Biofilm Pilot Study for Sewage Treatment with Composting of Waste Sludge on Yap

by

Joseph D. Rouse

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WATER AND ENVIRONMENTAL RESEARCH INSTITUTE OF THE WESTERN PACIFIC UNIVERSITY OF GUAM

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ABSTRACT

On Yap Island the sole sewage treatment plant consists of an Imhoff tank system, which by design provides only a primary level of treatment. Upgrading the plant to achieve a secondary level of treatment by adding a biological unit process would require a major capital investment and be met with higher O&M costs as well. Currently, air-dried sludge from the existing plant is being used for agricultural purposes without prior treatment to meet appropriate safety standards. Thus, the need for greater attention to sufficiency of treatment and management of the sludge as a potentially useful nutrient-rich resource is urgently needed

Pilot tests were conducted to identify practical and economically feasible means by which to enhance sewage treatment and establish a viable composting procedure. Improvement to sewage treatment efficiency was investigated by inserting frames with biocarrier material into the flow channel of the Imhoff tank and quantifying the removals of COD across the biocarrier zone over time. Results indicated that with only one (1) square foot of the biocarrier material per cubic foot of tank volume the COD removal could be increased by an order of magnitude (from 6 to 59 mg/L) using this attached-growth process. The possibility of applying a larger compliment of this biocarrier material as a relatively simple retrofit to achieve even greater enhancements of treatment efficiency was discussed.

In addition, pilot-scale composting bins were employed to assess the potential of this environmentally friendly technology to cut pathogens from the municipal waste sludge. Under less than ideal conditions, over 6 weeks of composting, cuts in *E. coli* from > 2,400/g of sludge to approximately 20/g of compost were demonstrated, which would be suitable for some uses not involving direct contact with people such as reparation of bad lands. With further refinement in technique, a compost product suitable for most uses including crop applications in a safe and environmentally sustainable manner should be possible.

Keywords: wastewater; sewage; sludge; treatment; composting; sustainable infrastructure; tropical islands; Yap; Micronesia.

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INTRODUCTION

Inadequate treatment of domestic wastewater (sewage) in the islands of the Western Pacific has resulted in damage of natural resources and contamination of water supplies, thus leading serious environmental and human health problems [**1**]. The reason for this has often been attributed to the lack of functional technologies, which are difficult to obtain and maintain due to the vast geographical distances among the island communities and the high costs for providing services.

Yap (**Figure 1**) is the western-most state of the Federated States of Micronesia (FSM). It covers approximately 500,000 square miles (1,300,000 square kilometers) of ocean, yet has only 45.8 square miles (119 square kilometers) of land surface consisting of numerous small islands. Only about 20 of these islands are inhabited. The main island of Yap (**Figure 2**), traditionally called "Wa'ab," is actually four closely interconnected continental islands with a population of approximately 7700 people, or 65% of the state's population (estimated to be 11,863 persons in 2015 [**2**]) [**3**]. The only centralized sewage treatment plant (STP) in the state provides a primary level of treatment for the town of Colonia on the island of Yap. In addition, many households on the island are equipped with pit latrines or septic tanks, though the degree of treatment and extent of upkeep being provided are largely unknown [**4**]. Furthermore, waste sludge from the STP is being used for agricultural purposes without prior treatment to meet appropriate safety standards. Thus, the need for greater attention to sufficiency of treatment and management of a potentially useful nutrient-rich resource is urgently needed [**4**].

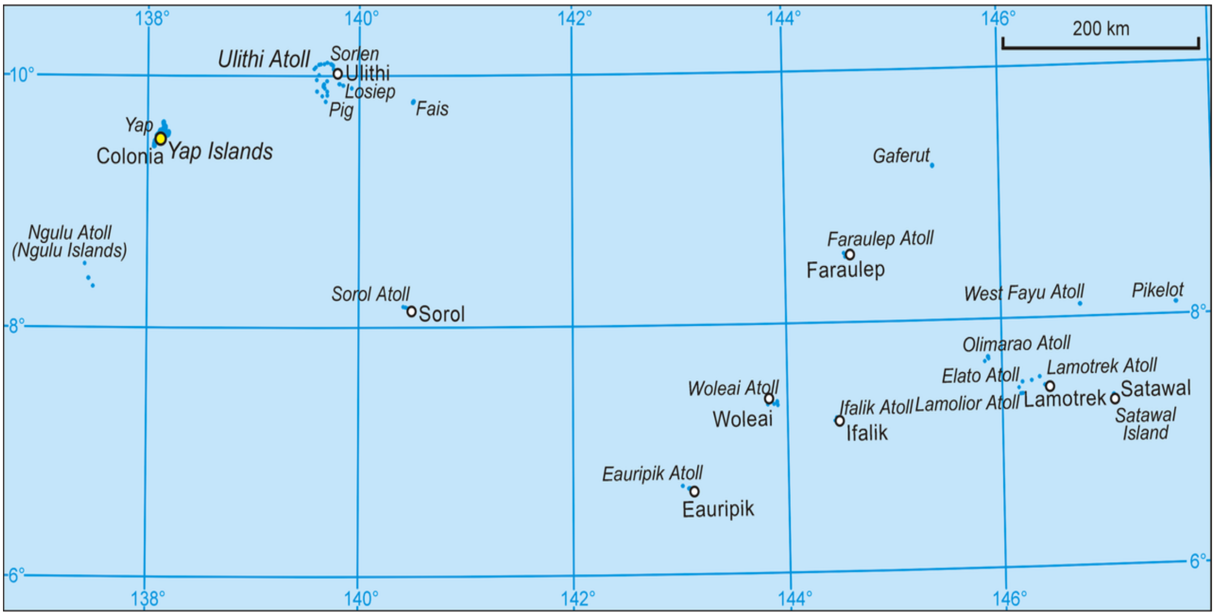

Figure 1. Map showing the island of Yap (upper-left) among the islands of Yap State of the Federated States of Micronesia. Image source: Aotearoa–Wikimedia Commons [**5**].

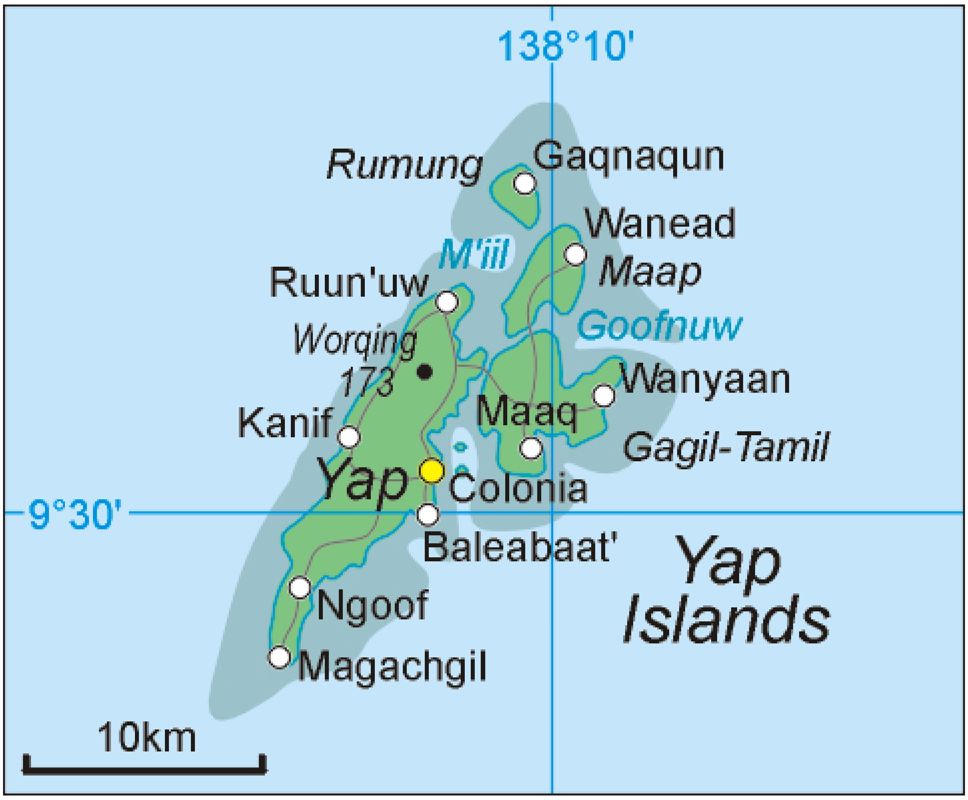

Figure 2. Map showing the island of Yap proper, of Yap State, consisting of four interconnected islands. Image source: Aotearoa – Wikimedia Commons [**5**].

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

On Yap Island the treatment provided by the sole STP is clearly insufficient with essentially raw sewage being discharged via a short outfall to the shallow ocean bay near the business center of Colonia [**4**]. The existing STP was commissioned in 1974 and consists of an Imhoff tank system, which by design provides only a primary level of wastewater treatment with removal of easily settleable solids. Upgrading the plant to achieve a secondary level of treatment by adding a biological unit process, such as activated sludge, for the removal of dissolved organic compounds would require a major capital investment. In addition, this would be met with higher O&M costs, including the need for treatment and disposal of the excess sludge yielded by biological treatment. However, the possibility exists of enhancing treatment efficiency by fitting the existing structure with an attached-growth medium to promote retention of beneficial biomass without the need for a separate sedimentation tank or recycle pumps to retain the biomass [**6, 7**].

The nature of this project is that of conducting tests for treatment of wastewater and waste sludge, including collecting samples and analyzing data to evaluate the results. The conceptual scope of the project consists of identifying practical means by which to enhance the treatment efficiency of the STP and to establish a viable composting procedure to allow for reuse of the waste sludge. The physical scope of the project will be limited to the site of the STP in Colonia Town on Yap Island.

The objective of this project is to perform a pilot test to evaluate the use of an attached-growth process in the existing primary treatment system and to determine an effective procedure for composting the waste sludge. This objective was met by inserting frames with biocarrier material into the flow channel of the Imhoff tank and quantifying the removals of contaminants across the biocarrier zone over time. In addition, pilot-scale composting bins consisting of wooden frames were constructed using local materials and employed to assess the potential of this environmentally friendly technology to cut pathogens from the municipal waste sludge.

METHODOLOGIES

The methods employed over the course of this project incorporated civil engineering fieldwork and water quality laboratory analyses. The work was carried out under the supervision of the principal investigator (PI) and the manager of the Water and Wastewater Division of Yap State Public Service Corporation (YSPSC).

The biocarrier mesh material was purchased by the PI at a DYI hardware store in Guam and delivered to YSPSC in Yap State. The material consists of a very durable synthetic fabric (nylon). Fabrication of six (6) frames using PVC pipes to support the mesh material and fitting them into the flow channel of the Imhoff tank was accomplished by YSPSC employees under the direct supervision of the PI. Sampling and water quality analyses were performed by local staff as instructed by the PI.

As an aggregate indicator of the quantity of organic compounds in the sewage, chemical oxidation demand (COD) was used. For the COD analyses, the manganese (Mn-III)-based method (HACH) was employed rather than the more universally accepted chromium (Cr)-based and cadmium (Cd)-based methods. The Mn-based procedure does not generate a hazardous-waste byproduct that would require expensive and difficult disposal procedures in accordance with international standards.

For the composting pilot test, a simple wood-frame structure was used. Industrial thermometers were be used to monitor the temperature of the compost piles. The Yap EPA staff assisted with the monitoring of pathogens, which required mixing approximately one (1) gram of sludge or compost into 100 mL of sterile water along with the manufacturer’s nutrient supplement and following the prescribed incubation procedure (IDEXX, Colilert Test Kit). Results are reported as most probable number (MPN) of organisms per gram of sludge/compost.

RESULTS AND DISCUSSION

Wastewater treatment

The municipal STP in Colonia (**Figure 3**), serving the main residential area and business center on Yap, consists of an Imhoff tank system with two treatment lines designed to operate in parallel (**Figure 4**); however, only one line is used at a time due to the relatively low intermittent flow entering the plant from approximately 300 service (mostly household) connections. The unmetered inflow is thought to be somewhat less than the design flow of 170,000 gallons per day (640 cubic meters per day). Imhoff tanks are very user friendly and have low operational costs due to the absence of mechanical aeration and internal recycle. However, they provide only a primary level of wastewater treatment consisting of a limited removal of suspended solids. The solids that settle into a compartment below the flow channel undergo some degree of anaerobic digestion and are periodically expelled to a sand drying bed under the intrinsic natural hydraulic head of the system, thus eliminating the need for mechanical pumping. No chemical or biological treatment is employed at the plant, hence the effluent, which is being discharged to the ocean, is not much different (by appearance and odor) from raw sewage. Furthermore, the 1000-foot (300-meter) outfall is known to be broken open at approximately 500 feet (150 meters) from the shore. As a consequence, it is discharging sewage in a shallow area at a depth of only 10 to 20 feet (3 to 6 meters) near the industrial district, which is about a half mile (one kilometer) from the main business district in Colonia. Testing by the Yap EPA for Enterococci bacteria in the coastal zone has, surprisingly, yet to yield a count of greater than 30 organisms per 100 millimeters of sea water, which would require the posting of warning signs.

Figure 3. Imhoff tank sewage treatment plant in Colonia, Yap. Image source: author.

Figure 4. One flow line in the Imhoff tank sewage treatment plant. Image source: author.

To explore the possibilities for achieving a higher degree of treatment in a cost-effective and sustainable manner, a pilot test was initiated using an attached-growth process for retention of beneficial biomass consisting of a durable mesh material fixed to PVC-pipe frames (**Figure 5**). The empty Imhoff-tank prepared for insertion of the frames is shown in **Figure 6**. After insertion of the complete complement of frames (**Figure 7**), wastewater was then directed to flow through the maze-like configuration in the pilot zone (**Figure 8**).

Figure 5. One of six PVC frames (upside-down, behind small papaya tree) used to support mesh material for biofilm attachment. Image source: author.

Figure 6. Imoff tank emptied in preparation for insertion of biocarrier frames. Image source: author.

Figure 7. Biocarrier frames inserted in the channel of the Imhoff tank. Image source: author.

Figure 8. Wastewater flow directed through the biocarrier-frame matrix. Image source: author.

Results during the six-month startup period from June through December 2014 indicated extreme variations in influent COD levels (data shown in 2014 Project Synopsis Report). With closer observation it became apparent that the extremely low and high measurements were due to dilution by storm-water intrusion and, possibly (not confirmed), the dumping of septic-tank contents into the sewer line in close proximity to the STP. Thus, subsequent efforts were made to avoid irregularities attributable to the timing of sampling events. At the end of this startup period, a visual check was made of one of the biocarrier frames confirming a healthy growth of biofilm on the mesh material (**Figure 9**).

Figure 9. Inspection of a biocarrier sheet showing biofilm growth. Image source: author.

Using the sampling stations depicted in **Figure 10**, sampling across the STP over a 14-month period was conducted as shown in **Table 1**. The biocarrier frames were inserted between stations 2 and 4 (station 3, at the midpoint of the biofilm insert, was not evaluated during this phase of testing, though it had been used during the startup phase). For evaluation of the pilot test, treatment performance across the whole channel was assessed with samples drawn at stations 1 and 5.

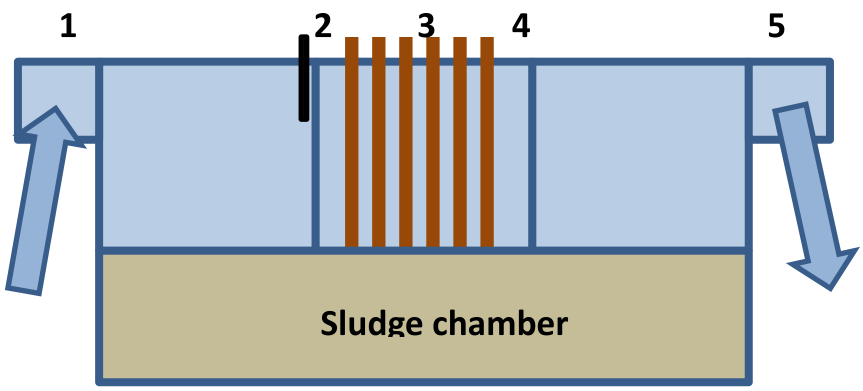

Figure 10. Schematic (profile view) of Imhoff tank showing sampling stations 1-5. The red bars between stations 2 and 4 indicate biocarrier frames.

Background, or control, data was obtained from testing with the wastewater flow directed through the channel without the biocarrier material. These results revealed COD removal efficiency of only 1.5% (SD = 14%, n = 8), with a COD cut of approximately 6 mg/L. Sampling methods used here were intended to catch total COD, including the contribution from suspended solids. However, the pipet used for distributing samples could not catch larger components that would readily settle or float and thus be removed in the first 1/3 of the channel (prior to station 2). Thus, results here represent removals of components that are water soluble or contributable to very fine solids (e.g., bacterial component, or of a size contributing to cloudiness of the solution).

With wastewater flow directed through the channel containing the biofilm pilot, treatment performance was enhanced to 15% (SD = 17%, n = 10), with a COD cut of approximately 59 mg/L. This indicates an improvement contributable to inclusion of the biocarrier by an order of magnitude. Defining the surface area that would accommodate biofilm growth to be the two sides of the biocarrier sheets included in the central 1/3 of the channel, the specific area amounts to approximately one (1) square foot (SF) of biocarrier surface per cubic foot (CF) of tank volume. In an actual full-scale attached-growth application, this ratio could be as much as 500 SF/CF, such as with suspended media in a complete-mix reactor [**8**]. For the case employed here, using sheet material, clearly a level of 500 SF/CF would not be obtainable; however, the surface area could easily be doubled, or with some effort increased by a factor of three.

Table 1. Time course of COD concentrations (as mg O_2/L). Results are from channel without or with biofilm matrix as indicated. Biofilm material had exposure to influent flow since June 2014.

Sample point →	1	2	3	4	5
Date (2015)	Flow directed to open channel (without biofilm)				
1/23/15	331	273			234
1/30	328	290			285
2/6	256	272			254
2/11	330	300			340
2/13	297	305			295
3/27	355	425			383
4/24	223	289			246
4/30	Flow directed to pilot channel (with biofilm)				
5/16 (with bio.)	464	476		301	311
5/19 (with bio.)	349	286		260	284
7/10 (with bio.)	389	280		282	311
7/24 (with bio.)	311	315		310	293
8/21 (with bio.)	267	363		280	290
9/25 (with bio.)	389	280		282	311
10/2 (with bio.)	424	384		339	394
10/9 (with bio.)	362	274		216	214
10/16 (with bio.)	294	268		219	326
Late October	Flow directed to open channel (without biofilm)				
11/6	309	355			341
Mid December	Flow directed to pilot channel (with biofilm)				
2/5/16 (with bio.)	334	243		232	259
2/28	End of project funding				

It is not demonstrated here that a linear increase in removal efficiency would follow with an increase in surface area; though it would not be unreasonable to consider that a significant enhancement in treatment performance would be likely (engineering judgement), with an investment of several thousand USDs. Granted, it would not be reasonable to assume an attached-growth process as used here could achieve a treatment performance of 80% to 90%, as should be possible with an activated-sludge system, but construction of such a plant would require several million USDs, and be further coupled with more expensive O&M concerns. Conversely, employment of an attached-growth process, as demonstrated here, would constitute a relatively simple addition to the existing facility and require no extra operator attention or added expense over extended periods of operation.

Progressing to a full-scale application, would simply be a matter of increasing the number of inserts, over that which were used for the pilot test. Such an endeavor could fall with the budget of a typical research grant (as used for this pilot test). Furthermore, upgrading the biocarrier mesh to a product that had been researched and developed for this purpose would be worth considering. Pricewise, though, this could constitute an increase from several hundred dollars (as for the durable synthetic mesh material used here) to several thousand dollars for a proprietary biocarrier medium.

Sludge handling

Partially digested sludge is drawn from the under chambers of the Imhoff tanks approximately four times per year (**Figures 11** and **12**). This sludge is then held on a sand drying bed (**Figure 13**) for one week prior to intended disposal in the solid-waste landfill. By engineering judgement, this sludge product is estimated to be 50% dry solids (i.e., 50% moisture content). Prior to delivery to the landfill, this material is always taken away by local farmers and used as a soil amendment for production of food crops.

To probe for a safe, beneficial use of this nutrient-rich waste material while relieving the landfill of undue burden, composting pilot tests were conducted using one-cubic-yard shipping crates to hold the compost material, consisting of waste sludge and grass cuttings (straw), which are both in abundance at the STP grounds. Guidance was initially gleaned from various sources [e.g., **9, 10**], though some experimentation was necessary to determine the best mix ratio for grass cuttings and dried sludge and the turning/mixing frequency. Temperature and moisture were monitored and mixing conducted. Total coliform and *E. coli* indicator microorganisms were quantified in the original sludge and final compost product.

Figure 11. Sewage sludge from Imhoff tank being discharged to a sand drying bed. Image source: author.

Figure 12. Wet sewage sludge in drying bed at beginning of drying period. Image source: author.

Figure 13. Air dried sludge with an estimated 50% moisture content. Image source: author.

For the first round of testing (of 6/24/2015, **Table 2**), two bins were loaded with three layers of sludge sandwiched within four layers of straw. Each bin contained 75 lbs (34 kg) of sludge and 100 lbs (45 kg) of straw (wetted to an estimated 50% moisture content) for a total of 175 lbs (79 kg) per bin (or 350 lbs (160 kg) for the two bins combined). Temperature was monitored and was shown to climb steadily from 90°F (30°C) to a peak of 120°F (50°C) during the first week, after which it gradually dropped down over one week to a plateau of approximately 92°F (33°C), which was maintained for two more weeks prior to assuming what appeared to be an ambient temperature of 85°F (29°C). Mixing was attempted twice a week, which proved to be difficult; thus, this requirement was reduced to stabbing the pile with a pitchfork in an attempt to achieve some minimal amount of mixing and venting.

Table 2. Time courses of composting tests. Most probably number (MPN) of bacteria based on one gram of sludge or compost material suspended in 100 mL of sterile water with standard nutrients.

Date & description	Total Coliform MPN/g	*E. coli* MPN/g	Comments
6/24/15, raw sludge	> 2,400	> 2,400	After 7 days on drying bed
8/6/15, 42-day compost	> 2,400	21	From mid part of compost heap
1/14/16, cured compost *	> 2,400	Zero	From mid part of compost heap (see **Figure 14**)
1/14/16, near by soil	> 2,400	Zero	Ca. ½" below surface
1/14/16, near-by sand	7.5	Zero	Ca. ½" below surface (sun baked)
1/14/16, raw sludge	> 2,400	> 2,400	After 5 days on drying bed
2/25/16, 42-day compost	> 2,400	10	From mid part of compost heap

***** Compost heap remaining since 8/7/15. Odor and texture of cured compost appeared as ordinary garden soil – totally un-offensive.

As shown in **Table 2**, the initial sludge used as input for the test was very high in both total coliform and *E. coli* (both MPN > 2,400/g). Upon return of the PI to the site near the end of the 42-day testing period, the compost did not smell offensive, but there were some mosquitos swarming in the bins, which disappeared quickly upon mixing and did not reappear. The compost mix in both bins had some parts that appeared to be degraded and others that still looked like the original mix of sludge and straw (i.e., unchanged). The moisture content had not been checked and maintained as instructed, and the material appeared much too dry. Samples collected from the mid sections of both bins indicated the MPN of total coliform was still > 2,400/g; *E. coli*, though, had dropped greatly to an MPN of 21/g (**Table 2**, 8/6/15). The contents of both bins were then combined (having shrunk somewhat during the test) and the moisture content raised to approximately 50% and left to cure until the next visit of the PI. Upon return (1/14/16), as shown in **Figure 14**, the contents looked and smelled like a rich garden soil and *E. coli* had dropped to zero (0), while total coliform persisted at an MPN > 2,400/g.

At that time, sampling was conducted to determine background levels of the indictor organisms, by which it was shown that total coliform bacteria were at high levels (MPN > 2,400/g) in nearby natural soil. This indicates that total coliform does not always serve dependably as an indicator of human contamination, considering that the same soil sample and also nearby sand were found to be absent of *E. coli* (**Table 2**, 1/14/16).

Figure 14. Cured compost following completion of first test. Image source: author.

The second round of testing (of 1/14/16), as before, started off with the MPN for total coliform and *E. coli* both being > 2,400/g. For this round only one bin was used, which was loaded with 12 layers of material (**Figure 15**), each consisting of 30 lbs (14 kg) of air-dried sludge, 25 lbs (11 kg) of straw (wetted to 50% moisture), and one shovel of seed compost (ca. 5 lbs (2.5 kg) from the previous test). These components, manually mixed for each of the 12 layers, totaled 720 lbs (330 kg) of material. In addition, a layer of dry straw was included under and above the mix (25 lbs (11 kg) each). Furthermore, two pipes were inserted, which would allow for some ventilation and a limited amount of mixing by periodically shuffling the pipes (**Figure 16**).

Figure 15. Contents (prior to mixing) in one layer (of 12) added to compost bin for the second round of testing. Image source: author.

Figure 16. Compost bin with dry-straw blanket and ventilation pipes. Image source: author.

In this case, the greater sludge content applied in more numerous layers (12 versus 4) and a larger total mass of material (by a factor of 4) per bin was used in hopes that a greater activity and higher temperature would be achieved. However, the staff appointed to follow up with these monitoring duties was, without warning, sent off island for most of the testing period; thus, temperature was not recorded. In addition, the moisture content had not been checked; however, due to the under- and over-lying straw “blankets,” following 42 days of composting the contents still appeared to be at a proper moisture level of approximately 50% (i.e., with a dark, wet appearance, but without any standing or dripping water upon handling), thus still containing sufficient void spaces for ventilation. Under these testing conditions, the *E. coli* count was further cut to an MPN of 10/g (**Table 2**, 2/25/16).

The results obtained here are not meant to give us a final design for a full-scale composting operation; they do, though, show that the sludge is compostable and that such a project should be undertaken, and could be done at a very minimal cost. With a full-scale operation, it is considered that it would actually be easier to obtain better results. A greater mass of material (considering the depth and width of the mound) would be needed to obtain the 130^{o}F (54^{o}C) called for by the US EPA to achieve the necessary total cut in *E. coli*. With the limited mass used here, only 120^{o}F (50^{o}C) was observed. In addition, consideration should be given to the possibility that the "partially" degraded sludge drawn from the tanks may have been further along that thought. As such, perhaps introducing other "fresher" kitchen or garden wastes would contribute to a more amiable mix with higher levels of available nitrogen and phosphorus. Nonetheless, even without the total cut required for food-crop applications, such a product could still be used for reparation of badlands, etc. [**11**].

An estimate of the total amount of air-dried waste sludge (50% moisture content) per sludge-drawing event (approximately four times per year) comes to only 100 cubic feet (3 cubic meters). It is envisioned that this would be workable volume, not requiring any special equipment (e.g., forklift, tractor, pickup truck, etc.) for initial piling and occasional partial mixing. Furthermore, with four sand drying beds, each 20 X 60 feet (6 X 18 meters), available and with never more than one being used at a time for drying, one or two of the extra beds could be sacrificed for composting use. One bed would suffice for one cycle of composting, but if deemed necessary, a second row could be shaped while the first row is allowed to undergo extended curing. Possible configurations that could be employed for composting are shown in **Figure 17.**

In consultation with the utilities manager, it was deemed that it would not be necessary to lay new concrete over the sand drying beds to be used for composting. Some capital expenditures, though, would be required for, potentially, wood-frame or cinder-block dividers; awnings to provide shelter from the weather, consisting of sheet metal or tarps; and tools such as shovels and pitchforks. A careful evaluation would be needed to determine if the existing staff would be sufficient for the labor that would periodically be called for, or if investing in equipment for handling the material would be expeditious.

Image-a *Image-b*

Image-c *Image-d*

Figure 17. Configurations for composting that would be compatible with the sewage treatment plant in Colonia, Yap. Source for *Image-a, -b, -c, -d*: Bing.com [**12**].

CONCLUSIONS

Pilot tests were conducted at the STP in Colonia to identify practical and economically feasible means by which to enhance sewage treatment and establish a viable composting procedure. Improvement to sewage treatment efficiency was probed by inserting frames with biocarrier material into the flow channel of the Imhoff tank and quantifying the removals of COD across the biocarrier zone over time. Results indicated that with only one (1) SF of the biocarrier material per CF of tank volume the COD removal could be increased by an order of magnitude (from 6 to 59 mg/L). The possibility of applying a larger compliment of this biocarrier material to the existing tank as a relatively simple and inexpensive retrofit to achieve even greater enhancements of removal efficiency was discussed.

In addition, pilot-scale composting bins were employed to assess the potential of this environmentally friendly technology to cut pathogens from the municipal waste sludge. Under less than ideal conditions, over 6 weeks of composting, cuts in *E. coli* from an MPN > 2,400/g of sludge to approximately 20 MPN/g of compost material were demonstrated, which would be suitable for some uses not involving direct contact with people. With further refinement in technique, a compost product suitable for most uses including agricultural applications in a safe and environmentally sustainable manner should be possible.

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