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Stabilization of the urban sludge from sewage plants using carbide lime waste

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ABSTRACT

The objective of this work is to promote carbide lime waste (CLW), rejected in nature to reduce the pathogens in urban wastewater sludge. We have engaged in this research project, which is notably based on an integrative approach to CLW in urban sludge stabilization. Due to their intrinsic physical and chemical properties, CLW showed excellent and attractive results for urban wastewater sludge stabilization of Bordj Bou Arreridj city. The obtained results show that the stabilization of sludge is most efficient with high level of CLW percentage. The best elimination of pathogenic microorganisms and dryness is obtained for a 50% CLW dose for various microorganisms such as fecal D Streptococcus, fecal coliform, total mesophilic flora and sulfate-reducing clostridium bacteria. Therefore, the valuing of CLW efficiency in the laboratory showed that their valorization could be extended to the sludge stabilization field.

Keywords: Valorization; Carbide lime waste; Pathogenic microorganisms; Sludge treatment

1. Introduction

In developing countries such as Algeria, where more diversified development projects and industrialization are in conjunction with rapid urbanization, the major problem is the environmental pollution occurred from increasing generation of domestic and industrial wastes. Depending on their characteristics, wastes can represent an important source of secondary raw materials replacing the natural resources. The growing amount of carbide lime waste (CLW), a by-product of acetylene production, has resulted in an environmental problem.

One of the conventional methods for producing acetylene ($CH \equiv CH$) is the action of water on calcium carbide. Calcium carbide (CaC_2) is produced in an electric furnace by heating a mixture of lime and carbonaceous materials such as coke, coal or charcoal. The calcium carbonate is first converted into calcium oxide and for the coal into coke, then the two are reacted in order to form calcium carbide and carbon monoxide [Reaction (1)] [1,2].

$$CaO + 3C \rightarrow CaC_2 + CO \quad (1)$$

Calcium carbide (or calcium acetylide) and water are then reacted to produce acetylene and lime slurry [Reaction (2)] [3,4].

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 + 64\ Kcal \quad (2)$$

In acetylene manufacturing process, the lime slurry is pumped from the reactor to settling tanks where water is removed for recycling and sediment formed. Water from the slurry is saturated with acetylene and it is therefore preferred as a source of water in the reactor.

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By using recycled water, the overall efficiency of the reaction is increased. Once water has been removed from the slurry for recycling, the sediment formed in the holding tanks is stockpiled on site or landfilled [5,6].

CLW is referred to as carbide lime waste, carbide lime sludge, hydrated lime waste, calcium hydroxide waste and other such designations. It is generated as an aqueous slurry composed essentially by calcium hydroxide ($Ca(OH)_2$ ≈ 85%–95%) with minor parts of calcium carbonate ($CaCO_3$ ≈ 1%–10%), unreacted carbon and silicates (1%–3%) [3,7]. The characteristics of the sludge are influenced by processing parameters during acetylene fabrication [1,8]. Although it is not classified as dangerous/hazardous, its management and disposal require a special caution. Ammonium hydroxide present in supernatant (100–300 ppm) and acetylene dissolved in the water fraction may also be an issue, requiring appropriate ventilation during storage [3,7–9].

For every production of lime milk with a flow of 1.82 m^3/h, a daily amount of CLW equal to 19.2 ton is rejected [10].

Carbide lime can be considered either as waste, affecting the environment, or as a resource when an appropriate valorization technology is implemented. The CLW can be used alone to improve the clayed soils that contain a high level of pozzolanic material [11–14], in acid mine drainage [15], civil constructions and several industrial processes [16–19]. However, it appeared to be suitable for wastewater treatment. A by-product was tested in order to introduce the CLW in wastewater treatment field and to increase its application for environment protection [20,21].

The aim of the present work is to demonstrate the possibility of CLW utilization in wastewater treatment. The widespread use of this by-product in wastewater treatment would ensure a very large market and allows simultaneous dual action favorable to the environment: removal of industrial waste and wastewater. Moreover, utilization of CLW leads to acceptable performance and economically attractive implementation of process.

There are many processes for treatment and stabilization of sludge, but liming is one of the most processes that can significantly reduce pathogenic microorganisms such as bacteria, viruses, protozoa and eggs of parasitic worms [22]. Previous studies reported that high pH treatment by adding calcium oxide (CaO) was effective for lethal inactivation of pathogenic bacteria and viruses in short term and it is also known that wood ash can increase pH [23]. It was also reported that raising the pH was an effective way to rapidly and lethally reduce both pathogenic bacteria and viruses that were contained in human feces. Vinneras et al. [24] indicated that, apart from low moisture content contributing to successful inactivation of pathogens, high pH (addition of lime) >12 helps in the inactivation process. Jepsen et al. [22] compared the effects of three processes of pathogenic bacteria reduction: lime hydrated stabilization, aerobic thermophilic stabilization and composting method. During lime hydrated stabilization, pH values of 12.3 were reached and indicator microorganisms were devitalized during 24 h after lime addition [25]. The addition of a high dose of $Ca(OH)_2$ to increase the pH of compost to 8.1 reduces the concentration of pathogenic bacteria in sludge [26].

In Algeria, the majority of urban wastewater in the different wastewater treatment plants (WWTPs; treated by biological methods) using the bacteria present in wastewater naturally. At the exit of WWTP, the treated water was dumped into the natural environment and suspended solids, once it were recovered in sludge form, are transformed, enhanced and/or eliminated. These stations produce about 2,000 ton per month of sludge. This amount was expected to double in the near future as the volume of waste dumped is increasing. Then the sludge is becoming a serious problem. The preferred way is recycling it on the physicochemical properties of the soil (structure and stability) [27–29]. This requires continuous recycling efforts to control garbage the waste dump. Thus, to ensure the safety of the sludge, there are standards for discharge of waste which must be strictly followed. In this study, the aim is to examine the possibility of using carbide lime waste, by-product of the manufacture of acetylene, for the treatment and stabilization of sludge obtained from biological treatment of urban wastewater of Bordj Bou Arreridj city. The widespread use of this by-product in water treatment would ensure a broad market and can simultaneously perform a dual environmental action: the elimination of industrial waste and the treatment of sludge. In addition, it is necessary that the by-product in question leads to acceptable performance and an economically attractive implementation.

2. Experimental setup

2.1. Sludge sampling

The raw sludge samples were collected from National Office of Sanitation (office national de l'assainissement, ONA) of Bordj Bou Arreridj, Algeria, wastewater treatment plant, situated in north-east of Algiers city. The sludge withdrawals were made from the urban sewage water in primary sedimentation and in secondary treatment stages (biological). The samples were put into stabilized bottle with a volume of 5 L and maintained at 5°C to protect the bacteria flora for any change.

2.2. Carbide lime waste

CLW samples for the present research were collected from the National Company of Industrial Gases (entreprisenationale des gazindustriels, ENGI) situated in El-Hadjar, Annaba (Algeria). In total, 1 kg of carbide produces about 300 L of crude acetylene, collected in specially constructed generators and it is used for lighting and welding [30].

In addition to acetylene, a considerable amount of calcium hydroxide sludge was produced with a volume sensibly equal to twice that of the fresh carbide. The color of CLW sludge depends on impurities caused by the fabrication method of carbide, it is sometimes white, gray or ash gray.

The lime sludge is collected at the exit of the acetylene generator and dried at a temperature of 105°C during 48 h. After grinding and sieving, the obtained powder is stored in desiccator. The characterization of this product was carried out by Ayeche and Hamdaoui [8].

2.3. Sample treatment

The sludge samples are initially mixed before being introduced into the beakers of a volume of 2 L. The amount of CLW added to the sludge was adjusted at weight of 0, 1.44,

Table 1
Analytical methods for determining the physicochemical parameters and bacteriological parameters

Parameters	Methods	Norms
pH	Electrochemical	SM 4500-H^+B
Dryness		NF U 44-095
Total germs at 22°C (72 h)	Enumeration	ISO 6222
Total coliform bacteria	Enumeration	ISO 7899-2
Escherichia coli	Enumeration	ISO 9308-2
Clostridium	Enumeration	ISO 6461-2

2.16, 2.88 and 3.6 g/100 g to obtain 0%, 20%, 30%, 40% and 50%, respectively, of its original dry matter, that is, 7.2%. The mixtures thus obtained are stirred for 5 min at 150 rpm.

2.4. Analytical procedures

The analytical methods used to follow the physicochemical parameters and biological parameters are regrouped in Table 1. Determination of biological parameters is based essentially on the AFNOR and ISO standards. Then, the pH and temperature are measured using digital pH meter (Hanna instruments).

3. Results and discussion

3.1. Evolution of pH and dryness

The high pH of lime is likely the major factor inhibiting the microbial growth. It has obtained that its effect for liming the microbiological quality of sludge is related to the percentage of added lime. Fig. 1 showed that the pH of treated sludge increased when the percentage of CLW increased.

Adding of lime $Ca(OH)_2$ raises the pH and forms a basic medium when it was dissolved, as shown in the following reaction:

$$Ca(OH)_2 \leftrightarrow Ca^{2+} + 2\,OH^-$$

For CLW, the obtained results (Fig. 1) showed that the pH decreased day by day until the fourth day of contact time. Whereas pH increased rapidly from 6.5 to 9.26 after the addition of CLW dose of 50%, later it started to decrease during 4 d because of the slight acidification of medium by the pathogenic bacteria [31,32].

After fourth day, the pH increased for all studied concentrations. For CLW dose of 50%, pH increased to 7.8 after 44 d of treatment. This value of pH is even near neutrality, that is, the suitable pH for optimum biogas production [33]. The latter is relieved by few pathogenic bacteria that stay in sludge after 4 d of treatment. For example, the acetogens prefer a neutral pH, causing the resistance of the system by increasing pH, whereas methanogens have a maximum activity in a pH range of between 6.64 and 7.32. However, methanization can occur in slightly acidic or alkaline environment [31].

The curve in Fig2 indicates the evolution of dryness according to the quantity of added CLW. The results showed that the increase in the CLW concentration generates an increase in the drying of mud.

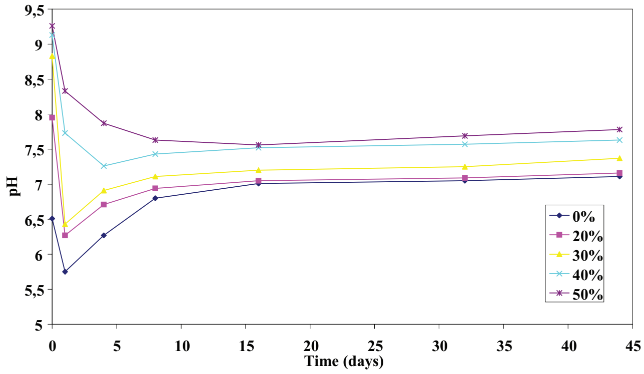

Fig. 1. pH change in 44 d after addition of different CLW concentrations.

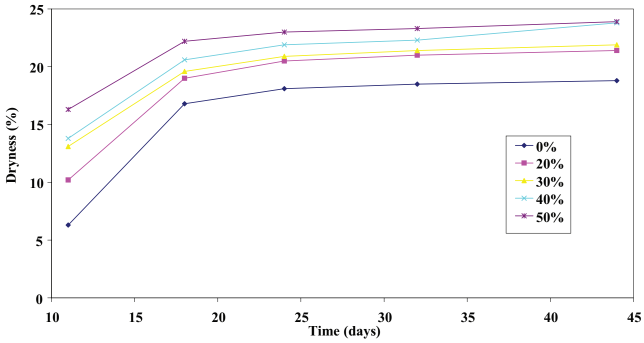

Fig. 2. Evolution of dryness with CLW concentration during the time of stabilization treatment.

The CLW may flocculate the suspended solids in sludge, that is, breaks the colloidal stability and allows to increase the particle size by flocculation [34,35].

The biosolid obtained from dewatered sludge with high dryness is biologically stable and their grains are well structured through its grain structure, biosolids can be used directly for waste-stabilized rammed earth [13,36,37].

From Fig. 2, it has been noticed that the sludge dryness increases during the time of drying for all treated samples. The best treatment results are obtained for the treated sludge by addition of CLW 50% dose, where it is arrived at a final dryness of 24% after 44 d of stabilization at an average temperature of 21°C, hence, a volume reduction of 20%.

3.2. Microbiological analysis

Enumeration of total germs was obtained at the sampling day. Generally, the obtained results showed that the pathogenic bacterial populations decreased significantly according to the concentration of lime and the extended time.

The average total germs number in the untreated sludge was 270×10^8 bacteria/mL. The number of germs is reduced with the increase of lime concentration, total germs were below 100×10^8 bacteria/mL after the addition of CLW dose of 50% and a contact time of 24 h (Fig. 3). At the end of the experiment (with prolonged contact time of 44 d), a great number of germs were eradicated using a CLW dose of 50%, we have recorded only 1×10^5 bacteria/mL of sludge sample. As a result, the number of total germs decreased vs. the concentration lime and the contact time (Fig. 3).

During the sampling, the initial number of fecal coliform bacterias was 140×10^8 bacteria/mL. After 24 h, this initial number of fecal coliform bacterias was not changed for both lime dose 20% and untreated sludge. Contrarily, when we increased the lime concentration beyond 30%, the number of fecal coliform bacterias decreased significantly below to 95×10^7 bacteria/mL during the first day. However, on the eighth day, the fecal coliform bacterias were completely eliminated for all lime concentrations tested (Fig. 4).

The efficiency of elimination of fecal D-streptococci bacteria increased significantly during the sampling days from the first day to the end of the experiment (32 d) and as function of lime concentration, following the order 50 > 40 > 30 > 20 > 10. The minimum lime dose required was 40% (Fig. 5).

In addition, the number of sulfate-reducing clostridium decreased with increasing of lime concentration. At 0% of lime concentration, the number of bacteria was 3×10^3 bacteria/mL. At the end of treatment, none of sulfate-reducing clostridium bacteria was survived while using a 50% of lime concentration and inactivation time of these bacteria was 32 d (Fig. 6).

In fact, this result showed a strong effect of waste lime for the stabilization of sewage sludge of Bordj Bou Arreridj city under certain condition of pH and lime dose. A variety of pathogenic microorganisms was contained in this sludge such as total mesophilic aerobic bacteria, fecal coliforms, fecal D-streptococci and sulfate-reducing clostridium bacteria.

At the end of experiment, the pH values were obtained near of neutrality (6.5–7.5) for all lime concentrations, which can generate a favorable environment to those pathogenic microorganisms. CLW showed an excellent efficiency for inactivating of different microorganisms.

The waste lime may participate directly to eliminate completely or reducing significantly those pathogenic microorganisms. Our results agree with the results found by Wong and Selvam [38], where they used lime as a co-composting material for stabilization of sewage sludge. They found that it plays a significant role for reducing the microbial content of sludge (pathogens).

These results demonstrate, from the biological point of view, that the stabilized sludge was an inert material and that lime is highly efficient in the removal of pathogens and in biological sterilization [39,40].

Many researchers have shown that the damages of pathogenic bacteria are related to pH of the sludge. Kazama and Otaki [23] have reported that high pH leading the pathogenic bacteria to more lethal damage [41]. In alkaline condition, hydroxyl ions are highly oxidant-free radicals that show extreme high reactivity with several biomolecules and cause

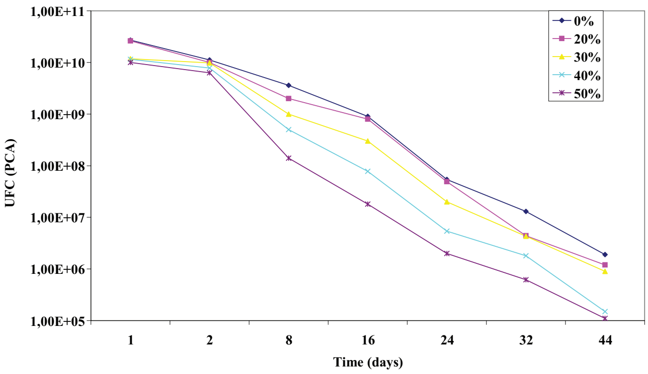

Fig. 3. Evolution of the total mesophilic aerobic flora according to the concentration of CLW and contact time.

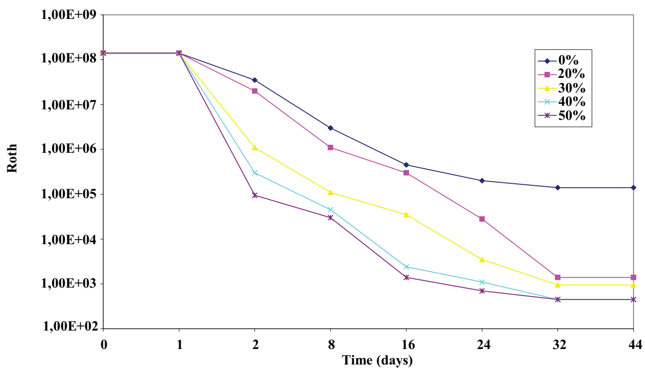

Fig. 5. Evolution of fecal D-streptococci according to the concentration of CLW and contact time.

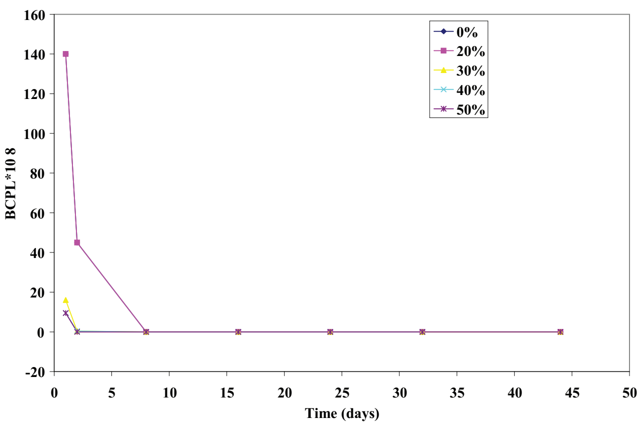

Fig. 4. Evolution of fecal coliforms bacteria according to the concentration of CLW and contact time.

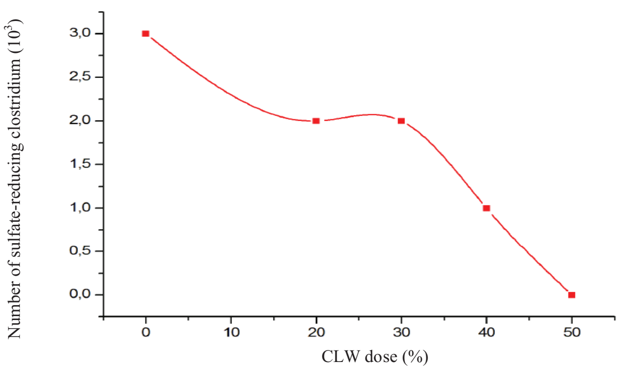

Fig. 6. Evolution of sulfate-reducing clostridium bacteria as function of the CLW concentration after 32 d of stabilization treatment.

lethal effects on bacterial cells. This is assumed that bacterial cytoplasmic membrane and DNA have been damaged, and protein has been denatured [42]. Alkalinity can induce the solubilization of bacterial surface proteins, resulting in exposure of hydrophobic sites of adjacent lipids to the extracellular environment. Vinneras et al. [24] indicated that, apart from low moisture content contributing to successful inactivation of pathogens, high pH (addition of lime) >12 helps in the inactivation process. Jepsen et al. [22] reported that during hydrated lime stabilization, the pH values about 12.3 were reached and indicator microorganisms were devitalized during 24 h after lime addition. Hamidatu et al. [26] indicated that the addition of a high dose of $Ca(OH)_2$ to increase the pH of compost to 8.1 is capable to reduce the concentration of pathogenic bacteria.

4. Conclusion

In the present study, CLW wastes are reclaimed for successful use in the stabilization of urban sludge from sewage treatment plants in the town of Bordj Bou Arreridj. First, we have studied the pH change with lime addition. The initial pH of the sludge was 6.50, but with the addition of the CLW, the pH increased to reach a value of 9.3 with a dose of 50%. The pH measurements were carried out to determine the optimum value for the sludge stabilization. The best sludge stabilization was obtained after an average period of 8 d using a CLW dose of 50% with an optimum pH = 7.5.

Moreover, we have compared the inactivation of different pathogenic bacteria during the liming of sludge. The obtained results showed that the inactivation rate increased as CLW dose increased.

It has obtained that CLW was participated directly to eliminate completely or reducing significantly the pathogenic microorganisms from urban sludge. The end inactivation of fecal coliforms and sulfate-reducing bacteria was achieved 32 d after addition of optimum CLW dose of 50%. The minimum CLW dose for maximal inactivating fecal D-streptococci bacteria in 32 d was obtained to be 40%. In general, CLW was found most effective for inactivation of fecal coliforms and sulfate-reducing clostridium bacteria compared with other pathogenic bacteria. The fecal coliforms and sulfate-reducing clostridium bacteria were completely eliminated after 32 d with a CLW dose of 50%. At the same time and with the same lime dose, up to 99% of fecal D streptococcus and total mesophilic bacteria were inactivated.

From the foregoing, this study revealed that the tested CLW tested can be effectively used in stabilization of the urban sludge from sewage plants. It was obtained that the inactivation rate increased as lime dosage increased. The removal of pathogenic microorganisms depended also on the pH reached by the sludge, the period of liming activity and the dryness of the sludge.

Hence, it was concluded that CLW increased the pH and promoted inactivation of different pathogenic bacteria.

The economic advantage of CLW is its alkalinity and its favorable effect on the physical structure of the sludge make it the most used reagent for stabilization of urban sludge in sewage plans.

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