Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2023, Volume 14, Issue 11, Page 1187-1195

http://www.jmaterenvironsci.com

Calcium carbide treatment of faecal sludge

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Received *08 Aug 2023,*
Revised *30 Oct 2023,*
Accepted *03 Nov 2023*

Keywords:
- ✓ *Faecal sludge;*
- ✓ *Calcium carbide;*
- ✓ *treatments;*
- ✓ *completely hygienized;*
- ✓ *agronomic*

Citation*: Akpaki O., Toi Bissang B., Megnassan S., Baba G. (2023) Calcium carbide treatment of faecal sludge, J. Mater. Environ. Sci., 14(11), 1187-1195*

Abstract: Biological processes for treating faecal sludge (composting, anaerobic digestion, etc.) although they are ecological present difficulties in their implementation. The aim of this study is to develop a simple and adapted process to overcome the constraints related to biological processes. Indeed, the study consisted in the treatment of faecal sludge with calcium carbide CaC_2. Faecal sludge of 75% moisture content was added in the proportions of 0.5% and 1% (w/w) of calcium carbide in beakers with permanent stirrings. The results obtained showed that with the addition of 0.5% (w/w) CaC_2 in the sludge, the temperature of the fecal sludge increased from 27.7°C to 41.23°C and made the reaction medium alkaline with a pH around 12 at day 6. Thus, the treatment resulted in a destruction of more than 95% of the thermotolerant coliforms, Entamoeba Coli, faecal streptococci, sulfito-reducing anaerobics contained the sludge. In addition, the treatment with this additive significantly reduced the solubility of trace metal elements and in particular lead Pb in the treated sludge. Then, the settling test showed that the sludge indices SI < 100 $mL.g^{-1}$ which will give a considerable economic factor in the drying time of treated sewage sludge on the drying beds. Finally, the germination test showed that a dose < 5% (w/w) of treated sludge is largely sufficient for an 80% germination rate of cowpea seeds. Calcium carbide treatment is a simple and reliable approach that allows to obtain fecal sludge completely hygienized and ready for agronomic uses as fertilizers.

1. Introduction

The approach aimed at improving the overall health situation of the environment by eliminating any cause of insalubrity is to evacuate the waste from the concessions and treat it in hygienic conditions (Akpaki *et al.*, 2023). Thus, the storage, disposal, transport, treatment and end use of fecal sludge remains a huge challenge in developing countries (Temitope *et al.*, 2016). However, the recovery and agricultural use of organic matter and nutrients from faecal sludge can improve soil structure and fertility, increase agricultural productivity and thus contribute to food security, benefits that can be achieved once faecal sludge is treated sufficiently to inactivate pathogenic germs to make them safe (Werner *et al.*, 2009; Maria *et al.*, 2013; El Ouadi *et al.*, 2017). The safe disposal of faecal sludge in the environment will require treatments to kill or disable pathogenic germs and stabilize sludge organic matter (Eugene *et al.*, 2020). Low-cost and environmentally friendly sanitation technologies can be considered to combat health and environmental pollution in order to effectively reduce the pathogenicity of microorganisms transported in faecal sludge to safe levels (Winker *et al.*, 2009, Maria *et al.*, 2013). However, it is therefore necessary to develop an innovative approach that can help reduce the high contamination of sludge for their use as fertilizer in agriculture in wetlands (Richard *et al.*, 2022). Chemical processes involving the use of additives such as urea, lime, ammonium sulphate, ferric chloride have been studied for their effectiveness in the treatment of faecal sludge. Indeed, these additives increase processes such as the decomposition of faecal sludge and dewatering, resulting in a reduction in the volume of sludge and pathogenic germs (Eugene *et al.*, 2020, Ogouvidé *et al.*, 2021, Richard *et al.*, 2022) Also, the process of disinfection of faecal sludge with calcium carbide, which is the subject of this study, is based on the chemical reactions that occur when calcium carbide is brought into contact with faecal sludge. The first reaction generates heat as well as calcium hydroxide also called slaked lime. Thus, it will follow a series of reactions making the mixture very alkaline. The present study evaluated the performance of calcium carbide for faecal sludge treatment at the laboratory level and revealed very conclusive results.

2. Materials and methods

2.1 Treatment

Faecal sludge treatment was performed at laboratory temperature which averaged 26.89 ± 1.15°C. For this study, the additive was calcium carbide CaC_2, it was added to faecal sludge with a moisture content of 75.17%. Indeed, the treatment consisted in hygienizing two (2) samples A and B of fecal sludge contained in two plastic beakers of capacity 1L. Thus, in samples A and B calcium carbide was added in proportions of 0.5 and 1% (w/w) respectively. Each beaker was associated with a glass rod allowing the complete homogenization of the reaction medium (**Figure 1**). However, a control sample (T) without the additive (0% w/w) was the reference for treatment.

Figure 1: CaC_2 processing reactors

Figure 2: Sample settling test

A: 0.5% treatment; B: 1% treatment

Calcium carbide used for faecal sludge treatment has a purity of 97%. However, for the CaC_2 dose, he measured sludge density was 1.07 g.mL^{-1}, so that the equivalent of 1 kg = 1 L is applied (Winker *et al.*, 2009). Thus, for the addition of CaC_2 to sludge, the calculation was made as shown in **Eqn. 1**.

$$CaC_2 \text{ dosage} = \frac{\text{weight FS} \times CaC_2 \text{conc.} (\%)}{CaC_2 \text{ purity} (\%)} \qquad \textbf{Eqn. 1}$$

The quantities of calcium carbide used in the treatment of faecal sludge in this are shown in **Table 1**

Table 1 : Weighted faecal sludge and amount of CaC_2 used in the treatment

CaC_2 treatment (% w/w)	Number of reactors	Mass of FS (kg)	Mass of CaC_2 to add (g)	g CaC_2/kg FS
0.0	1	0.5	0.00	0.00
0.5	1	0.5	2.57	5.14
1.0	1	0.5	5.15	10.30

The faecal sludge treatment lasted 7 days. After treatment, the treated sludge was dried with a drying rate of 95% and used for germination tests. The dryness was evaluated by **Eqn 2**. Indeed, a mass m1 of sludge is dried in the oven at 105°C, until a constant mass m2 after 24 hours.

$$\text{Dryness} = \frac{m_2 \times 100}{m_1} \qquad \textbf{Eqn. 2}$$

with m_1 the wet sample mass and m_2 its mass after drying

2.2 pH measurements

The pH was controlled with a pH meter electrode, brand Storius PT-10, before and after the addition of calcium carbide. Then, additional pH tests were performed daily during the seven (7) days of treatment to check whether the addition of calcium carbide would change the pH of the fecal matter.

2.3 Un-ionized ammonia

The fraction present as NH_3 in aqueous solution during the treatment of sludge with calcium carbide can be calculated according to **Eqn. 3**. The fraction of NH_3 in aqueous solution is affected by pH and temperature (Annika, 2010).

$$f_{NH_3} = \frac{1}{10^{pKa-pH} + 1} \qquad \textbf{Eqn. 3}$$

with $pka = \frac{0,0901821+2729,92}{T_k}$ où $T_k = t\,°C + 273,2$

2.4 Germination test

In order to know the inhibition factor of the organic fertilizers obtained (treated sludge) a germination test was carried out on cowpea seeds. Indeed, cowpea seeds are sown on supports containing a mixture «sand + sludge treated» in different proportions: Sand + 2.5%, 5% and 7.5% (p/p) of faecal sludge treated. However, a control sample (100% sand) was used to assess the fertilizing and inhibition power of the treated sludge (Chennaoui *et al.*, 2016). Thus, the germination rate is evaluated by **Eqn. 4**.

$$\text{Germination rate}(\%) = \frac{\text{Number of sprouted seeds}}{\text{Number of seeds tested}} \times 100 \qquad \textbf{Eqn. 4}$$

2.5 Organic matter content

Organic matter (OM) was determined by the fire loss method and directly measured organic matter in the treated sludge. The samples were dried for 16 hours in an oven at 105°C. Thus, a mass of each treated fecal sludge sample was taken from a dry crucible. Then the crucible and its contents were placed in an oven for 16 hours at 375°C (Ceaeq *et al.*, 2003). The percentage of organic matter is given by the **Eqn. 5.**

$$\%OM = \frac{m_1 - m_2}{m_1 - m_0} \times 100 \qquad \textbf{Eqn. 5}$$

where OM : organic matter (%); m_0 : empty crucible mass (g); m_1 : final mass (g) and m_2 : mass of the ash-containing crucible (g).

2.6 Settling test in test piece

The sludge index test is used to assess the suitability of faecal sludge treated by this innovative process for settling. Indeed, to 25 mL of hygienized faecal sludge taken from a 100 mL sample was added 75 mL clarified water to cause dilution to 1/4 ¼ (Akpaki *et al*., 2022). After a few agitations by a movement from the bottom to the top of the hermetically sealed test piece, the mixture is left to rest at laboratory room temperature and on a horizontal bench isolated from all vibrations. After 30 minutes of settling, the volume of mixed sludge settled in the graduated cylinder is noted V_{30} (**Figure 2**). The sludge index represents the volume occupied by one gram of sludge after 30 minutes of static settling in a 1 L test tube with graduated transparent wall (Akpaki *et al*., 2022). The measured sludge index (SI) expressed in $mL.g^{-1}$ of suspended solids (SS), defined by **Eqn. 5**.

$$SI = \frac{V_{30}}{SS} \qquad \textbf{Eqn. 5}$$

The determination of suspended solids is made by filtration on glass fiber filter taking into account the domestic origin of the effluents. The measurement of suspended solids by filtration is based on the principle of double weighing: a volume of sewage sludge is filtered on a membrane (previously weighed vacuum) of 1.5 microns and the residues on the latter are weighed (Akpaki, 2015).

2.7 Metal trace element content

The samples were mineralized by acid digestion with aqua regia. Each sample was subjected to 3 test samples of 1 g. Each intake is placed in a glass erlenmeyer where it receives 3 mL of demineralized water, 7.5 mL of concentrated hydrochloric acid (38%) and 2.5 mL of concentrated nitric acid (65%). The mixture is hermetically sealed and left at room temperature for 12 hours. The mineralization is then concentrated by boiling for 2 hours. After cooling, the volume is adjusted to 20 mL with demineralized water. Mineralized blanks (without sludge) are prepared simultaneously (Akpaki *et al*., 2022). The determination of trace metal elements in mineralisâts is carried out by flame atomic absorption spectrometry (Aanalyst 800/PERKIN ELMER).

2.8 Microbiological analysis

Determination of Thermotolerant coliforms, E. coli, Faecal sreptococci and Sulfito-reducing anaerobics in raw sludge and treated sludge is based on the research and counting of bacterial colonies by membrane filtration technique and seeding in suitable culture media followed by incubation at the appropriate temperature during 18 to 24 hours. The analyses were carried out according to the methods of routine analysis of the Association Française de Normalisation (AFNOR): order of 21 December 1979 (Ogouvidé *et al*., 2021).

3. Results and Discussion

3.1 Effects on physical and microbiological parameters

The addition of clcium carbide to faecal sludge increased the temperature from 27.7°C to 41.23°C for sample A and to 52.68°C for sample B. The analysis of the data in **Figure 3** shows that the temperature of the two media A and B began to stabilize from the 5^{th} day of treatment. The increase in the temperature of the reaction media showed that there was probably an exothermic reaction. During this time, at the control sample (T) the temperature is almost constant 27.77 ± 0.09°C suggesting that no particular reaction occurred unlike the samples treated with calcium carbide. The high temperature with treatments is due to the heat emission resulting from exothermic reactions of calcium carbide and faecal sludge (**Eqn. 6**) (Riad *et al*., 2012, Chukwu, 2014, Eugene *et al*., 2020).

$$CaC_{2(s)} + 2H_2O_{(l)} \longrightarrow Ca(OH)_{2(s)} + C_2H_{2(g)} \quad Q\ (heat) \qquad \textbf{Eqn. 6}$$

Figure 4 shows the gradual and significant increase in pH values from 7.45 to 11.45 and 11.67 for A and B, respectively, when the additive was added. The values of these pH values have been stabilized from day 5 also (**Figure 4**). But we note that the pH of the test sample (T) remained constant during the 7 days of treatment which shows once again that no reaction took place in this medium. However, pH increases in samples A and B can be attributed to the production of alkaline compounds such as hydroxides from reactions to calcium carbide with organic substances in sludge (Eugene *et al*., 2020) as shown in **Eqn. 7** (Temitope *et al*., 2016, Ogouvidé *et al*., 2021).

$$C_6H_{12}O_6 + 7O_2 + CaC_2 \longrightarrow Ca(OH)_2 + 8CO_2 + 2H_2O + 3H_2 \qquad \textbf{Eqn. 7}$$

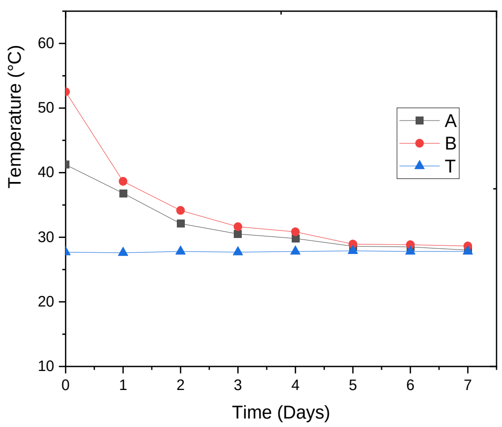

Figure 3 : Temperatures recorded

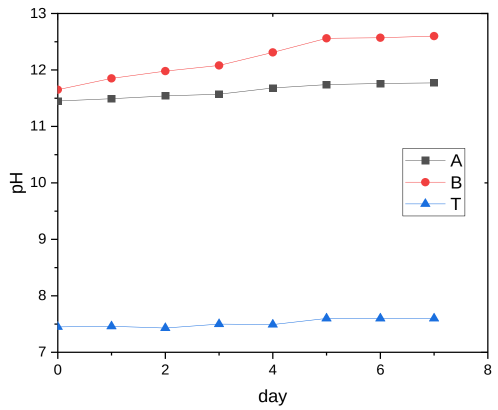

Figure 4 : pH values recorded

It is also noted that fecal sludge is very concentrated in ammonium ion NH_4^+ and with the formation of $Ca(OH)_2$ by the treatment with decalcium (**Eqn. 7**) justifies in addition the increase of the pH by formation of our alkaline compound amoniac $NH_{3(aq)}$ (**Eqn. 8**)

$$Ca(OH)_{2(s)} + 2NH^+_{4(aq)} \longleftrightarrow Ca^{2+}_{(aq)} + NH_{3(aq)} + 2H_2O_{(l)} \qquad \textbf{Eqn. 8}$$

Analysis of **Figure 5** shows that the fraction of $NH_{3(aq)}$ in fecal sludge + CaC_2 mixtures increased for 5 days and became stable from day 6 of treatment. The increasing evolution of the fraction of $NH_{3(aq)}$ proves that the un-ionized NH_3 formed and concentrated throughout the treatment.

However, the analyses of the results presented in **Table 2** show that the treatment of sludge with calcium carbide is very hygienizing. We note that the application of 1% (w/w) of CaC_2 to sludge already allows the destruction of almost all the microbiological germs sought in this work. The destruction of these patogenic germs is justified by the alkalinity of reactive media by the formation of $Ca(OH)_2$ and then by the formation of $NH_{3(aq)}$. Indeed, non-ionized ammonia $NH_{3(aq)}$ acts as the main hygienizing agent of sludge. Inactivation of pathogens by non-ionized ammonia is observed for several types of microorganisms, bacteria, viruses and parasites (Pérez, 2014, Akpaki *et al*., 2022).

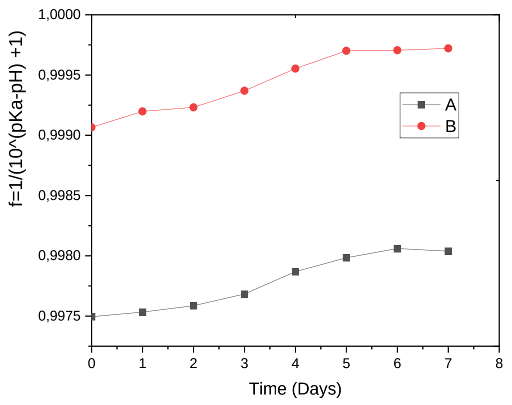

Figure 5 : Evolution of the non-ionized NH_3 fraction

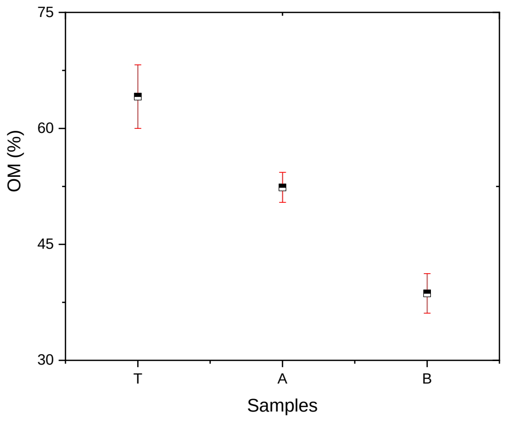

Figure 6 : Tevel of organic matter

Table 2: Effects of CaC_2 on microbiological germs

Samples	Number of germs in CFU.g^{-1} sample			
	Thermotolerant coliforms (44°C)	*E.coli* (44°C)	Faecal streptococci (37°C)	Sulfite-reducing anaerobes (44 °C)
T	7000	3000	190000	24000
A	4	2	10	6
B	0	0	0	0

Thus, when calcium hydroxide $Ca(OH)_2$ is released into fecal sludge (**Eqn. 7**), it acts as a disinfectant by killing the pathogens present. This includes bacteria, viruses and parasites that can cause diseases dangerous to human and plant health (Temitope *et al*., 2016).

3.2 Abatement effects on metal trace elements

The analysis in **Table 3** shows that for treated sludge A and B their concentrations of Zn, Cu, Pb and Cd dropped considerably compared to the control sample (T). Indeed, these concentration drops could be justified by the fact that calcium carbide has an alkaline effect and it allows to keep the treated sludge at pH 11 to 12, thus minimizing the solubility of the metals that are there by complexation or precipitation (Akpaki *et al*., 2022). It is noted that in the fecal sludge + CaC_2 mixture there is an anionic group that functions as inorganic ligands (OH^-) and can react with metal ions. However, for a very basic medium (pH ≥ 9) complex ions are formed that can contain up to six Pb atoms (for example $[Pb_6O(OH)_6]_4^+$) (García *et al.*, 2004), This hypothesis would justify the remarkable decrease in Pb concentrations after treatment. It can be seen that the higher the rate of CaC_2 added in the reaction medium, the higher the rate of Pb element abatement.

Table 3: Contents of trace metal elements

Samples	**Parameter in mg.kg^{-1}**					
	Zn	**Cu**	**Ni**	**Pb**	**Cd**	**Cr**
T (FS+0%CaC_2)	724.05 ± 3.56	49.94 ± 2.07	18.08 ± 0.12	21.95 ± 0.17	02.08 ± 0.15	85.04 ± 2.60
A (FS+1%CaC_2)	584.50 ± 4.28	27.07 ± 0.26	16.34 ± 0.27	08.20 ± 1.24	01.88 ± 0.41	71.21 ± 3.05
B (FS+1,5%CaC_2)	408.06 ± 5.13	18.94 ± 3.42	14.71 ± 1.06	06.87 ± 2.02	01.19 ± 1,07	63.13 ± 1.45

In addition, these reductions are justified by the formation of metal salts. Their formation results from an oxidizing attack: the metal is oxidized in positive ion (cation) and then combines with a negative ion (anion) to give a salt like sulphides, chlorides, sulphates, nitrates, phosphates of, lead, mercury, zinc, tin, nickel (Ogouvidé *et al*., 2021). However, the parallelism of the reductions in concentration of metal trace elements of the treated faecal sludge (A and B) shows that the reduction rate increases with the dose of CaC_2. These results show that calcium carbide has a strong precipitation power of metal ions. Then, the results of Table 3 would also be explained by the precipitation of elements in the form of metal carbonates (MCO_3) thus limiting the solubility of these metal trace elements. Like sludge liming, calcium carbide treatment also decreases the amount of soluble and bioavailable metals for plants and terrestrial organisms, both by dilution effect and by the movement of metals to stable forms. Thus, thanks to this treatment process, the metals brought by sludge take more stable forms, less mobile and bioavailable, and therefore less contaminating to the environment (Akpaki *et al*., 2022).

3.3 Germination test

The recovery of treated sludge in agriculture is the final destination of this study. Thus, the evaluation of the toxicity related to the treatment of sludge with calcium carbide led to the germination test to realize the optimal dose and fertilizing power of sludge thus obtained after treatment (**Table 4**).

Table 4: Cowpea seed germination test

	Sand + 0% of sludge	Sand + 2.5% sludge		Sand + 5% sludge		Sand + 7.5% sludge	
		A	B	A	B	A	B
Germination rate	60	100	80	70	40	30	10

The results presented in **Table 4** show that the incorporation of 2.5% sludge to the soil allows a germination rate of 100% and 80% of cowpea seeds respectively for A and B. However, the germination rate decreases as the sludge dose increases. The inhibition of seeds from 5% and 7.5% sludge is justified by contribution of dry matter provided by calcium carbide and which would have attenuated the content of fertilizers. The inhibition of cowpea seeds is also linked to the progressive alkalinity of the seed medium. Thus, this test then made it possible to note the fertilization of the soils by the sludge treated with calcium carbide and then to note that from the dosages 5% of the seeds are considerably repressed.

3.4 Organic matter content

The determination of organic matter made it possible to assess the amount of organic matter present in the treated sludge compared to the raw faecal sludge. Thus, the values of the rates of organic matter of the treated sludge are 52.37 1.94% and 38.66 2.56% respectively for the samples treated at 1% (A) and 1.5% (B). However, the analysis in **Figure 6** shows that the organic matter content decreases when the additive rate increases. Thus, the reduction in the rate of organic matter observed compared to control T (64.11 ± 4.12%) is due to a contribution of dry matter by calcium carbide whose organic matter content is very low. Nevertheless, we see that the percentage of organic matter in sample A is close to that of the control, which shows that the treated sludge can greatly increase the cation exchange capacity of the soils that will be almond. Moreover, the germination test shows that this contribution of dry matter by calcium carbide to the treated sludge hardly affects their fertilizing power and water retention assimilable by plants (Akpaki *et al*., 2022).

3.5 Settling test

In order to check the suitability of the treated sludge for settling, the sludge index SI test was performed. Indeed, the mud index is an essential tool for the operator of drying beds not planted with sludge for their dehydration. Thus, the calculations of the treated sludge indices gave values of 31.00 ± 0.32 mLg^{-1} and 30.00 ± 0.24 mL/g respectively for sludge treated with 1% and 1.5% (w/w) calcium carbide. However, for SI < 100 $mL.g^{-1}$, sludge easily sedimentates and is most often well mineralized (Ogouvidé *et al*., 2021). Thus, it can be said that these treated fecal sludges (A and B) will be easily dehydrated once admitted to the drying beds. In addition, the treated sludge is more suitable for settling due to the addition of ferric chloride ($FeCl_3$). Indeed, the addition of $FeCl_3$ to the sludge mixture + CaC_2 favored the dewatering of sludge by the formation of amorphous gels (Ogouvidé *et al*., 2021**,** Akpaki *et al*., 2022). Thus, the process of treating faecal sludge with calcium carbide is of great economic interest because it reduces the drying time of treated sludge once admitted into the drying bed.

Conclusion

The use of raw fecal sludge as fertilizer has shown a high level of hygiene and public health inconsistency. Thus, the treatment of faecal sludge with calcium carbide is one of the innovative means for the hygienization of fecal sludge. The study showed that the addition of 0.5% (w/w) of CaC_2 to fecal sludge allowed the fraction of non-ionized ammonia $NH_{3(aq)}$ to grow and thus make the reaction medium more alkaline with a pH around 12. This resulted in a neutralization of more than 95% of thermotolerant coliforms, escherichia coli, faecal streptococci and sulfito-reducing anaerobics. At pH ≥ 11.5, metal trace elements in the ionic state such as Zn, Cu, Ni, Pb, Cd and Cr were precipitated and complexed thus limiting their solubilities in the treated sludge. Then, the settling test assessed their suitability for settling by their sludge indices SI between 31 ± 0.32 mLg^{-1} and 30 ± 0.24 mLg^{-1} respectively for 0.5% and 1% (w/w) CaC_2 additions. The inhibition factor of the treated sludge was assessed by the germination test on cowpea seeds. The test results showed that for a dose < 5% (w/w) of treated sludge the seed germination rate is around 80% and a dose 5% (w/w) would affect seed germination. Also, the process has proven effective and simple to sanitize toilets in suburbs and rural areas to minimize the release of odors and the multiplication of pests in these non modern toilets.

Thus, disinfection of fecal sludge with calcium carbide on a large scale and its application in emergencies is more efficient. Future work will focus on methods of recovering C_2H_2 from treatments for economic uses.

Acknowledgement. The technical inputs of Dr Batcha Ouadja of Life and Earth Sciences Department are acknowledged.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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