Comparison of green and brown coconut husks as a packing material in an anaerobic filter

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ABSTRACT: *Septic tanks can become overloaded overtime due to increases in the size of households or the build-up of sludge. This results in the wastewater spending less time within the tank and therefore a reduced level of treatment. One solution to enhance treatment is to add an anerobic filter after the existing septic tank. The anaerobic filter requires media for the establishment of a biofilm, and the use of coconut husks was identified as a possibility due to their abundance. Both green and brown coconut husks were imported from Tonga and tested in laboratory scale anaerobic filters treating synthetic wastewater. The treatment performance was monitored in terms of the chemical oxygen demand (COD) which is a measure of organic strength. There was also potential for organic material to leach out of the coconut husks, so additional testing was done to evaluate this. It was found that four times more COD was leached from the green coconut husks showing that brown coconut husks were the better choice. The brown coconut husk reactor reduced the COD concentration by 49 %. This study has indicated that there is value in examining the feasibility of implementing an anaerobic filter using brown coconut husks to enhance wastewater treatment from septic tanks. Further research should focus on examining whether any nutrients are released from the husk and then practical considerations such as the scale needed for a household and maintenance requirements.*

KEYWORDS: *Anaerobic filter, Coconut husk, Septic tank effluent, Wastewater treatment*

1 INTRODUCTION

Many Pacific Island communities do not have centralised wastewater treatment facilities with the exception of some urban areas (Secretariat of the Pacific Regional Environment Programme, 2020). For example, in Tonga there are no centralised wastewater treatment facilities, and 94 % of households use septic tanks (Tonga Statistics Department, 2021). A recent survey showed that some septic tanks had not been emptied in 15 years (Radio New Zealand, 2020). This overloading and sludge build-up means that there is

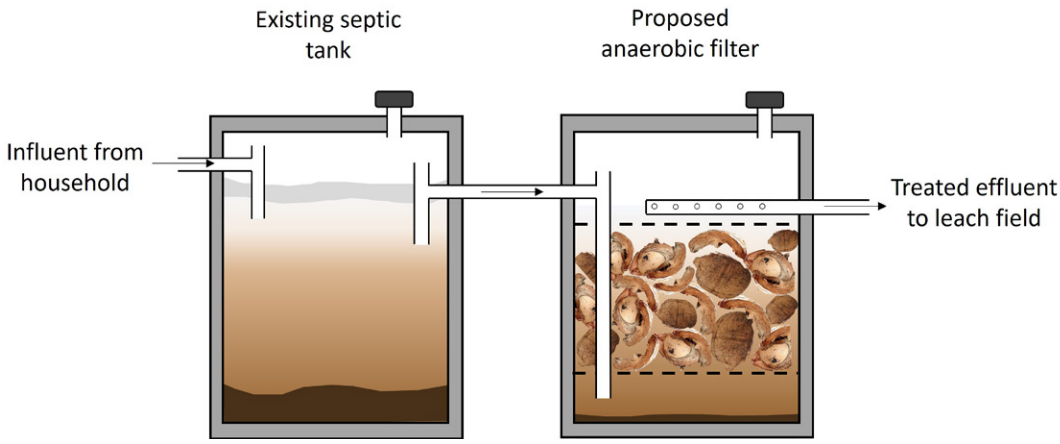

Figure 1: *Existing septic tank followed by proposed anaerobic filter. Image adapted from de Oliveira Cruz et al.* (2019)

less time for the wastewater to be treated in the septic tank. This reduced treatment can have negative consequences when the wastewater is discharged to the environment. This poses not only a direct health risk to the people, but it can also pollute the surrounding sea and impact marine life.

A solution to this problem could be to install an anaerobic filter downstream from the septic tank. Anaerobic filters are very effective at polishing effluent, without producing large amounts of sludge or need for maintenance (Toerien and Hattingh, 1969). These systems require a surface for microorganisms to attach to and grow in the form of a biofilm (Toerien and Hattingh, 1969). Ideally the packing material is locally available at low cost and has a large surface area for biofilm establishment. Many different types of media have been used in anaerobic filters including locally available rock or gravel (Lopez-Lopez et al., 2013; Kaetzl et al., 2013; Heredia et al., 2022), woodchips (Kaetzl et al., 2013), and coconut shells or husks (Heredia et al., 2022; de Oliveira Cruz et al., 2019; Silvia et al., 2015; de Oliveira Cruz et al., 2013). Coconut husks offer a potential solution due to the abundance of coconuts in the Pacific and the large surface area due to the fibrous nature of the husks.

Figure 1 gives an overview of the proposed system. The effluent from the existing septic tank passes into the anaerobic filter which is full of coconut husks. A biofilm grows on the husks and treats the wastewater. The treated effluent then leaves the anaerobic filter and can be disposed of as usual.

There have been other wastewater treatment systems where microbial growth is attached to coconut fibre-based material. Examples include the use of woven and non-woven coir geotextiles (Salim et al. 2020).

Coconuts can be harvested at different stages of their development depending on the end use of the coconut. If the aim is to maximise the amount of coconut water, they are harvested green or less mature, whereas they are harvested brown or fully mature if the focus is on coconut flesh. Previous studies on using coconut husks or shells within an anaerobic filter have used dried green husks (de Oliveira Cruz et al., 2019) or coconut shells (Silvia et al., 2015; de Oliveira Cruiz et al., 2013). Coconuts are typically harvested when brown in Tonga, and it is not currently known whether the different age of the coconut husks has an impact on their effectiveness as a packing material in an anaerobic filter.

The purpose of this study is to determine whether this system would be appropriate for use in Tonga. This is done by trying to closely mimic the conditions found in Tonga and analysing the treatment performance and stability of the anaerobic filter when comparing green and brown coconut husks. The treatment performance is measured in terms of chemical oxygen demand (COD), and pH is used as a measure of stability.

2 METHODOLOGY

This section first describes the two types of coconut husks used in the work (Section 2.1). The anaerobic filter reactor set-up and conditions are described (Section 2.2) followed by how the reactors were operated (Section 2.3). The experiments used to examine the release of COD from the coconut husks are described (Section 2.4). Finally, in Section 2.5, details on the sample analysis are given.

2.1 Coconut husks used in this study

There are two types of coconut husk evaluated in this study. These are green coconut husks and brown coconut husks. The green and brown coconut husks were sourced from Tonga and sent to our laboratory in New Zealand. Photographs of each type of coconut husk are shown

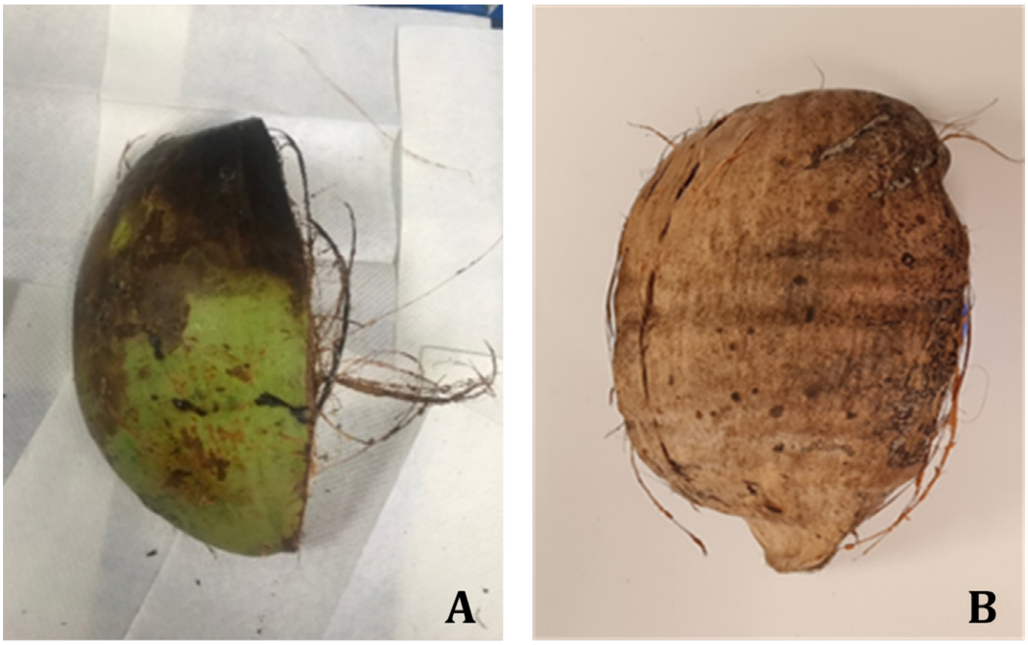

Figure 2: *Photographs of the different types of coconut husks sourced for this project (A – green coconut husk; B – brown coconut husk)*

Table 1: *Characteristics of the coconut husks*

Coconut husk type	Number of measurements	Mean length (mm)	Mean width (mm)	Mean depth (mm)	Mean weight (g)	Moisture content (%)
Green husk	1.06	399	100	30	345	0.863
Brown husk	7	230	100	30	96	35

in Figure 2, and information on their moisture content, weight and size is given in Table 1.

While the dimensions of the green and brown coconut husk pieces are similar, the weight of the green coconut husk is significantly higher due to its moisture content (Table 1). The aging process from green to brown has resulted in moisture loss from the husk.

2.2 Design of the reactors and experimental conditions

Laboratory scale reactors were constructed to mimic an anaerobic filter. The set-up consisted of a series of 20 L containers as shown in Figure 3. The feed was then pumped into the bottom of the anaerobic filter. Further detail of the filter is shown in Figure 4. There was a perforated plate towards the bottom and towards the top of the reactor to keep the pieces of coconut husk in place. The feed flowed up through the reactor and exited near the top of the reactor. A final container then collected the effluent and there was a sampling valve fitted to collect samples.

Two of the set-ups shown in Figure 3 were constructed. One was used for the green coconut husks and the other was used for the brown coconut husks.

Temperature

The mean temperature in Tonga was reported to be 24.3 °C in 2020 (Climate data.org, 2021). Our collaborators in Tonga from the Ministry of Lands and Natural Resources also measured the temperature of two septic tanks and found them to be 19.5 °C and 20 °C (A. Pale, personal communication, 11 June 2021). It was therefore decided that the reactors would be operated at approximately 20 °C.

Synthetic wastewater

Synthetic wastewater was used as the influent into the anaerobic filters and was designed to mimic the wastewater

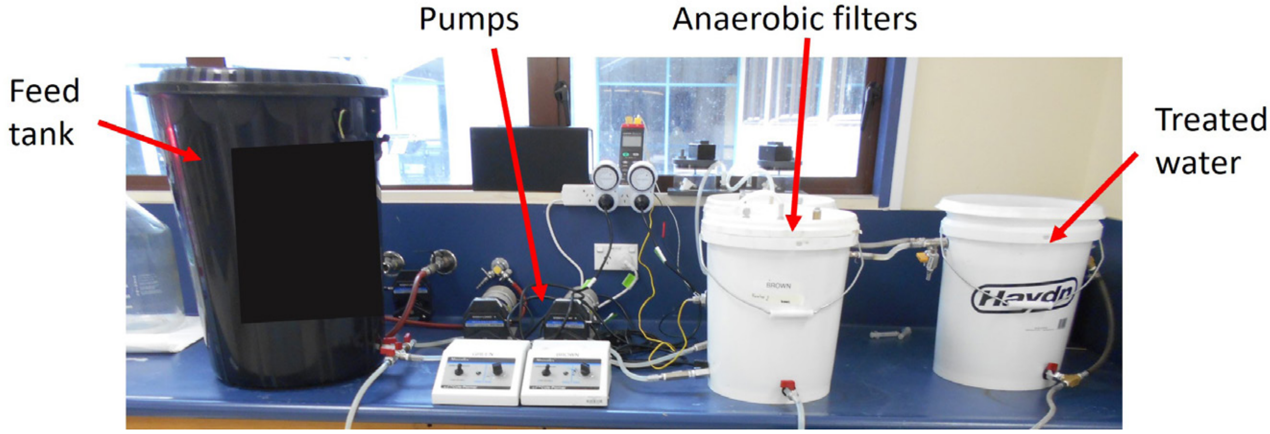

Figure 3: *Photograph of the setup for the anaerobic filters*

from a domestic dwelling which had already been treated in a septic tank. The synthetic wastewater used in this study was from Rodgers et al. (2010). The synthetic wastewater was found to have a chemical oxygen demand (COD) concentration of 690 mg/L and an average pH of 7.4. The synthetic wastewater was then further diluted to achieve the desired COD concentration.

Feeding regime

The conditions that the system would experience in Tonga were used to determine the feeding regime. Information from our collaborators from the Ministry of Lands and Natural Resources indicated that often residents do not stay in their homes during the day and therefore there is little flow to septic tanks at that time (A. Pale, personal communication, 13 July 2021). The feeding of the reactors was therefore set to mimic the residents' production of wastewater by having the pump turn on for a period of time in the morning and evening. While this does not account for wastewater production throughout the day, it is more representative than a constant feed rate.

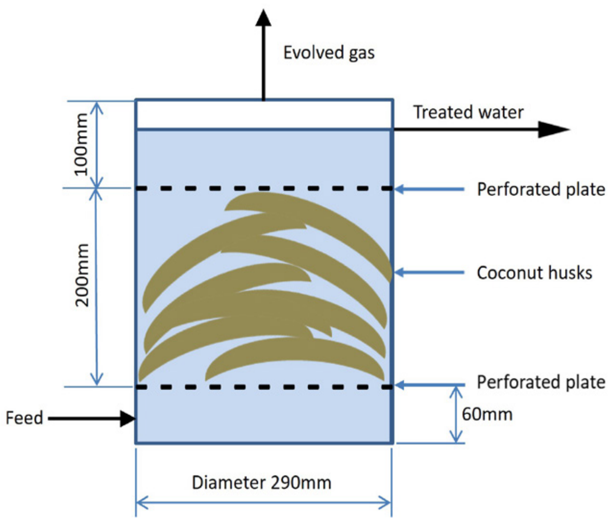

Figure 4: *Diagram showing the detail of how the anaerobic filters were constructed*

Anaerobic filters can operate at hydraulic retention times (HRT) of 12 to 96 hours (Young and Yang, 1989). The flow rate of the pump was based on achieving a HRT of 16.8 hours based on the study by de Oliveira Cruz et al. (2019). The different-sized pieces of coconut husk resulted in slightly different flow rates in order to achieve the same retention time in both reactors. The green coconut husk reactor had 7.8 L of fluid and therefore the reactor was fed with approximately 5.6 L morning and evening over a one-hour period. The brown coconut husk reactor had 8.8 L of fluid and therefore the reactor was fed with approximately 6.3 L morning and evening over a one-hour period. The resulting organic loading rate for both reactors was 0.18 g COD/L/d.

2.3 Operation of reactors

Start-up period

During the start-up period microorganisms within the reactor were established. To do this, first a source of microorganisms is needed which was collected from a dairy farm effluent pond. This contained anaerobic bacteria which would be able to establish within the reactor. The pieces of coconut husk were placed in the dairy farm pond water for 15 minutes and then taken out and placed in the reactor. Note that this would not be needed if this was downstream of a septic tank because the effluent from the septic tank would provide these microorganisms.

When feeding of the synthetic wastewater began, it was at a lower COD concentration and then slowly increased to 125 mg/L. To monitor the stability of the reactor, the

Table 2: Amount of coconut husk used in the COD release experiments

Coconut husk type	Wet weight (g)	Dry Weight (g)	Moisture Content (%)
Green husk	257	36	86
Brown husk	150	98	35

pH was measured. The concentration of the synthetic wastewater was slowly increased if the pH was stable.

Evaluation period

Once the reactor reached a COD concentration of 125 mg/L, then the evaluation period started. During the evaluation period, the COD concentration remained constant. Data were then gathered to establish the performance of the reactors and compare green and brown coconut husks.

2.4 COD release from coconut husks

An additional set of experiments focused on testing whether any COD was released from the coconut husk into the water. As coconut husk is an organic material, it is possible that carbon and nutrients such as nitrogen and phosphate could be released as the coconut husk breaks down. It is important to examine this aspect to enable the performance of different types of husks to be compared.

For these experiments, one piece of husk was placed in a container with 6 L of water. The containers were closed to minimise evaporation. Details of the weight and moisture content for each type of coconut husk are given in Table 2.

The liquid was monitored for COD and pH. Measurements for nitrate and phosphate were also taken towards the end of the experiment to determine if nutrients were being released from the coconut husks.

2.5 Sample analysis

Chemical oxygen demand (COD)

There are many organic substances which can have an adverse effect on the environment. This adverse effect is due to the oxygen required to break down these compounds. In order to measure the pollution potential of waste, the amount of oxygen which is consumed to break down the substances needs to be measured. The analytical method used in this study was the COD.

The COD analysis was conducted using the Thermo Scientific COD test kits and measuring the colour change using a spectrophotometer.

pH

There are a wide range of microorganisms involved in reducing COD in an anaerobic system. These microorganisms can be separated into two types. The first type are acid producers, and they start the process by breaking down the organic material into organic acids. The second type of microorganisms break down the organic acids into methane (CH4) and carbon dioxide (CO2) which are gases, and this ultimately results in the COD being reduced from the liquid. This process is summarised in Figure 5.

Both groups of microorganisms need to work together to reduce the COD. If the acid producing organisms do not break down the organic material, then there is no food for the methane producing microorganisms. This can also lead to a reduction in the pH due to the build-up of acids. This can be an issue as the methane producing microorganisms are sensitive to changes in pH, and they prefer a pH above 6.5 (Young and Yang, 1989). By measuring the pH, the process can be monitored to ensure that both sets of microorganisms are working effectively.

The pH was measured using a probe and a handheld meter. The probe was calibrated using a two-point calibration before measurements were taken.

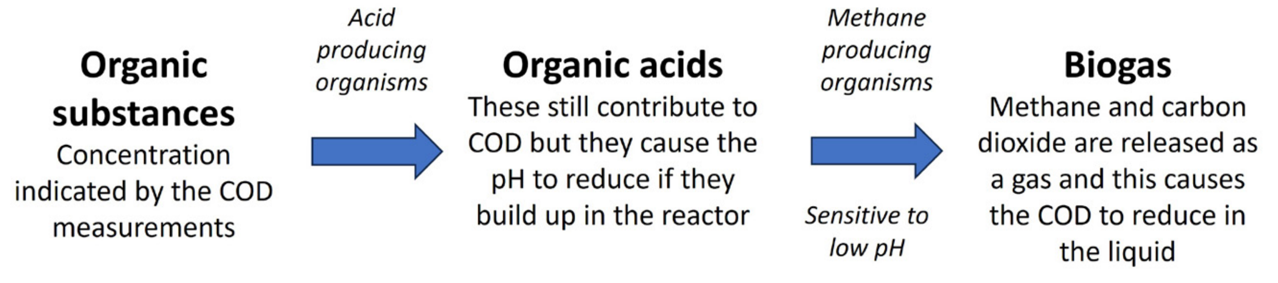

Figure 5: The biological processes occurring within the anaerobic filter

Nitrate and phosphate

It is possible that as the coconut husk breaks down, nutrients like nitrate and phosphate are released. It is important to analyse for these components as these nutrients can have adverse effects on the environment. Samples from the feed and the anaerobic reactors were analysed to determine if there was an increase in nitrate and phosphate. Anaerobic processes do not typically achieve high nutrient removal, so no significant change between influent and effluent would be expected if there is no leaching from the coconut husk.

Prepared Hach test kits were used to analyse samples for nitrate and phosphate.

3 RESULTS AND DISCUSSION

3.1 Reactor performance

The key parameter of interest for this study is the COD reduction within the reactor. First there is a period where the reactor is being slowly started up before it reaches the full COD concentration in the feed. In this study the start-up period was done slowly to ensure that the reactor remained stable. The purpose of this study was to see if a stable reactor could be maintained and to evaluate the COD reduction, therefore a cautious approach was taken to start-up.

After the start-up period, a steady COD concentration was used in the feed, and the COD removal in the reactors could be determined. The data summarised in Figure 6 show the percentage COD removal once start-up had been completed for the green and brown husk reactors.

The average percentage COD removal for the green coconut husks was 21 % (Figure 6) with an average effluent concentration of 103 mg/L. For the brown coconut husks, the performance was better with an average COD removal of 49 % (Figure 6) and an average effluent concentration of 64 mg/L. Prior work by de Oliveira Cruz et al. (2019) reported a COD removal efficiency of 52 % which is similar to the performance of the brown coconut husk reactor. The work by de Oliveira Cruz et al. (2019) was conducted using dried green coconut husks. It is possible that the drying process led to the coconut husks behaving in a similar way to the brown coconut husk rather than the fresh green coconut husks.

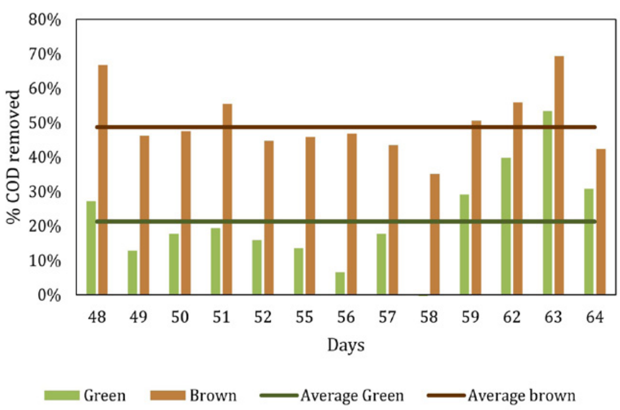

Figure 6: Green and brown coconut husk reactor COD removal performance during the evaluation stage of the experiment

3.2 pH of the reactors

Throughout the experiments, the pH was monitored. Typically, healthy anaerobic reactors have a pH above 6.5 (Young and Yang, 1989). Figure 7 shows the pH throughout the experiments. During the start-up phase, the pH was more likely to drop below 6.5; however, during the evaluation period, the pH was more stable. The average pH during the evaluation period was 6.49 for the green coconut husk reactor and 6.60 for the brown husk.

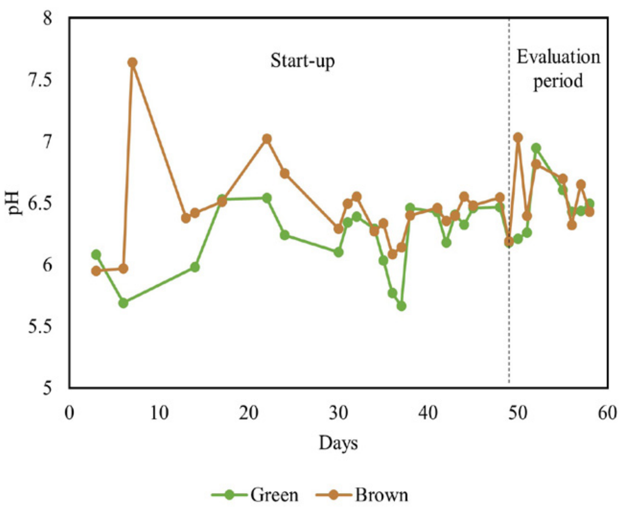

Figure 7: pH of the green and brown coconut husk reactors. The dotted line shows when the evaluation period started

3.3 COD release from coconut husks

The leaching tests were conducted to determine how much COD was released from the coconut husks as this would contribute to the COD in the effluent. Figure 8 shows why this is important. There is a certain amount of COD entering the reactor in the feed. Some of this COD will be consumed by the microorganisms in the biofilm. There will also be some untreated COD which they do not consume which will pass out of the reactor in the effluent. As the coconut husk is an organic material, it will slowly break down and, as a result, some COD will be released out of

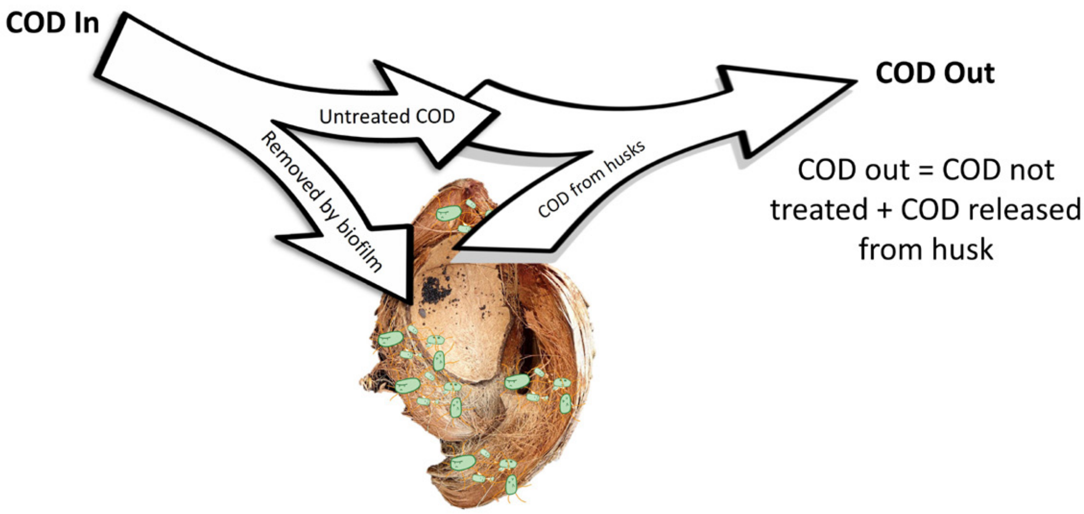

Figure 8: *Existing septic tank followed by proposed anaerobic filter. Image adapted from de Oliveira Cruz et al.* (2019)

the husk into the surrounding water which is referred to as leaching. The COD which is leached from the husk then passes out of the reactor with the effluent. This means that the effluent contains a combination of the COD which is not removed from the feed plus some COD which has been leached from the coconut husks.

It was expected that there would be a difference in the COD released from the green and brown coconut husks. The brown husk has been naturally matured over time, and it is likely that some of the COD that it once contained has already been released in the environment.

The pieces of coconut husk tested were different sizes; to account for this, the results are presented as the amount of COD leached per amount of dry coconut husk (Figure 9). Higher values mean that more COD is being released from the coconut husk and therefore the COD removal happening within the reactor may be masked by the large amount of COD being released.

As expected, there was more COD released from the green husk compared to the brown husk (Figure 9). The COD values do fluctuate, and this is probably due to microorganisms growing in the reactor and on the surface of the husk which would consume some of the COD. The maximum COD values for the green and browns husks were 71.3 and 17.5 mg COD/mg dry husk, respectively. This means that more than four times the amount of COD was leached for the green husk. This confirms the expectation that the brown coconut has already started to break down during the ageing process.

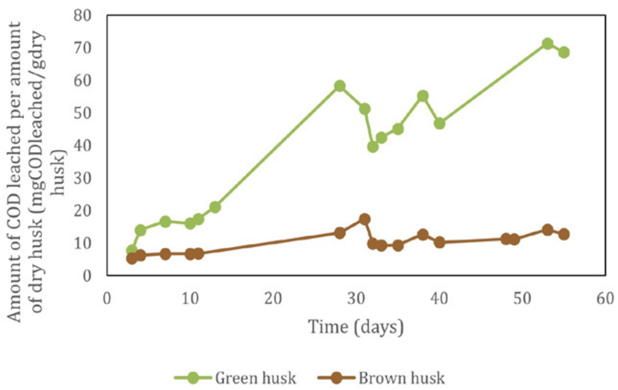

Figure 9: *COD released from the coconut husks in the leaching experiments. Results are presented as the COD per amount of dry coconut husk to correct for different amounts of coconut husk in the test*

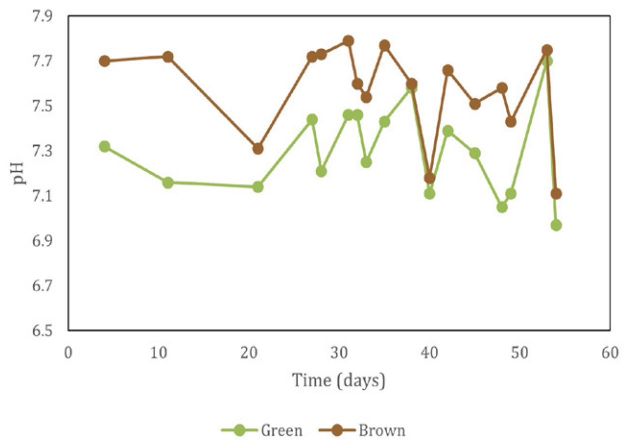

Figure 10: *The pH of the water in the leaching experiments*

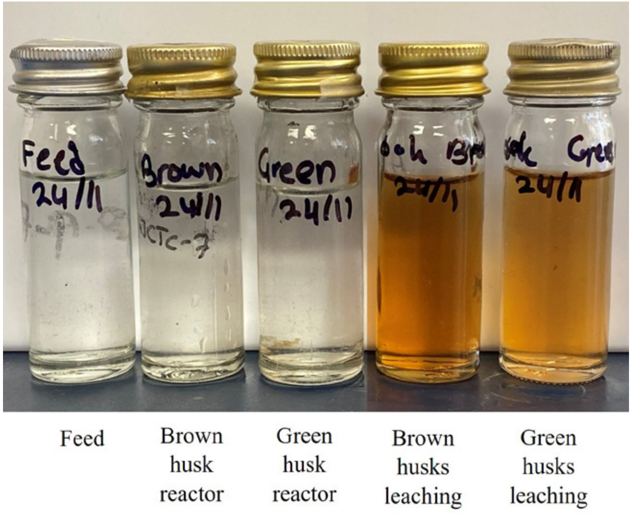

Figure 11: Photograph of samples from each trial to compare the colour

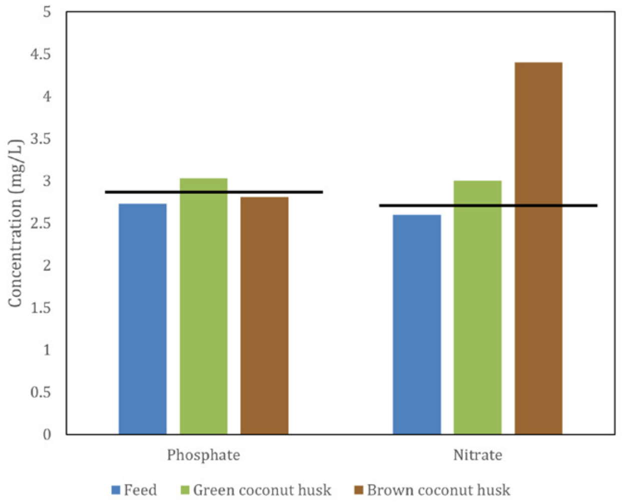

Figure 12: Phosphate and nitrate concentration in the feed and each of the coconut husk reactors. The black line is to allow easy comparison with the feed concentration.

The pH of the liquid during the leaching experiment was also of interest (Figure 10). For both the green and brown coconut husks, the pH was above 7 which is not acidic and should not negatively impact the anaerobic digestion process.

Colour leaching out of the coconut husk was observed in the COD release experiments, so samples were taken from each reactor to compare. As seen in Figure 11, the up flow anaerobic filter reactors did not show a significant amount of colour; however, all of the COD release experiments did. The lack of colour in the anaerobic filters is probably due to dilution from the synthetic wastewater which is colourless and the fact that these reactors were run continuously whereas the leaching trials were batch.

3.4 Nitrate and phosphate release

The results have shown that COD is leached out of the coconut husks, and it is possible that other components are also being leached out of the husks. Particular compounds of interest include nitrogen and phosphorus which could cause adverse effects on the receiving environment. Figure 12 shows the concentration of phosphate and nitrate in the feed and the effluent from the reactors. Significant nutrient removal is not expected in the anaerobic filter, so any changes in the nutrient concentrations are likely to be due to leaching from the coconut husk. The amount of nutrients leached out of the coconut husk can be examined by looking at the difference between the feed and the reactors. The black line in Figure 12 assists with this. If the bars are above the black line, then this indicates that nutrients may have been released by the coconut husk. The only measurement which suggests that there may be some leaching is the nitrate value for the brown coconut husk reactor. However, it should be noted that this is based on very limited data. More data would be required before a conclusion can be drawn.

3.5 Implications of the findings

The performance of the anaerobic filter is determined by a combination of COD being treated by the microorganisms in the reactor and COD being released by the coconut husk back into the water. The final effluent COD concentration for the brown coconut husk reactor was 64 mg/L. To put this value in perspective, one manufacturer reported that package sewage treatment systems, which are small-scale wastewater treatment plants, are designed to achieve a COD effluent concentration of 75 mg/L (Butlerms, n.d.). Based on the initial findings presented in this report, this level of treatment could be achieved by adding an up flow anaerobic filter using brown coconut husks as the surface for attached growth of microorganisms.

There are several areas which require further work before this technology could be implemented. As already identified, the potential for nutrients to be leached from the coconut husk needs to be examined in more detail. Long-term data are required to determine maintenance requirements. Previous work has shown that coconut shells can be used in an anaerobic filter for two years (Silva et al., 2015), but this would need to be confirmed with coconut husks as the rate of breakdown could be different. Determining the size of a reactor for a household will also be important, but further optimisation of the process by varying the HRT is needed before this can be determined. The stability of the process to handle changes in the COD concentration should also be considered to mimic times when the septic tank does not work as expected or when there is a higher loading due to more occupants of a household than expected.

4 CONCLUSIONS

The potential of an anerobic filter using coconut husks as the attachment media was examined, and both green and brown coconut husks were trialled. It was found that there were two mechanisms simultaneously occurring which determined the effluent concentration. COD was removed due to anaerobic treatment, but COD was also leached from the coconut husk back out into the liquid. The green coconut husk was found to release larger amounts of COD and therefore the reactor did not remove as much COD. The brown coconut husk released less COD and therefore that reactor was able to remove 49 % of the COD overall.

There could be several aspects to focus on in future work. These could include determining the start-up procedure, examining nutrient removal in more detail, conducting work to determine the size of the unit required for a typical Pacific Island household, and gathering long-term data to establish when maintenance is required.

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6 REFERENCES

Butlerms (n.d.) '*Sewage parameters 7: Chemical oxygen demand (COD)*'. Available at: https://butlerms.com/sewage-parameters-7-chemical-oxygen-demand-cod/ (Accessed: 9 December 2021).

Climate data.org (2021) '*Climate: Tonga*'. Available at: https://en.climate-data.org/oceania/tonga-97/ (Accessed: 9 December 2021).

de Oliveira Cruz, L.M.O., Gomes, B.G.L.A., Tonetti, A.L., and Figueiredo, I.C.S. (2019) 'Using coconut husks in a full-scale decentralized wastewater treatment system: The influence of an anaerobic filter on maintenance and operational conditions of a sand filter', *Ecological Engineering,* 127, pp. 454-459.

de Oliveira Cruz, L.M.O., Stefanutti, R., Filho, B.C., and Tonetti, A.L. (2013) 'Coconut shells as filling material for anaerobic filters', *SpringerPlus,* 2, pp. 655.

Heredia, R.M., Layedra-Almeida, A.P., Torres, Y., and Toulkeridis, T. (2022) 'Evaluation of a microbial consortium and selection of a support in an anaerobic reactor directed to the bio-treatment of wastewater of the textile industry', *Sustainability,* 14, pp. 8889.

Kaetzl, K., Lubken, M., Gehring, T., and Wichern, M. (2013) 'Efficient low-cost anaerobic treatment of wastewater using biochar and woodchip filters', *Water,* 10, pp. 818.

Lopez-Lopez, A., Albarran-Rivas, M.G., Harnandez-Mena, L., and Leon-Becerril, E. (2013) 'An assessment of an anaerobic filter packed with a low-cost material for treating domestic wastewater', *Environmental Technology*, 34, pp. 1151-1159.

Pale, A. (2021) personal communication, 11 June.

Radio New Zealand (2020) '*The trouble with talking about toilets in Tonga*'. Available at: https://www.rnz.co.nz/audio/player?audio_id=2018750503 (Accessed 23 October 2021).

Rodgers, M., Walsh, G., and Healy, G. (2010) 'Different depth intermittent sand filters for laboratory treatment of synthetic wastewater with concentration close to measured septic tank effluent', *Journal of Environmental Science and Health,* Part A, 46, pp. 80-85.

Salim, M.K., Linta, N.P., Roush, A.H.M., Ismail, M., and Nazim, F. (2020) 'Treatment of wastewater using woven and non woven coir geotextiles', *International Journal of Creative Research Thoughts*, 8(5), pp. 1502-1507.

Secretariat of the Pacific Regional Environment Programme (2020) '*State of the environment and conservation in the Pacific Islands*: 2020 *regional report*: *Indicators* 31 – *access to and quality of sewage treatment*'. Available at: https://library.sprep.org/content/state-environment-and-conservation-pacific-islands-2020-regional-report-indicators-31 (Accessed 09 June 2021).

Silva, J.C.P., Tonetti, A.L., Leonel, L.P., and Costa, A. (2015) 'Denitrification on upflow-anaerobic filter filled with coconut shells (Cocos nucifera)', *Ecological Engineering,* 82, pp. 474-479.

Toerien, D.F. and Hattingh, W.H. (1969) 'Anaerobic digestion I. The microbiology of anaerobic digestion', *Water Research,* 3(6), pp. 385-416.

Tonga Statistics Department (2021) '*Population and housing census* 2021'. Available at: https://tongastats.gov.to/census-2/population-census-3/ (Accessed 07 October 2022).

Young, J.C. and Yang, B.S. (1989) 'Design considerations for full-scale anaerobic filters', *Research Journal of the Water Pollution Control Federation,* 61(9/10), pp. 1576-1587.