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Treatment of Swine Wastewater Using Almond and Cherry By-Products as Coagulants †

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Abstract: Swine wastewater (SW) has a high content of organic matter, nutrients and hazardous pollutants which can lead to eutrophication, posing a significant environmental problem. In this study, SW was treated through a coagulation–flocculation (CF) process. Moreover, almond and cherry by-products were used as coagulants. The results showed a removal of chemical oxygen demand (COD), turbidity and total suspended solids (TSS) of 16.9, 43.3 and 61.4%, respectively, for almond hulls (AHs) and 13.5, 61.7 and 73.2%, respectively, for cherry pits (CPs) at optimal experimental conditions (pH 3.0 and 0.1 g/L of coagulant). It can be concluded that the CF process depends on the pH level and coagulant concentration. Additionally, the application of by-products as coagulants proved to be successful in the SW treatment.

Keywords: swine wastewater; coagulation–flocculation; plant-based coagulants; sustainability

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1. Introduction

There is a rise in global swine farms to meet the increasing demand for proteins, resulting in a significant amount of swine wastewater (SW). The SW is characterized by a high amount of organic matter, suspended solids, nitrogen and phosphorous. Moreover, it is an important source of antibiotics and hormones in the environment due to their intensive application in the swine industries [1]. The discharge of SW without proper treatment into water bodies leads to the consequent degradation of the environment.

Different SW treatments can be employed such as traditional methods (e.g., chemical, physical and biological) and advanced oxidation processes (AOPs) [2,3]. AOPs are a promising technology for wastewater treatment. However, their implementation in industries leads to additional costs. Therefore, the combination of AOPs with other wastewater treatments should be considered to optimize the cost-effectiveness of the treatment process [4]. The coagulation–flocculation (CF) process is used to remove organic and inorganic substances and colloidal particles during wastewater treatment. The efficiency of CF depends on the operational condition (e.g., pH and temperature), wastewater characteristics and coagulant type. Studies focused on plant-based coagulants have demonstrated their efficiency during CF treatment [5,6]. These coagulants are water-soluble proteins containing positive charges that bind with the negatively charged particles which cause turbidity in wastewater [7]. The principal advantages of using plant-based coagulants are biodegradability, safety for the human population and the environment, cost-effectiveness, sustainability, reduction in waste and application of abundant resources [8]. Furthermore, the application of plant-based coagulants promotes a sustainable economy and valorizes food and agriculture waste since several by-products and invasive plants can be used [5,9].

Considering these factors, the aim of this work was to optimize the CF process with the application of almond hulls (AHs) and cherry pits (CPs) as coagulants to treat SW.

2. Material and Methods

2.1. Swine Wastewater Sampling

The swine wastewater (SW) was collected from a swine farm located in Douro region, North of Portugal. The samples were stored in plastic containers, transported to the laboratory and kept at −40 °C until used.

2.2. Analytical Techniques

To characterize the swine wastewater (SW), different physicochemical parameters were determined, including chemical oxygen demand (COD), turbidity and total suspended solids (TSS). Table 1 presents the characteristics of SW.

Table 1. Characterization of swine wastewater.

Parameter	Value
pH	7.5 ± 0.1
Electrical conductivity (μS/cm)	90 ± 8.2
Turbidity (NTU)	4800 ± 18
Total suspended solids—TSS (mg/L)	5100 ± 22
Chemical oxygen demand—COD (mg O_2/L)	24 557 ± 102
Biochemical oxygen demand—BOD_5 (mg O_2/L)	12 883 ± 236
Nitrates (ppm)	1343 ± 136
Phosphate (mg P_2O_5/L)	137 ± 2
Biodegradability—BOD_5/COD	0.52

2.3. Preparation of Natural Coagulants

The samples of almond (*Prunus dulcis*) and cherry (*Prunus avium*) were obtained directly from producers of Douro region, North of Portugal. In the laboratory, the almond hulls (AHs) and cherry pits (CPs) were washed and dried in an oven at 70 °C for 24 h. Then, each coagulant was grounded using a groundnut miller, cooled and stored in a closed plastic jar.

2.4. Coagulation–Flocculation Experimental Set-Up

The coagulation–flocculation (CF) process was performed in a Jar-test device (ISCO JF-4, Louisville, KY, USA), with four mechanical agitators powered by a regulated speed engine. Each coagulant was mixed with the samples of SW with a fast mix of 150 rpm/3 min and a slow mix of 20 rpm/20 min, at ambient temperature (25 °C), as described previously [4]. To optimize the CF process, different levels of pH (3.0, 6.0, natural and 9.0) and coagulant concentrations (0.1, 0.5, 1.0 and 2.0 g/L) were tested. The samples remained in sedimentation overnight and were subsequently collected for analysis. All the experiments were carried out in triplicate. Figure 1 illustrates the CF process to treat the SW.

2.5. Statistical Analysis

The data were checked for normality using the Shapiro–Wilk test and the equal population variances using the Brown–Forsythe test. One-way analysis of variance (ANOVA) with Tukey's post hoc multiple comparisons were used for normal data, and findings were presented as mean and standard deviation (GraphPad Prism version 9.0). P-values were considered significant when $p < 0.05$.

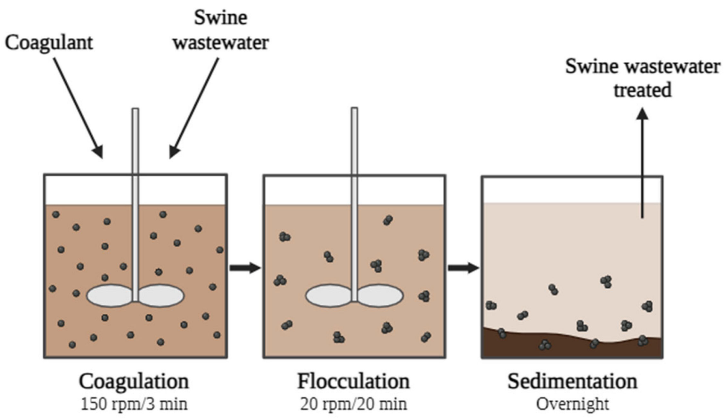

Figure 1. Coagulation–flocculation experimental setup.

3. Results and Discussion

3.1. Coagulation–Flocculation: Almond Hulls

Almond hulls (AHs) were used as a coagulant during the coagulation–flocculation (CF) experiments. Different pH values were tested (3.0, 6.0, natural and 9.0) to optimize the CF process (Figure 2). When pH 3.0 was used, a significant removal of chemical oxygen demand (COD), turbidity and total suspended solids (TSS) was observed: 15.9, 51.4 and 67.3%, respectively. Moreover, the turbidity and TSS removal effectiveness slightly reduced as the pH value increased. Previous studies using plant-based coagulants reported that the negatively charged wastewater at lower pH may accelerate the adsorption process of the particles into protein-contained coagulants, increasing the turbidity and TSS removal [4,10]. Therefore, pH 3.0 was chosen to test different concentrations of coagulant.

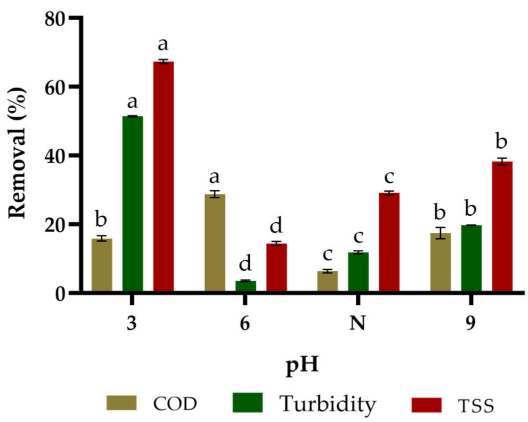

Figure 2. Coagulation–flocculation experiments with the application of almond hulls (AHs): optimization of pH (3.0, 6.0, natural (N) and 9.0) under the following conditions: [AH] = 1.0 g/L; fast mix = 150 rpm/3 min.; slow mix = 20 rpm/20 min; sedimentation = overnight. The different letters represent the statistically significant differences ($p < 0.05$).

The AH concentrations 0.1, 0.5, 1.0 and 2.0 g/L were tested to optimize the CF process (Figure 3). It was observed that 0.1 g/L of AHs presented a significant removal of COD, turbidity and TSS, respectively: 16.9, 43.3 and 61.4%. As the coagulant concentration increased, the removal percentage of the evaluated parameters decreased. A study carried out by Maurya and Daverey (2018) observed that high dosages of plant-based coagulants (banana peel powder, papaya seed powder and neem leaf powder) had a negative impact on the coagulation activity [11]. Thus, the results are in accordance with the previous literature.

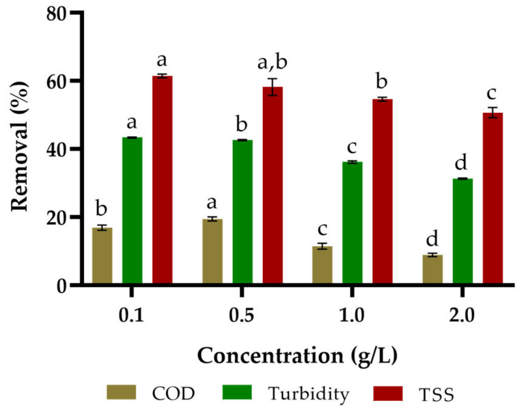

Figure 3. Coagulation–flocculation experiments using almond hulls (AHs): optimization of AH concentration (0.1, 0.5, 1.0 and 2.0 g/L) under the following conditions: pH = 3.0; fast mix = 150 rpm/3 min.; slow mix = 20 rpm/20 min; sedimentation = overnight. The different letters represent the statistically significant differences ($p < 0.05$).

3.2. *Coagulation–Flocculation: Cherry Pits*

Different pH values (3.0, 6.0, natural and 9.0) were tested to optimize the CF process. As can be seen in Figure 4, the pH 3.0 presented a significant removal of COD, turbidity and TSS (13.6, 74.8 and 13.5%). Among the different factors that contribute to greater CF efficiency, pH plays an important role during this process, as it prompts various mechanisms that assist in the CF process. Previous studies have demonstrated similar results with the application of plant-based coagulants in CF experiments [4,12]. Som et al. (2023) observed that pH is the factor that most affects the TSS removal, registering the highest TSS removal at the lowest pH level [12].

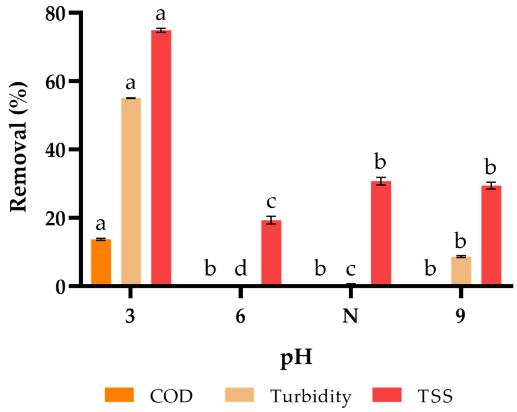

Figure 4. Application of cherry pits (CPs) as a coagulant in the coagulation–flocculation process: optimization of pH (3.0, 6.0, natural (N) and 9.0) under the following conditions: [CP] = 1.0 g/L; fast mix = 150 rpm/3 min.; slow mix = 20 rpm/20 min; sedimentation = overnight. The different letters represent the statistically significant differences ($p < 0.05$).

The pH 3.0 was chosen to test the different concentrations of cherry pits (CPs) (0.1, 0.5, 1.0 and 2.0 g/L). The results showed that 0.1 g/L of CPs achieved the greatest COD, turbidity and TSS removal (13.5, 61.7 and 73.2%) (Figure 5). The application of different coagulant concentrations is important in terms of economy to guarantee a cost that can be carried by the industries and to prevent inappropriate coagulant dosing during wastewater treatment [12]. Similar results were obtained in previous studies with plant-based coagulants [11,12].

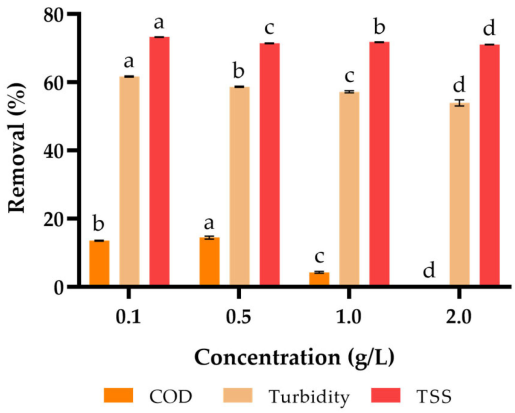

Figure 5. Application of cherry pits (CPs) as a coagulant in the coagulation–flocculation process: optimization of CP concentration (0.1, 0.5, 1.0 and 2.0 g/L) under the following conditions: pH = 3.0; fast mix = 150 rpm/3 min.; slow mix = 20 rpm/20 min; sedimentation = overnight. The different letters represent the statistically significant differences ($p < 0.05$).

4. Conclusions

The increase in population results in the increase in animal protein consumption, with pork meat being among the most consumed globally. Moreover, swine wastewater (SW) poses a high environmental risk if discharged into water bodies without proper treatment. It is important to treat this wastewater and, when possible, valorize it to promote a circular economy. In this work, a coagulation–flocculation (CF) experiment was carried out using almond hulls (AHs) and cherry pits (CPs) as natural coagulants to treat SW. The results showed that the optimal conditions were achieved at pH 3.0 and 0.1 g/L of coagulant. Furthermore, a COD, turbidity and TSS removal of 16.9, 43.3 and 61.4%, respectively, for AHs and 13.5, 61.7 and 73.2%, respectively, for CPs were observed.

It can be concluded that the CF process depends on the pH level and coagulant concentration. The increase in these two factors tends to decrease the CF efficiency. Moreover, the utilization of AHs and CPs, by-products of the food industry, proved to be effective in the treatment of SW. It is important to continue with studies that carry out the effective treatment of wastewater through sustainable methods.

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