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Physicochemical and microbiological characterization of cement kiln dust for potential reuse in wastewater treatment

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ABSTRACT

Cement kiln dust (CKD), a byproduct of cement manufacturing process, was collected from Misr Cement Co. at Qena, Egypt. CKD was characterized by X-ray diffraction and FTIR analysis. This byproduct was investigated for its physical–chemical characters, antibacterial activities on sewage water and the presence of nematode, parasites and algae in the treated water. The efficiency of CKD-treated water was also examined on *Hibiscus sabdarriffa* seed germination. Total bacteria, total and fecal coliform, as well as fecal streptococci were completely inhibited by CKD. Interestingly, zinc, manganese, iron, nickel and lead were completely absent from sewage water as these metals precipitated after treatment with 10 g l^{-1} CKD. On the other hand, among all the tested plant criteria, only root length was significantly reduced by 55% and 15% after zero and 3 days of CKD addition respectively compared to control. Furthermore, plant lipid peroxidation showed no significant differences between treated sewage water and control after zero and 3 days time addition of CKD. Catalase enzyme activity showed significant decrease by 56% and 64%, while peroxidase activity significantly increased up to 49% and 63% compared to untreated sewage after zero and 3 days of treatment, respectively. The absorption of lead, iron and copper by treated and untreated plants showed no significant differences. Chromium ions were highly absorbed (0.075 mg l^{-1}) by plants irrigated only with treated sewage water at zero time, and decreased gradually to 0.018 mg l^{-1} after 3 days of CKD addition. This study highlighted the efficiency of cement kiln dust as an antibacterial agent and its ability of scavenging heavy metals leading to the use of treated sewage water in activities such as crop irrigation.

1. Introduction

With the increase in global population, the gap between water supply and demand is widening and is reaching such alarming levels. Scientists around the world are working on new ways of conserving water, such as wastewater recycling (Hussain et al., 2002). In Egypt, 8,888,000 m^3 day^{-1} of wastewater is discharged from 233 treatment facilities (El Awady and Ali, 2012). The use of wastewater is widespread and represents around 10% of the total irrigated surface worldwide (Jimenez, 2006). Although the use of wastewater has a positive effect for farmers, mainly related to their income level, it also has a negative effect on human health and treatment is necessary before it is reused (Jimenez, 2006). Water reuse and reclamation will play a significant role in achieving sustainability and public health protection in the future (Rose, 2007). Insufficient treatment of carbonaceous organic load, odor, heavy metals and persistent organic pollutants, in sewage, has a negative effect on human beings (El Awady and Ali, 2012). For that, some researches were focused on the use of chemical coagulants to enhance the coagulation or flocculation of wastewater particles (Mahmoud, 2009).

Cement kiln dust (CKD) is a fine grained alkaline material which is a byproduct of cement clinker production (Mackie, 2010). In Egypt, approximately one million tons of cement dust are discarded annually from cement manufacturing. The emissions have a negative impact on the environment and causes serious problems on the national level. CKD, when properly used, will be a valuable source as a soil conditioner and partial fertilizer (El Awady and Ali, 2012). X-ray diffraction analysis of cement kiln dust showed that the main constituent is calcite ($CaCO_3$), quartz (SiO_2) and calcium sulfate ($CaSO_4$) (Zaki et al., 2007). CKD has potential as an amendment for the neutralization of acidity and adsorption or removal of aqueous metals and nutrients (Mackie, 2010). CKD was used as a chemical coagulant in wastewater, sludge and industrial effluents treatment because it is a low cost

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material for heavy metal scavenging in industrial wastewater (El Awady and Sami, 1997; Mahmoud, 2010, 2014). Effective removal of nutrient and trace metals from industrial, agricultural and domestic wastewater is critical to efficient water reuse (Mackie, 2010). Heavy metals and other toxic pollutants are considered extremely harmful because they are toxic, non degradable and environmentally persistent (Weng and Huang, 1994). These metals are biologically beneficial in small quantities, but become harmful at high levels of exposure (Jimenez, 2006). Adsorption is the most effective and widely used technique for the removal of toxic heavy metals from wastewater (Selvi et al., 2001). Due to the high cost and difficult procurement of activated carbon as an adsorbent material, efforts are being directed towards finding efficient and low-cost adsorbent materials (Mahmoud, 2010, 2014). The high adsorption ability of cement kiln dust, and its availability in high quantities, as an inexpensive byproduct of cement industry, it could be effective in the removal of chromium from tannery wastewater (Al-Meshragi et al., 2008). Studies revealed that CKD remove metals from solutions by its precipitation as metal hydroxides and phosphate precipitate as hydroxyl apatite (Mackie, 2010). In order to maximize metal adsorption by this waste dust, it is recommended to use it for treating acidic wastewater streams (El Awady and Sami, 1997). Previous investigations on the removal of heavy metals from wastewater suggest that systems containing calcium in the form of CaO or $CaCO_3$ and carbonate in general are particularly effective in the removal of heavy metals in wastewater (Howari and Garmoon, 2003). Cement kiln dust may also be effective in removing other harmful or undesirable species such as dyes in waste effluent (Al Meshragi et al., 2008).

In this study, we have analyzed a new effective and inexpensive therapeutic approach for sewage water treatment and heavy metals removal based on effective lethal dose of cement kiln dust, characterization by X-ray diffraction and FTIR analysis. The physico-chemical characters, antibacterial activities on sewage water for removal of heavy metals and reuse in wastewater treatment for irrigation. The application was done on *Hibiscus sabdarriffa* seed germination. Seedlings growth criteria including antioxidant enzyme activities demonstrated a healthy un-stressed germination after sewage water treated by CKD. Therefore, the application of the results can be useful for treating feacal coliform bacteria in sewage water.

2. Materials and methods

2.1. Collection of samples

Sewage water was collected from South Valley University, Qena, Egypt just before experimentation. Cement kiln dust was collected from the factory of Miser Cement Co. at Qeft, Qena, Egypt.

2.2. Characterization of cement kiln dust (CKD)

2.2.1. X-ray diffraction (XRD)

X-ray diffraction (XRD) of the original CKD was carried out using a D8 Advance Bruker diffractometer (Germany) at ambient temperature. The instrument uses Ni-filtered CuK radiation ($\lambda = 1.5406$ Å), an electron source of 40 kV and 40 mA. Diffractograms were recorded for 2 values ranging from 10 to 80° with a scanning speed of 0.01 s per step. The obtained diffraction patterns were compared with references from Joint Committee on Powder Diffraction Standards (JCPDS) database to identify the phases and characterize materials.

2.2.2. Fourier transform infrared spectrometer (FTIR)

The presence of bioactive functional groups in CKD material was determined by Fourier transform infrared spectrophotometer (FTIR). Analysis was carried out using a Magna-FTIR 560 (USA) instrument at a resolution of 2 cm^{-1} range from 4000 to 400 cm^{-1} in KBr pellet using diffuse reflectance mode operated by Nicolet Omnic Software as instructed by the manufacturers.

2.3. Evaluation of microbiological quality of CKD-treated sewage water

In a greenhouse, two glass boxes were prepared with two liters of sewage water in each. Based on cfu ml^{-1}, concentration of 10 g l$-^{1}$ CKD was added to one box as a lethal concentration according to the preliminary experiment (data not shown). The other box served as control. Samples were taken and examined from each box every 24 h interval for three days. Each sub-sample, over the sampling period, was microbiologically analyzed directly after collection to minimize changes in the bacterial population. All media and chemicals were supplied by Merck Co., England, prepared with distilled water and autoclave at 121 °C for 15 min prior to use.

2.3.1. Heterotrophic plate count (total bacterial count)

The used media were nutrient agar and buffer peptone water (APHA, 2005). The used bacterial sample volumes were 1 and 0.1 ml. The sterile agar medium was melte and kept in a water bath at 44–46 °C until used. Three plates were set up for each treatment. The melted medium was mixed thoroughly with sample in the plates by swirling. After being solidified, the plates were incubated for 48 ± 3 h at 35′0.5 °C and 68 ± 4 h at 22 ± 0.5 ºC. By the end of the incubation period, the number of colonies developed on each plate was counted to determine the plate count as cfu (colony forming unit) per ml of sample.

2.3.2. Determination of total coli, fecal coliform and fecal Streptococcus bacteria

The used culture media were M-Endo agar, M-FC agar, *M-Enterococcus* agar, buffer peptone water, lauryl tryptose broth, briliant green bile broth, aesculin bile azide agar, and EC broth as indicated for each test (APHA, 2005).

For the detection of total coliform, sample bottles (one of untreated sewage water and the other of sewage water treated with 10 g l^{-1} CKD) were shaken vigorously and then filtered through 45 μm membrane filter. The filter was then placed on the M-Endo agar plate and incubated for 22–24 h at 35 ± 0.5 °C. After incubation, red colonies with metallic golden sheen were counted as coliform bacteria. Verification of all typical and non typical coliform colonies was carried out by picking up two typical and two atypical colonies fro a membrane filter with a sterile loop, placing in lauryl tryptose broth tubes and incubating at 35 ± 0.5 °C for 48 h. Tubes that produced gas were verified by inoculation on brilliant green lactose broth and incubated at 35 ± 0.5 °C for 48 h. Gas-forming colonies in lauryl tryptose broth confirmed in briliant green lactose broth, within 48 h, were verified as coliform bacteria.

Detection and verification of fecal coliform and fecal *Streptococcus* were determined according to APHA (2005).

2.4. Evaluation of physical–chemical quality of treated sewage water

All the following determinations were carried out according to APHA (2005). The pH was determined by using "HACH Sension 156, Loveland Co., USA" pH meter. Total dissolved solids (TDS) were determined by filtration of 100 ml sample on a 45 μm glass fiber filter connected to vacuum pump and weighing the filtrate.