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To cite this article: D N K Vo *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1009** 012003

The Effect of Adding Wood Chips on The Decomposition of Sludge from Seafood Processing Wastewater Treatment System

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Abstract. This study evaluates the effect of various wood chips on the sludge decomposition process. Sludge from Surimi processing wastewater treatment system (AS) of Danifood factory in Danang city was mixed with local wood chips as bulking agents (BA) including Khaya senegalensis (D), Acasia (A) and sawdust (S). The weight ratio of AS/BA added to each aerobic model was 1:1, 1.5:1 and 2:1 for K, A and S, respectively. The results showed that variations of temperature and pH were suitable for aerobic biochemical process. K and S model reached 50 ^{o}C in three days and remained stably for next four days, whereas A reached 50 ^{o}C after ten days and remained stably for six days. The value of seed germination index from decomposed sludge was more than 80% for K and A whereas 48 - 60 % for S. It is necessary to consider the type or composition of sawdust when utilize it as a BA. In addition, the TOC and T-N of AS after decomposition met Vietnamese standard for organic fertilizer quality, so they could be used to supply nutrients to plants. This study is an important basis for the BAs selection to conduct experiments aim at AS recovery.

1. Introduction

According to the seafood research institute, there are currently 1,015 seafood processing factories in Vietnam of different sizes, producing domestic and export products. The total seafood production in 2020 was 8.4 million tons. The rapid development of this processing industry also entails inadequacies in other ancillary fields, including management and treatment of wastes from seafood processing. Aquatic sludge (AS) is the last product of the wastewater treatment process in seafood processing factories, and it is a growing source of waste in the environment. This amount of sludge accounts for 10 % of the total wastewater in the wastewater treatment system of seafood processing factories [1]. This sludge contains a lot of organic materials [2] and is managed and discharged as a source of waste [3]. If the amount of sludge generation increases more and more while there is no reasonable plan for treatment, it will cause damage to the environment [4]. Even the large backlog of sludge at these factories may have the presence of some pathogenic microorganisms, which cause serious consequences and effects on the soil, water environment and public health.

Because sludge treatment costs around 40 % of the total cost of wastewater treatment [5], most countries in the world apply burning or landfilling method for sludge treatment, while a small one selects reuse method for agricultural purposes [6]. In Vietnam, among sludge treatment methods landfilling accounts for 50 % - 75 %, whereas reuse as fertilizer for field crops accounts 25% - 35% [7].

Co-composting is the process of the aerobic degradation of organic compounds using more than one feedstock. A review article done by Barthod *et al.* (2018) [8] described clearly how the composting of four major categories of organic wastes (food waste, green waste, municipal solid waste and sewage sludge) has been mainly conducted by mixing them with several additives, with the aim at improving specific aspects of the composting process. In fact, AS has been studied and used directly as organic fertilizer [9] or mixed with other organic materials to produce organic fertilizers [2], [10].

In addition, a large amount of wastes from periodic tree pruning activities in urban areas in Vietnam including Danang city, is being deposited improperly. These materials could be made to wood chips and utilized as BAs to balance the moisture content of sludge and raise its porosity which allows ventilation [11]. On the other hand, these materials are used to promote microbial activity by balancing the C/N ratio and providing additional carbon [12]. Additional BAs can help composters achieve optimal free air space (FAS) and void dispersion [13], which allow adequate water and gas exchange between the gas and solid phases, as well as prevent excessive composting material compaction [14]. Based on the co-composting methodology, this study is conducted to evaluate the effect of adding some wastes from tree pruning (wood chips) on AS decomposition at an aerobic pilot-small scale. A suitable wood chip will be selected for adding as BA through monitoring some physical parameters such as temperature, moisture, pH during the decomposition process and evaluation of decomposed sludge quality. From the results of this study, the next in-depth research will be considered for co-composting technique application to treat AS combines tree pruning.

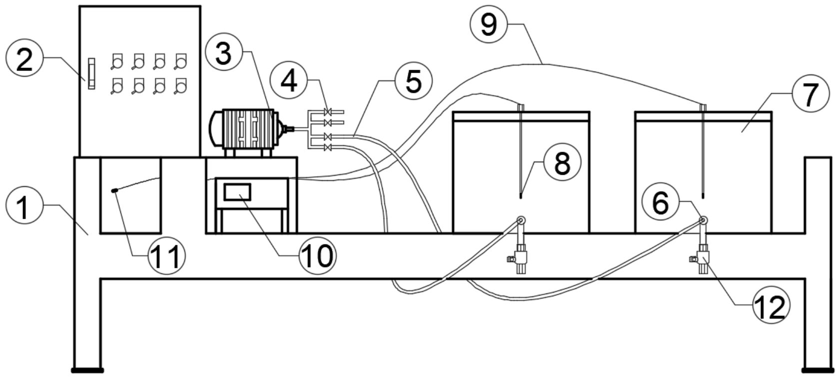
2. Materials and Method

2.1. Materials

2.1.1. Sludge and wood chips. The sludge sample from a wastewater treatment plant (WWTP) of Danifood factory (D&N) in Danang city, Vietnam was selected for this study. D&N was one of the large-scale Surimi processing factories in the Danang seafood service industry zone. The system treats wastewater from Surimi processing using Dissolved Air Flotation-DAF technology in conjunction with a Sequencing Batch Reactor-a continuous batch reaction process (SBR). The system generates roughly 2 - 3 tons of sludge each day after being dewatered by the belt press. The belt press has a capacity of 2.5 to 5 m^3/h (operating cycle: 5 to 6 times per week). For dewatering the sludge, the specfloc C-1492 LMW flocculant cation polymer with the primary constituent Polyacrylamide-PAC ($CONH_2[CH_2\text{-}CH\text{-}]_n$) was added. The polymer was made by Kemira (England), and it was commonly utilized in the sludge concentration process at a ratio of 4 kg PAC/3.5 tone pressed sludge [15]. The sludge after pressing still contains high moisture and organic matter but is not reused. It is only stored in plastic bags and kept at the factory. D&N contracts with an urban environmental company (URENCO) to collect and dispose of sludge on a regular schedule. Currently, the significant volume of pressed sludge storage results in odor pollution and increases sludge treatment costs. The pressed sludge samples were collected and transported to the laboratory for analysis. The sampling frequency was twice a week. The pH, humidity, ash, T-N, T-P, C/N ratio of sludge were analysed.

Wastes from tree pruning in urban areas including Khaya senegalensis and Acacia were used in this study. Khaya senegalensis (scientific name: Desr. A. Juss.) is a species of tree in the family Meliaceae native to Africa. Common names include African mahogany, Dryland mahogany, Gambian mahogany, Khaya wood, Senegal mahogany, Cailcedrat, Acajou, Djalla, and Bois rouge. Acacia (scientific name: Acacia) is a genus of several species of shrubs and trees native to the ancient mainland of Gondwana, belonging to the subfamily Mimosoideae of the legume family Fabaceae. These two types of trees that are commonly planted in urban areas, including Danang city, Vietnam. The branches and trunks of these 2 trees after pruning are collected and cut into small pieces called wood chips. Wood chips were determined the surface structure before mixing with AS for decomposition process. In addition, sawdust from a local wood processing factory was used as a comparison BA.

2.1.2. Experimental pilot scale. An aerobic decomposition model of AS mixing with wood chips as BA was used for this study. The principle of process is based on the microorganisms activating by the wood chips as a catalyst to decompose wastes and increase the evaporation by fresh air supply, without bioenzimes. The model and related equipments for the experiment are shown in Figure 1. The model was a foam box with the dimensions of 600 × 450 × 400 (mm). The inside is layed with a waterproof nylon layer. At the bottom of the model, two air supply pipes with a diameter of 21 mm were installed. The air supply hole on the pipe has a diameter of 2 mm and the distance between holes is 30 mm. A valve was installed to collect the leachate during the sludge decomposition process, as well as an exhaust gas valve. The monitored temperature data was saved in the data logger (Multi-Channel Digital Thermometer AT-4508).



Where: (1) Materials fixed shelf; (2) Control cabinet; (3) Air pump; (4) Air flow control valve; (5) Air supply pipe; (6) Air supply valve; (7) Incubation tank; (8) Temperature sensor; (9) Signal transmission line; (10) Data logger; (11) Ambient temperature sensor; (12) Bottom discharge valve.

Figure 1. The diagram of experimental equipment setting.

2.2. Methods

2.2.1. Sludge sampling and analysis. Sampling and analysis are carried out in accordance with standard methods. The sludge sample was collected, preserved and transported to the laboratory for analyzing. Sampling frequency was two times/week.

2.2.2. Characteristic of wood chips. Desr. A. Juss. (D) and Acasia (A) were cut into pieces with sizes of about 10 - 20 mm by a machine and were tested for the material's surface structure by the Scanning Electron Microscope equipment (SEM), JSM-6010PLUS/V, at 500 times magnification. The moisture, ash, total organic carbon, total nitrogen and total phosphate of wood chips were analyzed to test whether their suitability for experiments.

2.2.3. Sludge decomposition ability. The ability of sludge decomposition was evaluated by monitoring temperature variations during the process and the time temperature of three models reached the ambient temperature. AS mixed well with each BA, the moisture was adjusted to the values of 50 - 60 %, and then loaded into the aerobic decomposition model. The weight ratio of AS/BA added to each model was 1.0:1, 1.5:1 and 2.0:1 for D, A and S, respectively. When the temperature inside the annealing material tended to drop below 50 ^oC continuously for two days and the moisture was less than 40 %, sludge was added to each model. Fresh air circulation was provided by aquarium pumps which its airflow could be adjustable (power: 15 W, pressure: > 0.015 Mpa, flow: 10 Liters/min) with the mode of 2 minutes of blowing and 58 minutes of breaking.

The seed germination index (GI) determination method was used to test AS after decomposition process was toxic or not and could be used as a fertilizer for plant growth [16]. The GI calculation procedure consisted of three major steps. Firstly, prepare extract solutions of sludge:distilled water with two ratios of 1:5 and 1:10; secondly, incubate seeds with the extracts; thirdly, measure and calculate the indicators related to the test results by GI including the seed germination (SG), the relative seed germination (RSG), the relative radicle growth (RRG) and the seed germination index (GI), where:

$$GI = RSG \times RRG \times 100\ (\%) \quad (1)$$

3. Results and Discussion

3.1. Sludge of D&N WWTP

The properties and composition of pressed sludge are presented in Table 1. The moisture content of aquatic sludge ranged from 80.2 % to 83.6 %, was similar to the aquatic sludge moisture in the research of Phuong *et al.* [2], which ranged from 74.95 % to 86.19 %, and also in the reports of Duc *et al.* [6] on fish processing, with the values of 82.6 %.

The pH of aquatic sludge samples varied between 6.9 and 7.4. This finding was similar to the 6.15 - 7.6 reported by Phuong *et al.* [2], the 7.3 reported by Oanh *et al.* [5] for catfish sludge, and the 7.26 - 7.68 reported by Van *et al.* [17] for shrimp pond sludge.

Overall, the samples had high carbon content, with the values of 28.6 - 35.3 %, which was comparable to the carbon content of aquatic sludge samples in the researches done by Phuong *et al.* [2], with the values of 21.53 - 42.81 %, and by Thomas and Rahman [7] and Lakhdar *et al.* [18], with the values of 36 % and 27.2 %, respectively.

Total nitrogen content (T-N) of the aquatic sludge ranged from 4.12 % to 5.01 %, being no significant fluctuations in comparison with those in the research of Phuong *et al.* [2], which was 1.81 % to 5.62 %, much higher than the T-N content in the research of Oanh *et al.* [5], which was 3.2 %, and Duc *et al.* [6], which was 2.6%. Meanwhile, the total phosphate content (T-P) was around 0.93 % - 1.38 %, which was lower than the values of 3.3 % - 7.29 % done by Phuong *et al.* [2], but higher than those values of 0.21 % done by Van *et al.* [17], who studied the bottom sludge of shrimp ponds.

Although the content of heavy metals in sludge was not assessed in this study, referring to the researches of Phuong *et al.* [2], and Duc *et al.* [6], who found that the concentration of heavy metals such as Pb, Cd, and Zn in aquatic sludge was below the Vietnamese standard (QCVN 50/2013/ BTNMT) on the hazardous threshold for sludge from wastewater treatment processes. As a result of the evaluation and comparison, D&N aquatic sludge had a composition and properties that was suitable for biodegradable process, safe for experiments as well as nonexistence of hazardous components in post-decomposition sludge samples.

Table 1. The pressed sludge characteristics (Total samp.: 12).

No.	Parameter	Min - Max	Mean ± SD (Median)	No.	Parameter	Min - Max	Mean ± SD (Median)
1	Mois. (%)	80.2 - 83.6	81.3 ± 1.15 (80.75)	4	TOC (%)	28.6 - 35.3	33.1 ± 2.34 (33.7)
2	Ash (%)	10.7 - 14.2	12.1 ± 1.20 (11.7)	5	T-N (%)	4.12 - 5.01	4.51 ± 0.30 (4.48)
3	pH (-)	6.9 - 7.4	7.2 ± 0.21 (7.25)	6	T-P (%)	0.93 - 1.38	1.15 ± 0.15 (1.16)

3.2. Characteristic of Wood chips

The SEM image of wood chips showed the surface of both chips shaped a hive, uniform in hole size (40 - 50 µm). In particular, the D surface had different structures outside and inside, whereas the A surface had small pores. It revealed a favorable environment for microorganism activation on the surface of the wood chips. The characteristics of three kinds of wood chips are presented in Table 2. The moisture and ash contents of three wood chips were very low, which influenced the moisture balance of the material mixture. In addition, the TOC of all wood chips was high, so it would supply enough carbon to balance the C/N ratio in the sludge for the aerobic decomposition process.

Table 2. The characteristic of three kind of wood chips.

Parameters	Unit	D	A	S
Moisture	%	2.63	1.39	1.28
Ash	%	0.97	0.95	0.84
TOC	g/100g Dry	39.37	33.15	42.85
T-N	g/100g Dry	0.017	0.013	0.0084
T-P	g/100 g Dry	0.26	0.38	0.22

3.3.The decomposition ability of sludge combined with BAs in an aerobic condition

3.3.1. Variation of physical parameters during the sludge decomposition process. The temperature monitored in three models has a higher amplitude than the ambient temperature due to the aerobic decomposition of organic matter taking place in the mixture. The temperature in both the D model and S model increased to 50 ^oC within 2 - 3 days, while the A model reached this temperature on the sixth day. The temperature in the D model increased above 50 ^oC after three days and maintained there for more than one day before beginning to decrease. When the temperature of the material mixture was decreased below 45 ^oC, and the moisture at the fifth day dropped to 40 %, sludge was added the second time. After sludge addition, the temperature reached above 50 ^oC within 24 hours and was maintained for nearly four days. Until the third time of sludge loading on the tenth day, the temperature increased rapidly above 55 ^oC within one day and then it gradually decreased to the ambient temperature on the thirtieth day. For the A model, the temperature gradually increased and reached 50 ^oC after ten days and reached over 55 ^oC for the next two days. When it was kept for more than one day, it tended to decrease quickly. On the tenth day, when the temperature decreased below 45 ^oC while the moisture of the sludge mixture was still maintained at 55 %, no additional sludge was added. When the sludge was added for the second time on the date of fourteenth, the temperature increased quickly again and reached approximately 55 ^oC and was maintained for six days. For the S model, the temperature increased above 50 ^oC after three days and maintained at this temperature for more than one day. After that, the temperature started to decrease. Similar to the trend of temperature variation of the D model, when sludge was added for the second time on the fifth day, the temperature reached above 50 ^oC within 24 hours and was maintained for three days. Until the third sludge addition on the date of tenth, the temperature reached a range of 50 - 53 ^oC and was maintained for seven days. In general, the heat created in the models is due to the natural fermentation process, therefore there was a distinct variance depending on the stages of organic matters decomposition in the sludge. Comparision with previous research by D.N.K.Vo *et al.* (2020) [19] on sludge stabilization with cedar chip combined with heated air supply at 50 ^oC, The temperature of the mixture was monitored in the range of 26 - 43 ^oC, whereas was around 35 ^oC at the end of 30 days.

The moisture and pH of three models tended to change similarly. The initial moisture tended to decrease to the range of 40 - 50 % in the first five days, then gradually increase to the range of 55 - 65 % in the following days until the process was completed. Because of the effect of the pH value of wood chips, the pH was initially quite high. After a few days of monitoring, it lowered to a range of 5.5 - 6.5. The pH tended to rise from 7 to 7.5 in the following days, which was within the range for aerobic biochemical processes. These results can be explained by the fact that at the beginning of the sludge decomposition process, the pH was acidic due to the acid-forming bacteria's degradation of organic matter, then it became alkaline due to ammonia formation, and finally it dropped back to near neutral due to humus formation forming its pH-buffering capacity [20].

The dissolved solids content (TDS) in the mixture tended to increase gradually during the incubation. TDS values ranged from 55 to 158 mg/L for the D model, from 138 to 182 mg/L for the A model and from 32 to 135 mg/L for the S model. Although the TDS fluctuations were not large, it showed that there were the oxidation and mineralization of fermented materials in all three models.

3.3.2. Sensory evaluation of materials. In this study, during the sludge decomposition under aerobic condition, the presence of fungi in the mixture of each model was considered. In the D model, the white fungus appeared on the fifth day. It became dense after ten days and fifteen days. On the 25^{th} day, and at the end of the decomposition process, there was no fungus. The white fungus appeared in large numbers on the fifteenth day for the A model as well. There was no fungus after twenty days and at the end of the decomposition process. Comparison with the S model, on the fifth day, the white fungus appeared at a sparse density in comparison with the two remain models. Similarly, no fungus appeared after the twenty fifth day and at the end of the decomposition process. The results showed that the S model inhibited fungi and actinomycete growth in the thermophilic phase. The reason could be explained that the original wood material has been treated by chemicals before processing to create sawdust.

3.4. The potential reuse of decomposed sludge

3.4.1. The quality of decomposed sludge. The decomposed sludge after 30 days of decomposition was analyzed for quality testing according to the Vietnamese standard of 10TCN 526:2002/BNN&PTNT (The standard of Organic-Biofertilizer from household waste-Technical parameters and testing methods). The decomposed sludge had a brown-grey colour and had the faint smell of wood. The quality of decomposed sludge screened to a size ≤ 4 mm is shown in Table 3.

Table 3. Analysis results of decomposed sludge.

No.	Parameters	D	A	S	10TCN 526:2002/BNT&PTNT
1	pH (-)	7	6.8	6.6	6-8
2	Moisture (%)	22.71	18.99	21.08	≤ 35
3	Ash (%)	7.99	7.64	5.92	-
4	TOC (%)	27.49	32.03	34.76	≥ 13
5	T-N (%)	2.96	2.72	2.2	≥ 2.5
6	T-P (%)	0.67	0.55	0.48	-
7	P_2O_5 (%)	1.34	1.08	0.94	≥ 2.5

The results in the Table 3 shows that pH, total organic carbon and total nitrogen of the decomposed sludges met the standard 526:2002/BNN&PTNT (22 % for TOC and 2.5 % for T-N), whereas the phosphate (calculated as P_2O_5) of three decomposed sludges was lower than 2.5 % of the permitted standard. The T-N of S sample with a value of 2.2 % was rather low.

3.4.2. The stability of decomposed sludge and GI value. Compost stability and maturity are terms which indicate the degree of organic matter decomposition and potential of phytotoxicity caused by insufficient composting [21]. The decomposed sludge from the three models was taken and filled into a 500 mL cylindrical bottles which was put in the laboratory. The temperature of the material inside of each bottle was monitored for 7 days to determine the compost stability. The result shows that the material temperature of three bottles was different in a low range, from 0.5 to 1.3 ^oC compared with the ambient temperature, indicating that the sludge had been stabilized and organic matter degradation was at the end [22].
The test of the seed germination index was performed with each petri dish (containing a filter paper, 20 green beans and 5 mL of extraction solution from each decomposed sludge). Keeping all the petri dishes in the dark at 28 - 30 ^oC for 48 hours. The GI value is calculated following Equation (1). The GI of decomposed sludges from D and A models was greater than 80 %, whereas the S model was at 48.81 %

and 60.77 %. These values demonstrated that decomposed sludge of the S model could contain some toxicants to plants [23].

3.4.3. Utilization of decomposed sludge on the plant. The decomposed sludge was used as a fertilizer for Jasmine growth to evaluate the potential of reusing it as an organic fertilizer. Four models with the same weight ratio of 5 soil: 1 fertilizer in which fertilizer being from local market organic fertilizer (N1), decomposed sludge D (N2), decomposed sludge A (N3) and decomposed sludge S (N4) were used for Jasmine growth. All four models were monitored for Jasmine growth and the characteristics of stems, leaves, and flowers for three weeks in the same conditions of cultivation. After three weeks of cultivation, the growth of Jasmine plants was significant difference between four models. In terms of colour, morphology of branches and leaves, all models showed hard stems, leaves were large and dark green, whereas the number of flowers of N1, N2 and N3 was higher than N4. It proves that the decomposed sludge had a certain role during the growth cycle of Jasmine.

4. Conclusions

The D&N factory in Danang city created a significant amount of AS and it contained a high concentration of moisture and nutrients. Sludge after the pressing process was collected and disposed of by URENCO, resulting in waste and increasing sludge treatment costs.

AS decomposition in aerobic conditions of mixture including AS and wood chips as BAs could reduce the volume of sludge, without supplying effective microorganisms because of wood chips as a bio-carrier addition to decompose organic composition. The combination of AS with each BA in this study reduced the moisture of the sludge and supplied carbon to balance the C/N ratio in the sludge for the decomposition process. Temperature variations during the monitoring process revealed that the efficiency of sludge decomposition with Khaya senegalensis, Acacia, and sawdust was considerably different. The results showed that Acacia took ten days to reach 50 ^{o}C, whereas the two remaining BAs needed only three days. In addition, the GI value and nutrients of decomposed sludge of the Sawdust model were lower than the standard, it was necessary to consider the origin and the chemical properties of the wood to decide whether using sawdust as a bulking agent for an experiment.

The total carbon and total nitrogen concentration of the products after stabilization by the models met the 10TCN 526:2002/BNN&PTNT standard for organic fertilizer quality. Under the same cultivation and monitoring conditions, the test on plant growth fertilized by decomposed sludge and a market organic fertilizer revealed that the decomposed sludge could have the potential to reuse and add nutrients to the soil for plant growth.

Some initial results in this study on comparison of adding different wood chips on the sludge decomposition process by aerobic small-scale models and evaluation of the decomposed sludge quality were significant. From this study, the wood chip of Khaya senegalensis (Desr. A. Juss.) from tree pruning in urban areas can be used as a local bio-carrier. In subsequent studies, the biodegradable rate of AS in the large-scale model with various sizes of this wood chip will be investigated. In addition, to prove the product after stabilization can be used as an organic fertilizer, the heavy metals and pathogens need to be tested carefully.

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Acknowledgments

Vo Diep Ngoc Khoi was funded by Vingroup Joint Stock Company and supported by the Domestic Master/PhD Scholarship Programme of Vingroup Innovation Foundation (VINIF), Vingroup Big Data Institute (VINBIGDATA), VINIF.2020.TS.48.