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Many coagulants, mainly inorganic, are widely used in conventional water and wastewater treatment. Recent studies reported the occurrence of some chronic diseases associated with residual coagulant in treated wastewater. The use of alternative coagulants which are biodegradable and environmentally friendly could alleviate the problem associated with these diseases. This work investigates the capability of *Jatropha curcas* seed and presscake (the residue left after oil extraction) to reduce the turbidity of wastewater through coagulation. The coagulant was prepared by dissolving *Jatropha curcas* seed and presscake powder into solution. Then jar tests were conducted on kaolin solution as the model wastewater. The *Jatropha* seed was found to be an effective coagulant with more than 96% of turbidity removal at pH 1–3 and pH 11–12. The highest turbidity removal was recorded at pH 3 using a dosage of 120 mg/L. The flocs formed using *Jatropha* were observed to be bigger and to sediment faster when compared with flocs formed using alum. The turbidity removal was high (>98%) at all turbidities (100 NTU to 8000 NTU), suggesting its suitability for a wide range of industrial wastewater. The performance of *Jatropha* presscake after extraction of oil was also comparable to the fresh seed and alum at highly acidic and highly alkaline conditions. The addition of *Jatropha* did not significantly affect the pH of the kaolin samples after treatment and the sludge volume produced was less in comparison to alum. These results strongly support the use of *Jatropha curcas* seed and presscake as a potential coagulant agent.

Keywords: wastewater; coagulant; *Jatropha*; coagulation

1. Introduction

Coagulation processes are commonly used for treating wastewater from various industries such as textile, chemical, pharmaceutical, metal-working and petrochemical [1]. Commonly, the conventional coagulation/flocculation processes involve three stages. In the first stage, the chemical reagents are added to the wastewater, and these reagents destabilize the pollutants (or the formation of particles with reduced solubility from the pollutants). The aim of the second step is to achieve the formation of solids with bigger size, and it is attained by a soft mix that allows the collision between particles and their aggregation. The last stage consists of the separation of the solids by settling or dissolved air flotation [1].

Conventionally, employing coagulation, as a unit process, in water and wastewater treatment entails the use of metal salts (Al and Fe salts). Sometimes, synthetic organic polymers are used as a coagulant aid, with the metal salts as the primary coagulant. However, recent studies have discovered a number of problems concerning the use of alum salts, for example as a possible link to Alzheimer's disease [2,3] and other related problems associated with high volumes of residual alum in treated wastewater [4,5]. Moreover, the use of alum has also been reported to be inappropriate in some developing countries because of its high cost and also limited availability [6]. It is due to these factors that many researchers are searching for a cleaner and more environmentally friendly coagulant (biocoagulant) originating from natural resources such as plants, animals and microorganism. To date, several biocoagulants have shown good ability for coagulating action, including *Moringa olefiera* [5,7], chitosan [8–10], cactus [11,12] and starch [13].

Another potential source of biocoagulant is *Jatropha*. The genus *Jatropha* falls under the Euphorbiaceae family and contains approximately 170 known species. The name *Jatropha* derives from the Greek word *jatr'os* (doctor) and *troph'e* (food), which implies medicinal uses, and its common name is physic nut. By definition it is a small tree or large shrub, which can reach a height of 3 to 5 m, but under favourable conditions it may attain a height of 8 or 10 m.

Jatropha curcas oil extracted from the seeds is currently being used as a raw material in the biodiesel

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production. Other parts of this plant have been traditionally used for various purposes including therapeutic uses. Extracts from *Jatropha curcas* leaves and roots are claimed to be a remedy for cancer, and are antiseptic, diuretic, purgative and haemostatic. The nut of the plant has also been used traditionally for treatment of burns, fever, inflammation and convulsions [14,15]. The *Jatropha curcas* seed is in general toxic to humans and animals owing to the presence of toxic compound such as phorbol ester and curcin. The proximate composition of the seed is reported to be 23.6% crude protein, 29.8% ether extract, 3.2% ash, 1.8% crude fibre and 21.6% nitrogen-free extract [14]. It is believed that the presence of this water-soluble protein in the seed may contribute to its coagulating ability. The analysis and sequencing of amino acids [15] from *Jatropha curcas* from Cape Verdean, Nicaraguan and Mexican varieties show high content of glutamic acid, followed by arginine and also aspartic acid. The content of the other 15 types of amino acid is less than 7.5 g/16 g N.

Recently, Pritchard *et al*. [16] reported a preliminary trial of the use of *Jatropha curcas* extract for coagulation in shallow water treatment in Malawi. However, few studies have reported on the use of *Jatropha curcas* as a potential biocoagulant for water and wastewater applications. Since the seed cannot be used for human or animal consumption, it is of interest to investigate its use for other applications. Furthermore, the presscake residue remaining after oil extraction needs to be disposed of. Instead of sending to landfill, a better prospect would be if the protein in the presscake waste could be used in some way. This work aims to demonstrate the capability of using *Jatropha curcas* for coagulation purposes.

2. Materials and methods

2.1. *Preparation of coagulant agent from* Jatropha curcas *seeds*

Jatropha curcas was obtained from Malacca plantation (Malaysia). The skin was removed manually and good quality seeds were selected. The kernel was grounded to a fine powder (63–500 μm) using an electric blender (Model BL 333, Khind) and used in every experiment. To prepare the coagulant, 5 g of the *Jatropha* powder or presscake was blended with 100 mL of distilled water at room temperature for several minutes in order to extract the active ingredients of the *Jatropha* seeds. The resulting suspension was filtered through muslin cloth.

2.2. *Preparation of kaolin synthetic wastewater*

In this work, kaolin (R and M Chemicals, Essex, UK) was used as the model wastewater. Stock kaolin suspension was prepared by dissolving 10 g of kaolin in 1 L of distilled water. The suspension was stirred slowly at 20 rpm for one hour in a jar apparatus for uniform dispersion of kaolin particles. The suspension was then allowed to stand for 24 hours to allow for complete hydration of the kaolin. This kaolin suspension was used as the stock solution for the preparation of water samples of varying turbidities for the coagulation tests.

2.3. *Main coagulation experiments*

The coagulation test was carried out using jar floc test (JLT 6 Velp Scientifica, Usmate, Italy). The study involved steps such as rapid mixing, slow mixing and sedimentation in a batch process. The duration and speed used during the above mentioned steps were based on previous coagulation procedures using other types of biocoagulants [7,8]. Several beakers were filled with 500 mL of synthetic wastewater and placed on to the floc illuminator and agitated simultaneously to ensure uniform mixing. During a rapid mixing period of 4 minutes at 100 rpm, the coagulant dosage of *Jatropha curcas* was added to each beaker of kaolin sample. Next, slow mixing at 40 rpm occurred for 25 minutes before the samples were left to sediment for 30 minutes. After the sedimentation, the samples were filtered using muslin cloth, and the supernatant was collected to measure the final turbidity using a Hach Turbidimeter Model 2100 N. In this work, the effect of several parameters, including pH, dosage, initial turbidity and blending time for extraction of active ingredients, on the coagulation process was investigated. All the experiments were repeated twice.

The performance was evaluated by measuring the turbidity, sludge volume, the pH of the raw and treated kaolin samples and chemical oxygen demand (COD) using APHA standard methods [17]. The sludge volume was measured using Imhoff cones. The pH was obtained using a pH meter (Schott Instruments, Model Lab850), while the sedimentation time of the flocs formed was determined when most of them had settled at the bottom. The percentage of turbidity removal is given by the difference between initial and final turbidity over the initial turbidity, multiplied by 100.

The optimum conditions found from the above experiments using *Jatropha* seed was used to investigate the performance when using its presscake for coagulation. Initially, the seeds were cracked and the shells were carefully removed. The kernels were ground with a sieve plate and shaker grinder (Fritsch Cutting Mill P19). The seeds then were subjected to a solid–liquid extraction process with hexane (Systerm, Shah Alam, Malaysia) using a soxhlet extractor for eight hours at about 68 °C. Then, the solid residue (presscake) was filtered from the oil and solvent by vacuum filtration (Millipore glass base and funnel) and was then used for the coagulation process. The experiments were conducted at pH 3 and initial turbidity of 250 NTU, using a dosage of 120 mg/Lof presscake.

As a basis for comparison, similar experiments were also carried out using alum (Riedel-De Haen, Seezle Germany) as the coagulation agent at various pH values (pH 1–12) and dosages (2–120 mg/L) using initial turbidity of 2500 NTU.

2.3.1. Effect of pH

The effect of pH was studied by fixing the wastewater pH in the range from pH 1 to pH 12, and the coagulation test was performed at room temperature with an initial turbidity of 2500 NTU and coagulant dosage of 120 mg/L. The pH was adjusted using 1 M NaOH (Systerm, Shah Alam, Malaysia) and 1 M HCl (Systerm, Shah Alam, Malaysia) solutions.

2.3.2. Effect of coagulant dosage

For studying the effect of coagulant dosage, the synthetic wastewater pH was fixed at pH 3 with an initial turbidity of 2500 NTU. Various doses of coagulant (2 mg/L to 120 mg/L) were added to several beakers of wastewater samples and rapidly mixed. The suspension was slowly mixed and finally left for sedimentation to occur.

2.3.3. Effect of initial turbidity of wastewater

The effect of the initial turbidity of the kaolin water samples was examined at the optimum dosage and pH found from previous experiments. The turbidity range studied was 100 to 8000 NTU.

2.3.4. Effect of blending time for coagulant agent extraction

The effective blending time for active ingredient extraction was also investigated at pH 3 using 120 mg/L of *Jatropha* coagulant. The blending time of the seed was 2, 5, 10 and 15 minutes, and the initial turbidity of the kaolin solution was 2500 NTU.

3. Results and discussion

3.1. Effect of pH

The pH of each beaker was adjusted to the desired pH before the coagulation treatment took place using *Jatropha* seed. During the experiments, big flocs were observed, especially for conditions at pH 3. Smaller and fewer flocs were seen for pH 5 to 9. As can be seen in Figure 1, the percentage of turbidity removal for pH 1 to 3 is about 99%, whereas, at pH 5 to 9, there is a significant reduction in the coagulant performance. On the other hand, at pH 11, the percentage of turbidity removal rose again to 97%. It seemed that the coagulation is good at acidic pH less than 3 and also at pH greater than 11.

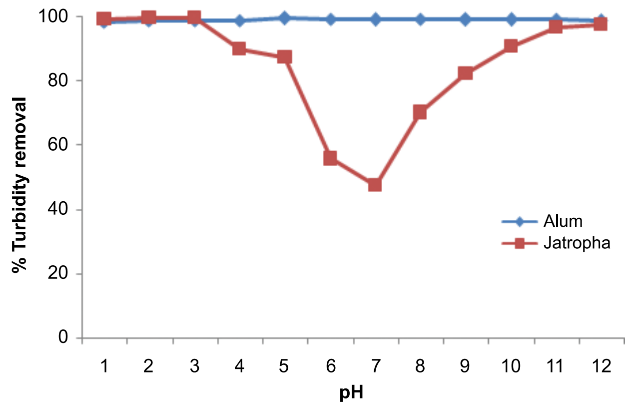

Figure 1. The percentage reduction of turbidity for pH range from 1 to 12 for kaolin wastewater sample using *Jatropha* seed and alum.

This may be because, at pH less than 3, the positive charges on the amino acids that make up the protein molecules dominate. Most of the amino acids present in *Jatropha curcas* protein [15] have isoelectric point (pI) values from 3.2 to around 11 [18]. Hence, it is expected that most of the amino acids will have positive charges at pH less than 3, and hence the protein can work very well as a cationic coagulant agent. As an amphoteric molecule, the charge on the protein is very much dependent on the pH values. At pH greater than 3, a mixture of positive and negative charges of various amino acids in the protein may have reduced the net cationic capability of the coagulant for the coagulation process. Above pH 11, the amino acids, except arginine, exhibit negative charges. However, according to Makkar and co-workers [15], arginine makes up a large percentage of the total protein present in the *Jatropha.* Thus, this large amount of arginine might play an important role in the coagulation process at pH >11. As *Jatropha* is similar to *Moringa oleifera* in its nature as a seed, it is believed that adsorption and neutralization of charges are the main mechanisms of coagulation using *Jatropha* seeds [19].

Although *Jatropha* appears to work well as a coagulant agent under highly acidic and highly alkaline conditions, it is still relevant for treating industrial wastewater where the pH can vary from pH 1 to pH 14. Situation may arise whereby *Jatropha* can be a useful coagulant in alkaline conditions such as in treating textiles wastewater [20] and also in acidic conditions such as in peat soil. Furthermore, if *Jatropha curcas* is proven to be very efficient indeed, then pH adjustments

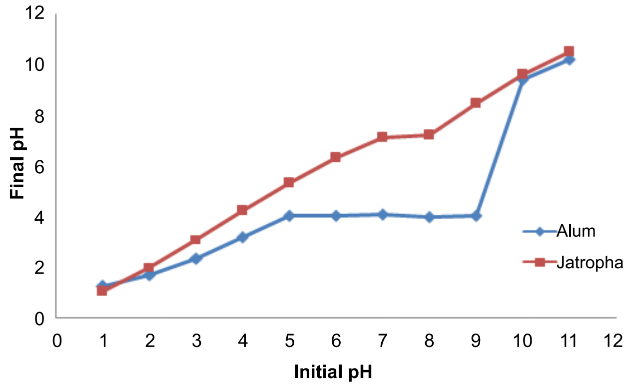

Figure 2. The changes in the final pH of the treated kaolin samples when using *Jatropha* and alum for initial kaolin pH ranging from 1–12.

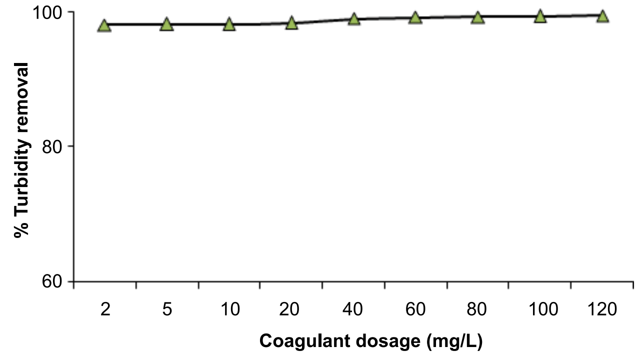

Figure 3. Trend of percentage turbidity removal for various dosages of coagulant agent (*Jatropha* seed) at pH 3 and 2500 NTU initial turbidity.

can be done to accommodate this situation. Further investigation on the final pH of the treated kaolin samples with *Jatropha* revealed that not much alteration was recorded (Figure 2) compared with the initial pH.

Similar coagulation experiments at pH 1 to 12 were also conducted using 120 mg/L of alum dosage. The initial turbidity of the kaolin wastewater was set at 2500 NTU for comparison purposes. At all pHs, alum recorded a percentage turbidity removal of more than 98% (Figure 1) and the highest removal was observed at pH 5 (99.3%).The ability of alum to remove high turbidity reflects its compatibility and flexibility for use at all conditions, compared with *Jatropha* seed which can only remove a high percentage of turbidity at highly acidic (pH < 3) and highly alkaline conditions (pH > 11). However, it was found that the final pH of the kaolin sample treated with alum decreased, which means compensation has to be made by addition of lime, and this conforms to previous results [19]. This means that both coagulants need pH adjustment either before coagulation or after coagulation for further processing.

3.2. *Effect of dosage of* **Jatropha curcas** *seed*

In studying the effect of dosage, the pH of each beaker was fixed at pH 3, where the maximum turbidity removal with big flocs had been shown to occur in previous experiments. The initial turbidity of the waste-water was set at 2500 NTU. The coagulant dosage was varied between 2 mg/L and 120 mg/L. Small solids were observed to form when wastewater samples were added with a coagulant dosage of 2 mg/L to 60 mg/L, and the wastewater appeared to be turbid even when the slow mixing was completed. For coagulant dosage of 80 mg/L to 120 mg/L, bigger flocs were seen to form, and the final wastewater after treatment was clearer. The results are shown in Figure 3. For dosage of 2 mg/L to 40 mg/L, the achieved percentage reduction of turbidity was more than 98%. For dosage greater than 60 mg/L, the percentage reduction was calculated to be more than 99%. These results are comparable to the ones obtained using *Moringa oleifera* [16,19,21–23] and also alum as reported earlier [19].

Figure 4 shows the sedimentation time taken by both alum and *Jatropha* after the coagulation process. The sedimentation of flocs formed using *Jatropha* was faster than that of flocs formed using alum owing to the former's bigger size. Furthermore, when the sludge volume was measured, *Jatropha* produced a smaller amount compared with alum, for dosages lower than 80 mg/L (Figure 5). For this comparison, the wet sludge volume (ml sludge per litre of kaolin sample) at the bottom of the beakers was used. For dosages >80 mg/L, *Jatropha* produced slightly more sludge compared with alum. Since *Jatropha* comes from plant material, its by-products are of an organic and biodegradable nature and hence offer a more environmentally friendly alternative to the other treatment process. The COD of the treated kaolin samples was also found to remain more or less unchanged with the addition of *Jatropha*.

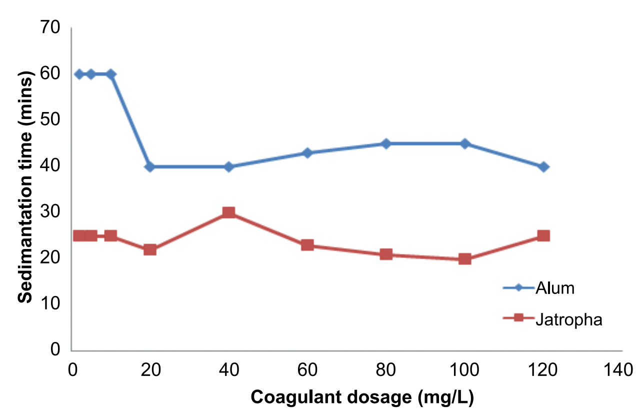

Figure 4. Sedimentation time of the flocs formed when using *Jatropha* and alum as coagulant at various dosages.

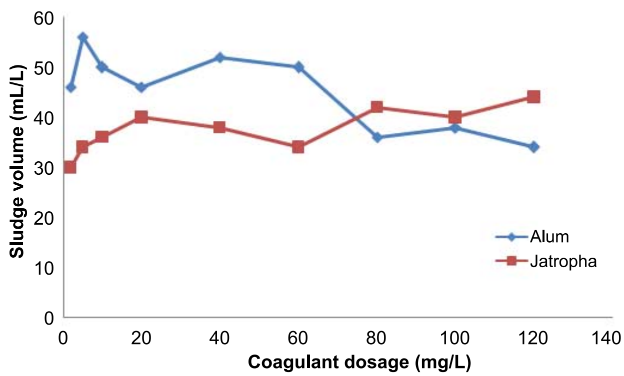

Figure 5. Volume of sludge produced when using *Jatropha* and alum as the coagulant for varying dosages at 2500 NTU initial turbidity.

3.3. Effect of initial turbidity of wastewater

The initial turbidity of the kaolin wastewater sample was varied between 100 and 8000 NTU. The pH of each sample was set at pH 3 and 120 mg/L of coagulant was added for optimum performance. Figure 6 depicts the percentage reduction of turbidity (NTU) against initial turbidity of synthetic wastewater. The turbidity removal increased for initial turbidity from 100 to 500 NTU before it slightly decreased as initial turbidity was further increased to 8000 NTU. The maximum turbidity removal recorded at 500 NTU was 99.5%. Generally, the percentage turbidity removal is still greater than 98.4% for all initial turbidity values. This suggests that *Jatropha curcas* is suitable for treating water and industrial wastewater with a wide range of initial turbidity.

3.4. Effect of blending time for extraction of coagulant agent

The blending time was varied between 2 and 15 minutes, and the pH of the wastewater in the beaker was fixed at pH 3. Figure 7 illustrates the percentage removal of turbidity against blending time. As the

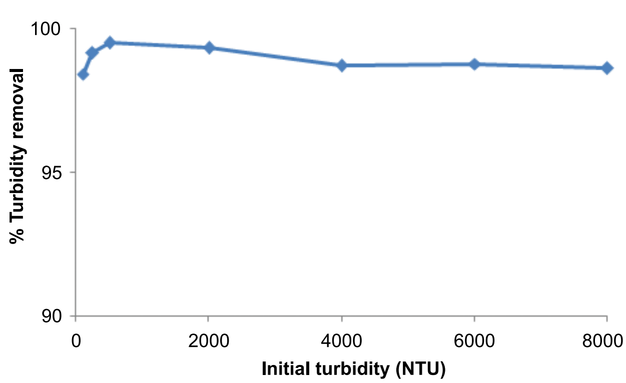

Figure 6. Percentage reduction of turbidity for various initial turbidity values at pH 3 using *Jatropha* seed.

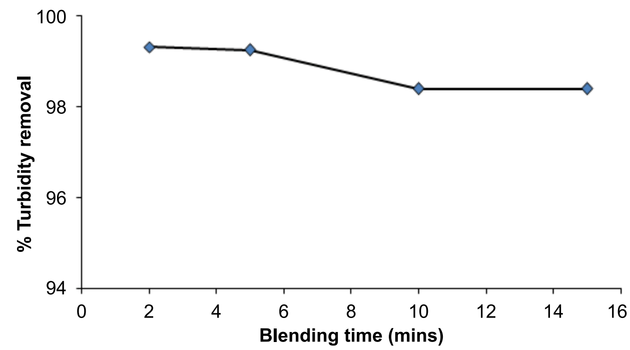

Figure 7. Percentage removal of turbidity for various extraction time (blending time) using *Jatropha* seed.

extraction time was increased, the percentage turbidity removal of the kaolin wastewater was reduced.

The percentage of turbidity removal for 2 and 5 minutes blending (extraction of active agent) time was 99%, while, for blending time at 10 and 15 minutes, the percentage of turbidity reduction slightly decreased to 98%. This is good as it means a smaller amount of time is sufficient to extract the required amount of active agent for an effective coagulation process. Moreover, the visual observation showed that the flocs formed using coagulant agent extracted for 2 minutes were bigger compared with the other extraction time. It is suspected that a longer extraction process may disrupt the protein and thus reduce its capability as a coagulating agent.

3.5. Using Jatropha *presscake after oil extraction*

The coagulation capability of *Jatropha* presscake was also investigated at the optimum condition of the coagulation process previously found using *Jatropha* seed. The process conditions were at pH 3 using 120 mg/L coagulant dosage and initial turbidity of 2500 NTU. Figure 8 shows the percentage turbidity removal of the kaolin wastewater is 99.7% which is comparable to the

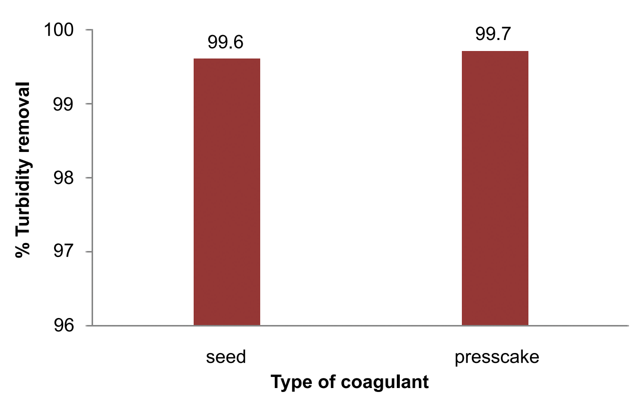

Figure 8. Comparison of turbidity removal using *Jatropha* seed and presscake at optimum conditions of pH 3, dosage 120 mg/L and 2500 NTU.

performance of the seed. This indicates good potential of utilizing this waste for the coagulation process.

4. Conclusion

From this study, it can be concluded that *Jatropha curcas* seeds have a good potential as a natural coagulant and are suitable for treatment of wastewater with a wide range of initial turbidity values. The best performance can be seen with a coagulant dosage of 120 mg/L at pH 3. A prolonged extraction time by the mechanical procedure is not advisable as this might reduce the capability of *Jatropha curcas* as a coagulating agent. The volume of sludge produced and the sedimentation time of the flocs formed using *Jatropha* were considerably less than when alum was used as the coagulant for most conditions studied. The pH of the final treated solutions also appears to be slightly affected by addition of *Jatropha*. The use of presscake as a coagulation agent can provide a means of utilizing the waste after oil extraction. The *Jatropha* seed and presscake performance as a coagulant are comparable to alum at highly acidic and highly alkaline conditions. Detailed analysis should be done on the protein content since *Jatropha curcas* grown at different locations and climate may affect its protein content. The presence of toxic phorbol ester and other toxic compounds in *Jatropha* seeds should not be overemphasized since the compound is being applied for wastewater treatment and the amount suggested is too small to cause detrimental health effects to living organism. Furthermore, the main coagulating agent of *Jatropha* is protein of a polar nature and it dissolves well in polar solvents such as water. Since phorbol ester is a slightly polar compound, it is very likely that the compound will minimally dissolve in water. Most of it will probably still be in the seed or cake. However, further analysis is still required to study the toxicity effect of the compound in wastewater treatment.

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