. Ajadi (2008) tested for heavy metals in Akinbo River and Itori River around Ewekoro cement factory in Ogun State, south west Nigeria and found that K, Na, Ca, Mg, Cr, Cu, Pb, Mn, Fe and Zn were present in significant amounts in the water samples, although the percentages of the elements reduced the farther away from the cement plant.

This Paper presents the aspect of the chemical and mineralogical analyses of the CKD produced at Lafarge Cement plant Shagamu, Ogun State, south-west Nigeria with a view to determine the potential threats of the waste on the environment, i.e. air, surface water, groundwater, soil and plants, in the neighbourhood of the cement factory.

2. Materials and methods

CKD samples were collected from Lafarge cement plants in Shagamu, Ogun State, south-west Nigeria. Fig 1 shows stock-pile of CKD in the disposal site in the factory. Tests conducted on the samples were X-ray flourescence (XRF) using Energy Dispersive X-ray (EDX) machine to determine the elemental oxides present in the CKD sample while Scanning Electron Microscopy (SEM) was conducted to determine the microstructures or morphology of the CKD sample. X-Ray Diffraction (XRD) was conducted to determine the minerals present in the CKD.

The XRF was conducted at the Defense Industry Corporation, Zaria, Kaduna State, Nigeria using the Thermoscientific Advant,X 1200 Model XRF Machine. The CKD sample was oven-dried at a temperature of $60^{o}C$ for 30 minutes before the sample was powdered to 0.15microns. The powdered sample was then mixed with sodium or Lithium tetra-borate (BORAX) in the ratio 4:1 of BORAX to CKD sample using Herzog Vibrating cup Miller. The sample was then loaded into the XRF machine with the results displayed through the goniometer after analysis.

The XRD test was conducted at the National Steel Raw Materials Exploration Agency, Zaria, Kaduna State using the X-Ray Diffractometer Schimadzu 6000 Model. The samples were prepared as for the XRF test before loading it into the XRD machine which was set to run between 0^{o} to 120^{o}theta Bragg angle at a running rate of 2-10° per minute. The peaks or diffractograms as shown from the machine were analysed in the machine goniometer which expressed the mineral compositions at various angle of theta degrees. The SEM test was conducted at the Department of Chemical Engineering, Ahmadu Bello University, Zaria using Pnenom scanning electron microscopy machine to understand the microstructure, distribution and composition of the minerals present in the CKD sample.

Fig.1. Cement kiln dust stock-piled at disposal site

3. Results and discussion

3.1 Chemical Analysis

The results of chemical analysis conducted on the CKD using X-ray fluorescence (XRF) is presented in Table 1. From the results, lime, CaO, has a value of 68.44% which indicates that CKD is rich in alkali. Other oxides found were silica oxides (SiO_2), aluminium oxide (Al_2O_3), and ferric oxide (Fe_2O_3) with values of 12.8%, 5.9% and 4.01% respectively. Some of the minor oxides present were potassium oxide (K_2O), tin oxide TiO_2), chromium oxide (Cr_2O_3), and zinc oxide (ZnO) with values of 0.96%, 0.40%, 0.032 and 0.03% respectively.

3.2 Scanning Electron Analysis (SEM)

The results of microstructural analysis conducted on the CKD using Scanning Electron Microscopy (SEM) is presented in Figure 2. From the results, the CKD particles shows a clustered fine and densely packed crystals with mineral composition and distributions as shown.

3.3 Mineralogical Analysis (XRF)

The results of mineralogical analysis conducted on the CKD using X-Ray Diffraction (XRD) is presented in the X-ray diffractogram in Figure 3. From the results, the minerals present in the CKD sample are shown in Table 2. The major peaks in the diffractogram shown in Figure 3 were correlated with card files to give the major minerals present in the CKD while the minor peaks gave the minor minerals. The analysis of the diffractogram from the X-ray goniometer together with the computer card files of the machine showed the major minerals present in the CKD sample as mordenite, chrysolite, osumilite, antigorite and sepiolite while the minor minerals were lizardite, ramsidellite, etc.

Table 1. Chemical analysis of cement kiln dust using x-ray fluorescence

Compound	**Unit Concentration %**
$A1_2O_3$	5.900
SiO_2	12.80
SO_3	5.380
K_2O	0.959
CaO	68.44
TiO_2	0.404
V_2O_5	0.026
Cr_2O_3	0.032
MnO	0.055
Fe_2O_3	4.010
ZnO	0.030
Y_2O_3	0.440
In_2O_3	1.200
BaO	0.06
HgO	0.300
Re_2O_7	0.030
Lu_2O_3	0.026

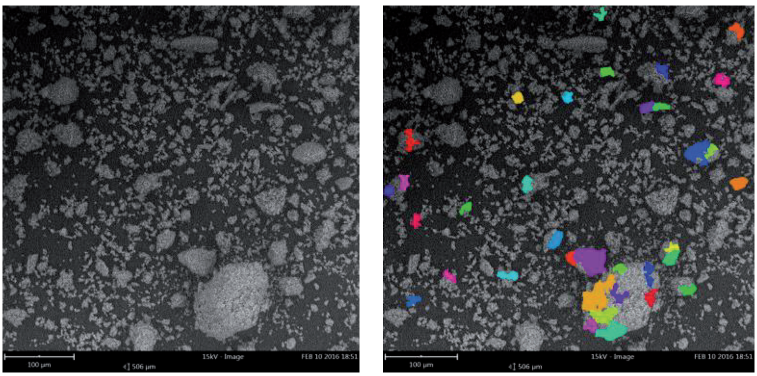

Fig.2. SEM analysis of cement kiln dust

Osumilite, one of the major minerals present in the CKD sample, belongs to the silicate mineral group with double ring structures. Chrysotile, antigorite and lizardite belong to the mineral groups known as serpentine {$(Mg, Fe, Ni)_3Si_2O_5(OH)_4$} has a structure similar to the kaolinite group (Berry et al., 2004).

4. Conclusions

From the analysis and discussions of test results above on the chemical and mineralogy of CKD, the following conclusions are made.

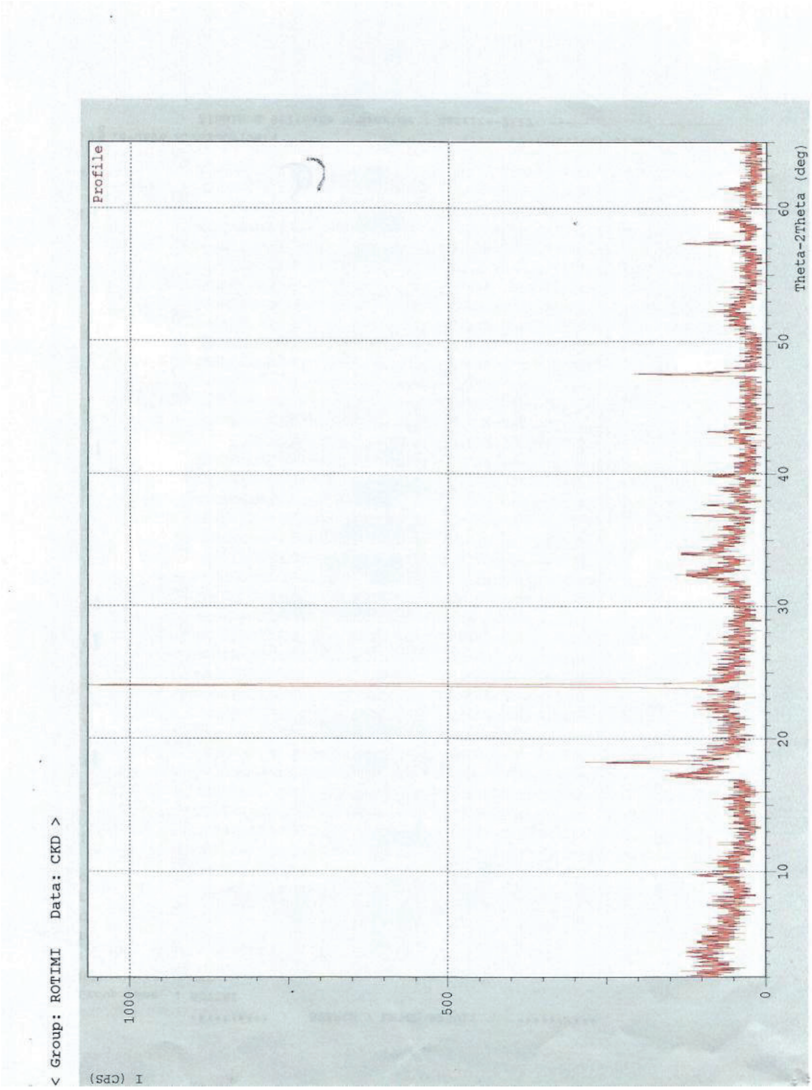

Fig. 3. XRD of Cement kiln dust (CKD) Sample

(a) The chemical analysis of CKD from Shagamu cement plant shows that lime is the predominating oxide with a value of 68.44%, which indicates that soils and water resources (whether surface or groundwater) contaminated with it will have its pH increased, thereby affecting the potability of such water resources for consumption by both human and animals.
(b) The increased pH of surface and groundwater contaminated with CKD shows that higher costs of treatment will be required to make the water source safe for consumption without health risk.

Table 2. Minerals present in CKD sample

Minerals Present	Chemical Compound	Chemical Formula
	Potassium Magnesium Aluminium Silicate Hydrate	$KMg_3 (Si_3A1)O_{10} (OH)_2$
	Potassium Iron Magnesium Aluminium Silicate Oxide	$K\text{-}MgA1\ SiO_2H_2O$
Chrysotile	Magnesium Silicate Hydroxide	$Mg_3[Si_2\text{-}xO_5](OH)_{4\text{-}4x}$
Antigorite	Magnesium Silicate Hydroxide	$Mg_3Si_2O_5(OH)_4$
	Calcium Magnesium Aluminium Silicate Hydroxide	$CaO.2(Al, Mg)2Si_4O10(OH)_2.4H_2O$
Sanidine	Potassium Sodium Aluminium Silicate	$(Na,K)(Si_3Al)O_8$
Talc-2	Magnesium Silicate Hydroxide	$Mg_3Si_4O_{10}(OH)_2$
	Potasium Magnesium Aluminium Silicate	$KMg_2Al_3(Si_{10}Al2)O_{30}$
Mordenite	Sodium Aluminium Silicate	$Na_2Al_2Si_{13}.3O_{29}.6+x$
	Magnesium Silicate Hydroxide Hydrate	$Mg_4Si_6O_{15}(OH)_2.6H_2O$
Halloysite-7	Aluminium Silicate Hydroxide	$Al_2Si_2O_5(OH)_4$
Hopeite	Zinc Phosphate Hydrate	$Zn_3(PO)_4.4H_2O$
	Magnesium ALuminium Silicate Hydroxide Hydrate	$(Mg, Al)_9(Si,Al)_8O_{20}(OH)_{10}.4H_2O$
Dickite-2	Aluminium Silicate Hydroxide	$Al_2Si_2O_5(OH)_4$
	Potassium Aluminium Silicate Hydroxide	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
Cristobalite	Silicon Oxide	SiO_2
	Potassium Aluminium Silicate Hydroxide	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$
Albite	Sodium Aluminium Silicate	$NaAlSi_3O_8$
Nacrite - 2	Aluminium Silicase Hydroxide	$A1_2Si_2O_5(OH)_4$

(c) The soil and water pollution potential of CKD at the environment of Lafarge cement plant in Shagamu still require further studies due to the presence of traces of heavy metals of tin, chromium, and mercury detected in the samples so as to provide possible solutions that can guard again toxic and carcinogenic effects on the environment.
(d) The geo-chemical implications of CKD minerals affecting or interacting with minerals of soils contaminated with CKD are currently being studied so as to understand its effects on both plants and humans.

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