Investigation of Water Recycling in an Anaerobic Digester

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Abstract— **Anaerobic digesters (AD) are important biogas production units that convert waste to energy. In this paper, the water recycling will be investigated in the digestate of the AD as a way to utilize the scarce resources. Mostly, the digestate are put in dry bed for water vaporization and recovery of the solid bio-fertilizer. This paper focusses not only on extracting of the solid content, but it also focusses on capturing water such that it can be reused in the anaerobic digestion system. The tests that were performed are the accumulated mass, water quantity and water quality tests. The experimental matrix for testing were also designed. In the results, it was determined that most suitable material was 60 micrometre stainless steel mesh. This material was found to have a separation efficiency of 44% while recycling 77% of the water from liquid digestate. The material's properties had a high durability, high corrosion resistance and high strength. This made the material long lasting and efficient for real life applications and due to its low corrosion, the recycled water does not have material impurities. The filtered water can be fed back into the digester while the filtrate can be used as a fertilizer.**

Keywords: **Anaerobic Digestion, Water Recycling, Liquid Digestate, Waste to Energy**

I. INTRODUCTION

Anaerobic digestion is a collection of processes that break down biodegradable materials in an oxygen free environment. During this process, organic materials are disintegrated into simpler chemical constituents, through hydrolysis, acetogenesis, acidogenesis and methanogenesis processes [5, 6]. The anaerobic digester is used to achieve two possible goals, which is to treat biodegradable waste and to produce sealable products (heat/energy and soil amendments) [5] as shown in Figure 1. The organic waste treated include farm waste, sewage sludge, solid wastes, industrial organic wastes and botanic wastes [5]. Energy crops can also be grown and used in the anaerobic digester, where high gas yields and good quality soil amendments are required [5]. The by-products of the anaerobic digester are biogas and digestate whose quality is dependent on the feedstock and contamination. The biogas and digestate can be further treated for special purposes, such as composting of digestate [5].

The process of anaerobic digestion can be divided into four phases; pre-treatment, digestion, gas upgrading and digestate treatment, see Figure 1. Relevant pre-treatment is performed on the organic waste before it is fed into the bio digester to ensure proper different feedstock mixing, water addition and removal of undesired items. The pre-treatment is performed to avoid failure during digestion process, to allow better digestion efficiency and digestate grade [5]. The type of feedstock also influences the level of pre-treatment required in the system. For instance, manures require mixing while municipal solid wastes (MSW) undergo sorting and shredding as a pre-treatment.

The digestion stage occurs in the digester, which is characterized according to temperature, number of stages, mixing devices and the water content in the feedstock. Digestion can be dry or wet based on the solid content. The feedstock is mixed with water and other suitable liquid wastes such as sewage slurry or re-circulated liquid from the digester's effluent [5]. There are two types of digesters namely the thermophilic and the mesophilic, which operate at temperatures of 55℃ and 35℃ respectively [5]. Mesophilic digesters have less operational costs and complexity but have lower production efficiency than the thermophilic digesters. The stages of digestion are separated into a multi-stage process, to allow better process control while maximizing digestion [5].

The biogas produced during the digestion phase is treated by removing carbon dioxide to produce fuel and energy [7]. It is also upgraded to remove contaminants such as hydrogen sulphide and water vapour that can damage engines or boilers. While the digestate can be dried and then used as a fertilizer or can be treated for higher quality uses such as compost [7, 8].

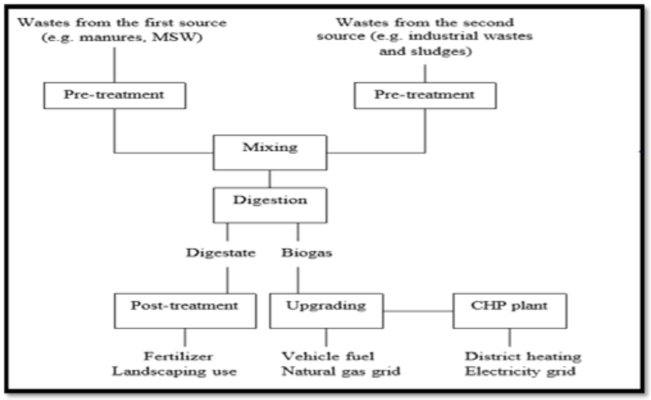

Figure 1: General process of an AD digestion plant [7]

A. Investigations on anaerobic digesters

Studies and experiments have been performed to improve the AD by considering factors such as methane emissions, type of feedstock, amount of water used and gas yield. Fugitive methane emissions were investigated by Flesch *et al* [1], which concluded that the lower the emissions from a biogas plant enables more biogas production. Biogas optimization was investigated by Shar *et al* [9] using key techniques of co-digestion, pre-treatment and digester design. However, this project is based on investigating water recycling in an anaerobic digester since water is a scarce mineral that should be used sparingly.

Water has also become a downfall in the use of the AD in many regions mainly due to low water availability. Smith et al. [3] investigated if the AD is feasible in rural South Africa under the current water availability, a study was run in Bergville KwaZulu Natal for a household AD. He concluded that the AD could not be feasible due to the low water available and insufficient infrastructure (bore holes, wells etc.) in the area. A study on the AD applicability in south Saharan Africa was also performed by Bansal *et al.* [10], were it was concluded that 72% of the countries required water recycling to be able to run the AD. The study was made on recycling water from aquaculture, rainfall and domestic water which includes drinking, cooking, bathing and laundry water. According to [11]. Bansal V *et al.*, [10] found as seen in Figures 2-4, that there is water scarcity in sub Saharan Africa and there is limited water that can be recycled [10]. Figure 2 shows the amount of water required for anaerobic digestion in various countries.

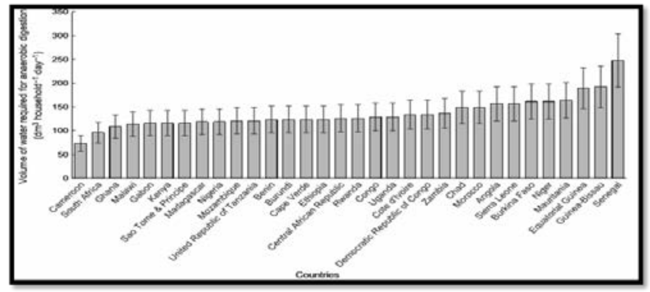

Figure 2: Volume of water required for anaerobic digestion [10]

The volume of water available for recycling is shown in Figure 3, where South Africa has a potential since there is enough water to recycle.

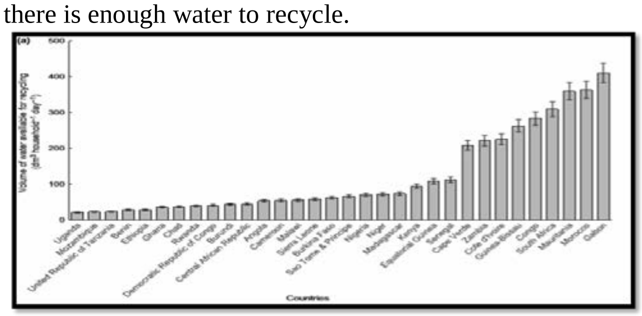

Figure 3: Volume of water available for recycling [10]

Figure 4 shows that water recycling can be effective in South Africa, which can then be fed into the anaerobic digestion system.

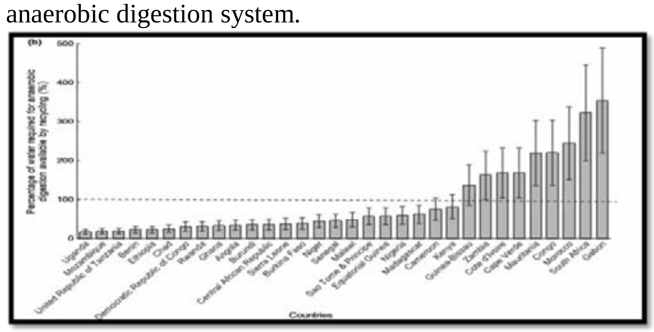

Figure 4: Percentage of water required for anaerobic digestion available by recycling [10]

From Figure 2 water recycling is imperative and highly required in the much of Africa. Figure 3 shows that there are limited supplies of water available for recycling according to the methods suggested by Bansal *et al.*, [10]. The percentage of water required for AD is excessively high for most countries making the technology not sustainable in most of the countries shown. Furthermore, underdeveloped countries cannot recycle as much domestic water as developed countries due to the infrastructure which is not as advanced in terms of water transporting and handling. Thus, a more general method is required to recycle water which would not be dependent on the infrastructure. This method should be simple, energy efficient and low cost in maintenance and usage.

B. Characteristics of slurry

To be able to recycle digestate, a clear understanding of it is required, therefore slurry or digestate is generally a liquid with a dry matter content ranging from 4 to 10%, the characteristics of slurry can vary due to storage time and manure treatments [12]. If the slurry has been stored at high temperatures for a long time the following can result; particle size reduction, organic compound mineralization and a decrease in separation efficiency [12]. The main physical characteristics of slurry are its moisture contents, its particle size and its viscosity. The sum of all the solids contained in the slurry is called dry matter. Dry matter consists of suspended solids and dissolved solids. The total solid content influences the density and viscosity of the slurry [12]. The density of the slurry is dependent on the DM content. The slurry used in this project is based on cow dung, hence the density of the slurry is calculated based on the cow dung.

$$\rho_{slurry} = \frac{DM + 236}{0.24}$$

$$\rho_{slurry} = \frac{DM + 279}{0.28}$$

Viscosity is the measure of a fluid's resistance to flow, which is driven by tensile or shear stresses. Viscosity influences the movement and transport of the slurry in a porous media like sand [12]. The viscosity of slurry can be computed using the viscosity equation for cattle dung-based slurry.

$$\mu_{slurry} = 4.10^{-5}.DM^{4.4671}$$

One of the main parameters that influences solid-liquid separation treatment is particle size and particle distribution. The animal species also highly influences the particle size of manure, the type of housing and feeding system. The particle size is usually larger cattle slurry, according to Moller et al. the particle size fraction can be as low as 0.025 mm. Particle size distribution is affected by factors such as feed composition, diet, animal category, storage time and temperature. According to Marcato *et al.*, [13], AD leads to modification of particle size distribution, resulting in a reduction of small particles, forming larger particle size distributions. Nutrients generally have small particle size, especially Nitrogen (N) and Phosphorus (P). In fact, 70% of the undissolved N and P have particle sizes ranging between 0.45-250μm.

II. METHODOLOGY

A. Materials Description

In this experiment reinforced non-woven materials was used for testing since they possess superior strength, stability and the ability to repel liquid. Since liquid digestate was passed through the filter fibres it was imperative to use materials of various pore sizes, such that a relationship can be determined between pore size and filtration. The smallest pore size of the materials to be used was 30 while the largest was 320 µm. Polypropylene of 30 µm was used in this experiment with the following properties [25]:

- Low density
- High stiffness
- Chemical inertness
- Stretchable
- Recyclability
- Low water absorbance of less than 0.01%

B. Specimen Preparation

The filtering materials were initially checked for any visible cracks or impurities such as gaps and tears. After visual inspection, the material was marked using a marker and a compass then a piece was cut that can cover the opening of the beaker using a Deli cutter blade. This is to ensure that the material was efficiently close to the opening of the beaker to ensure that no liquid digest could pass into the beaker without being filtered under gravity conditions.

For vacuum filtration, the size of the Buchner funnel base was measured then a compass and a marker were used to sketch the size of the material to be cut using a Deli cutter blade. After cutting the piece, the mass of the material cut was then measured using a balance scale and tabulated in the corresponding experimental matrix.

C. Experimental Setup

Two testing methods were used to accomplish filtration due to the difference in the pore size of the materials, the two testing methods to use were natural filtration and forced filtration using a vacuum. All the test materials were first passed through natural filtration to assess if the method was suitable for usage and if not, they were be put through forced filtration. The filtration method and the materials to be tested through the method are given as follows: i) Natural filtration by gravity and ii) Forced filtration using a vacuum.

Natural filtration by gravity

- XT21 Coarse Polypropylene 30 micron
- XT63 Coarse Polyester 30 micron
- XT23 Coarse Nylon 30 micron

Forced filtration using a vacuum

- Steel filter 60 micron
- Polyethene

- PP120 Polypropylene 120 micrometre
- Box 335b 200 micrometre
- Box 1004 340 micrometre

D. Experimental Procedure

Experiment 1: Gravity conditions

Gravity filtration testing was performed in simple and systematic steps listed as follows:

- Ensure all testing equipment are calibrated.
- Check if the beakers and graduate beaker to be used do not leak and are not broken.
- Carefully cut the size of filtering materials that should be able to cover a beaker using scissors.
- Mark the filter materials with their respective names, also mark the disposable glass vials with the name of the filtrate they will store.
- Measure the mass of the empty graduate beaker, filter fibres and that of the empty disposable glass vials.
- Now cover the opening of glass beaker 1 with the filter material and fasten the material using an elastic band.
- Pour the digestate from the storage bottle into the glass beaker 2.
- Carefully pour 10ml of the digestate from the glass beaker 2 into the graduate beaker using a glass funnel.
- Measure the mass of the graduate beaker with its contents.
- Pour out all the digestate from the graduate beaker through the filtering fibre into glass beaker 1.
- Wait for complete filtration, then remove the rubber band and extract the filtering material
- Collect the filtrate and pour into the disposable vial measure the mass of the disposable vial with its contents
- Put the filtering fibre into the oven and set it to 100℃ wait a few minutes to allow for drying.
- Now weigh the mass of the filtering fibre and its contents on the weighing scale
- Take the filtering material to a microscope and examine the average particle size trapped by the filter material with assistance from a lab technician.
- Use the pH meter to determine the pH and TDS of the filtrate in the disposable vial with assistance from a lab technician.
- Repeat steps 6 to 16 for other materials to be tested using vacuum.

a) Experiment 2: Vacuum conditions

Vacuum testing was performed in simple and systematic steps listed as follows:

- Ensure all testing equipment are calibrated.
- Ensure that the vacuum tap is operating with enough vacuum.
- Check the vacuum apparatus is not defective by checking that the rubber tubing is intact, Buchner flask and funnel are not broken or cracked, and the rubber seal is not broken.
- Setup the Buchner vacuum filter apparatus by inserting the Buchner funnel into the rubber seal and into the Buchner flask.
- Now connect the rubber tubing to the vacuum valve, with the large side on the Buchner flask arm and the smaller on the vacuum valve, do not open the valve yet.
- Carefully cut the size of filtering materials that will fit in the Buchner funnel using scissors.
- Mark the filter materials with their respective names, also mark the disposable glass vials with the name of the filtrate they will store.
- Measure the mass of the empty graduate beaker, filter fibres and that of the empty disposable glass vials.
- Fit the filtering fibre in the Buchner funnel and balance by placing the balancing piece to prevent vacuum from escaping on the sides.
- Pour the digestate from the storage bottle into the glass beaker.
- Carefully pour 10ml of the digestate from the glass beaker into the graduate beaker using a glass funnel.
- Measure the mass of the graduate beaker with its contents.
- Open the vacuum valve to allow for vacuum to enter the Buchner funnel.
- Pour out all the digestate from the graduate beaker into the Buchner funnel to allow for vacuum filtration.
- Cover the Buchner funnel with material using an elastic band to decrease amount of vacuum lost.
- Wait for complete filtration, then remove open the cover and extract the filtering material
- Collect the filtrate and pour into the disposable vial measure the mass of the disposable vial with its contents
- Put the filtering fibre into the oven and set it to 100℃ wait a few minutes to allow for drying.
- Now weigh the mass of the filtering fibre and its contents on the weighing scale
- Take the filtering material to a macroscope and examine the average particle size trapped by the

filter material with assistance from a lab technician.

- Use the pH meter to determine the pH and TDS of the filtrate in the disposable vial with assistance from a lab technician.
- Repeat steps 9 to 21 for other materials to be tested using vacuum.

III. RESULTS AND DISCUSSIONS

A. Solid content trapped

The number of solids trapped by the various filter fibres gave an indication to how suitable the filter material restored the solid content in the digestate. The material that trapped the highest quantity of material is not necessarily the best filter material, however it was a viable option when fertiliser production is the main driving factor. Figure 6 shows the accumulated mass of each material from a 10 ml digestate sample.

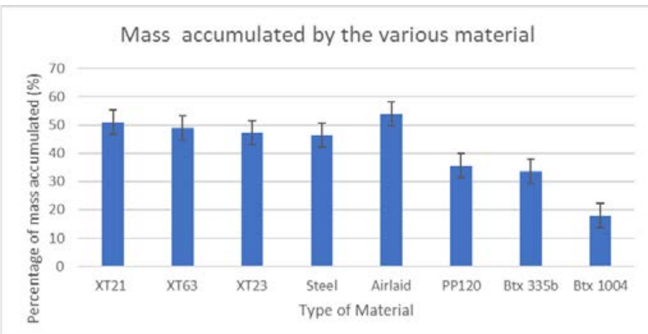

Figure 5: Accumulated mass vs material

From Figure 5, it can be understood that air laid polyester traps the most solid contents for equal digestate amount of 10ml. The 30 µm filtering materials follow air laid polyester in the order following order: XT21, XT63 and XT23. The next material is steel 60 micron. The bottom three materials in mass accumulation are PP120 followed by Box 335b and the least mass accumulating material being Box 1004.

According to Wegner *et al.*, [40], materials with smaller pore sizes collect more solids than bigger pore sized materials. This trend is true for all materials besides air laid polyester which has the highest mass accumulation, this is due to its spongy appearance and texture which allows for it trap the highest solids. However, air laid polyester has the disadvantage of trapping solids within its layers making it difficult to clean the material or extract the trapped solids. The other materials used do not have this disadvantage besides ease in clogging for the 30 µm materials. Excessively large pore size materials have a disadvantage of passing small particle solids which is a disadvantage if large number of solids are required to be trapped.

Careful considerations of grain size and porosity must be considered when selecting the suitable material for any filtration application. From these results in terms of trapping solids and then extracting them, the steel 60-micron filter material is the most for the application since solids can be easily extracted and it does not require vacuum such as the 30-micron materials. The least favourable material for this investigation's application is air laid polyester since solids are difficult to extract. Box 1004 is also least suitable since it trapped a low number of solids due to its large pore size.

B. Amount of water recycled

The amount of filtrate obtained from using the various filter fibres from 10 ml of digestate gave an indication of the amount of water recycled (see Figure 5). This was imperative since the filtrate fed back into the anaerobic digestion system.

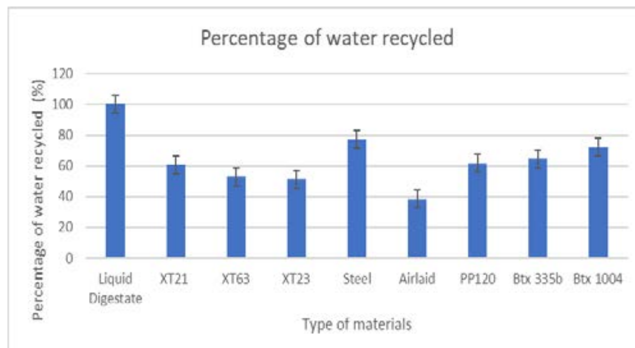

Figure 6: Mass of filtrate vs material used

From the graph shown in Figure 6 raw digestate prior filtration has a mass of 9.73 grams for a 10 ml sample. The use of filtration fibres to trap the solid particles that are required for fertilisers was expected to provide the filtrate with a volume less than that of the raw digestate. The steel 60 microns filter has the highest mass of filtrate at 7.51 grams resulting in 77% water recycling. This material has the largest volume of filtrate recycled, this is due to its non-fibrous nature and it therefore absorbs less water while filtering than its fibrous competitors. The Box 1004 is the second most water recycling material that recycles 72%, the third highest water recycling material is Box 335b which recycles 64% of water.

The least water recycling materials are the vacuum tested material: XT21, XT63 and XT23 which have 30 µm pore sizes. These materials recycled 60%, 53% and 51% water respectively, small pore sizes make it difficult for the filtrate to pass through the material and which results in faster clogging when compared to the larger pore size fibrous materials. The material with the lowest water recycled is air laid polyester at 38%, this is due to it cotton wool like texture resulting in a high-water absorbance.

C. Quality of the water recycled

In the quantity of water recycled section the amount of water recycled was investigated and compared graphically. This was to understand which filtering fibre recycles the largest amount of water and which recycles the least. In this section a further step was taken to understand the composition of the water in the sense of the total diluted solids to determine how much solids are left in the filtrate after filtration. The pH of the digestate and of filtrates was measured to find out if there are any changes introduced by filtration of the various media. Figure 7 shows the total diluted solids in the filtrate after filtration and Figure 8 shows the pH of the resulting filtrates.

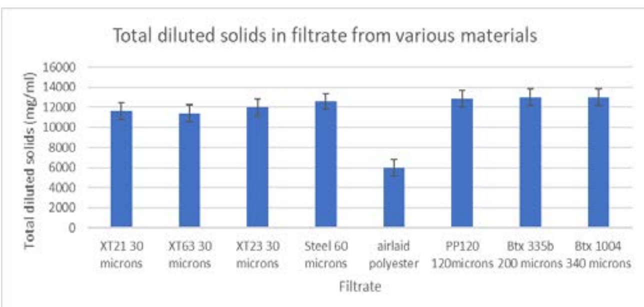

Figure 7: TDS for various filtrates

From the observation, it was expected that the material that trapped the higher amount of solid content will result in filtrate with lower a TDS. In this experiment, this expectation was satisfied as air laid polyester has the lowest TDS. This was caused by the high absorbance and has multiple layers that trap the solids, leading to an extremely low TDS of 6009 mg/ml when compared to the other filtrates. Further filtering fibres with the low TDS are: XT21, XT63 and XT23 having a TDS of 11643 mg/ml, 11423 mg/ml and 12045 mg/ml. These low values of TDS are a result of small pore sizes which allows the materials to remove most of the passing liquid, however clogging occurs quickly. Materials with highest TDS ate steel 60 micron, PP120, Box 335b and Box 1004 these materials have TDS values of 12587 mg/ml, 12871 mg/ml, 12994 mg/ml and 12976 mg/l. This was due to the large grain sizes; these grain sizes allow for small particles to pass through the grains even though they are not as prone to clogging as the 30 µm materials and not as absorbent as air laid polyester.

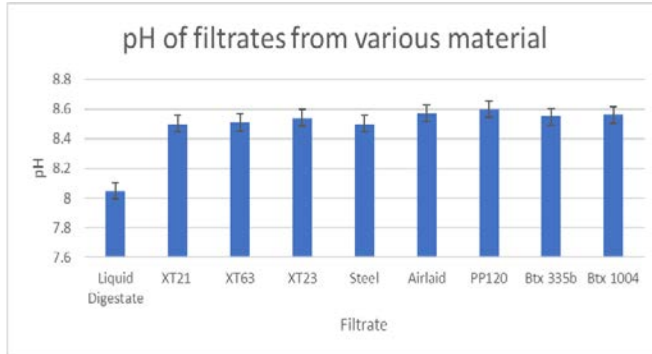

Figure 8: pH of filtrate obtained from filtration fibres

Figure 8 shows the pH of the filtrates obtained from the various materials, the pH was seen to increase by filtration for all filter fibres used, and this was caused by the filtering materials used. It can be understood that through filtration the removal of the solid particles resulted in a slightly more basic solution. This slight increase in pH from 8.05 does not present any hazard, thus the filtrate can be recycled back into the AD system without any harm. The material that results in the highest pH increase is PP120 of 8.6, the second highest is air laid polyester at 8.57 followed by Box 1004 at 8.56. Box 335 has a pH value of 8.55 which is slightly less than that of Box 1004. The material with the least pH is XT23 followed by steel filter 60 microns.

D. The separation efficiency of the materials

The separation index expresses the distribution of a specific compound between solid and liquid fraction is important in filtration techniques since it a performance indicator. The separation index (Et) was expressed as the mass of the solid trapped by the filtering material from the digestate

$$Et(x) = m(x)\ solid/m(x)\ slurry$$

Separation index of the various filtering materials is shown in Figure 9, it can be seen that the values ranges between 0.26 to 0.78%. The highest performing material was determined to be air laid polyester with the separation index of 0.78%, followed by the 30-micron materials. These materials are XT23, XT63 and XT21 that have separation indexes of 0.73 %, 0.70% and 0.68%. Steel 60 micron is the next most efficient material with an efficiency of 0.67%. The third least efficient material was PP120 having an efficiency of 0.51%, followed by Box 335b at 0.48% and the least efficient material is Box 1004 at 0.26%. Figure10 shows the visual comparison of the various material's separation index in terms of the accumulated solid content trapped from mass of liquid digestate.

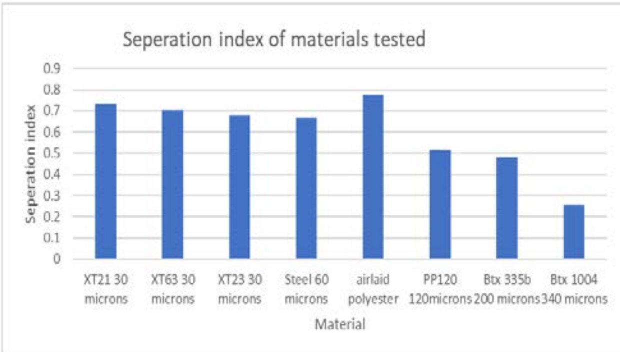

Figure 9: Separation efficiency of tested materials

IV. CONCLUSIONS

From the results, the mass of the solid content in raw digestate was obtained to be 0.14 grams by evaporating the liquid fraction using a furnace. From filtration tests, the material that collected the highest mass of solids was air laid polyester which captured 53.92%, the next most capturing materials are the 30 µm materials: XT21, XT63 and XT23 these materials capture 50.93, 48.93 and 47.36% of solids. The following most capturing material was the Steel 60 µm which captures 46.43% of solids. From the solid content, removal point of view, it was deduced that air laid polyester was the most suitable material. However, it did not satisfy the main goal of this project which was to trap the solids such that they could be reused. This disadvantage was due to the high absorbance and multilayer form, this made the extraction of solids difficult. This left the 30 µm materials and the steel 60-micron material the remaining viable options.

When focus was shifted to the other major requirement of this project which was to recycle a good quantity of water that was sufficiently filtered, it was seen in Figure 7 that 60 µm steel recycles 77.18 % which was the most amount of water. The second most water recycling method was Box 1004 which recycled 72.05% of water. The 30 µm materials recycled between 51 to 60% of water. From the water recycles perspective it was then determined that 60 µm steel material recycled the most amount of water. This was caused by the non-fibrous texture of the material making it absorb the least amount of water. When mass accumulation was compared with water recycling it was concluded that the 60-micron steel is the most suitable material for this project.

In terms of the total diluted solids the 60-micrometre material was found to have a TDS of 12587 mg/ml with an uncertainty of 41.72 mg/ml. This material resulted in the fifth most cleaned water, the top four water cleaning materials were air laid polyester and the 30 µm materials (XT21, XT63 and XT23). These materials have the following disadvantages: air laid polyester was found to be water absorbing while the 30-micron materials clogged easier than the larger pore sized materials. With respect to the pH poly propylene 120 microns and 60-micron steel filter recycled water that had the least increase in pH of 8.5. From the consideration of all tests it was then finally concluded that the 60-micrometre steel filter was the most suitable material for water recycling in an anaerobic digester. The material was found to be well suited for the project since it had desired properties such as corrosion resistance, durability and high strength.

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REFERENCES

[1] T. K. Flesch, R. L. Desjardins and D. Worth, “Fugitive methane emission from an agricultural biodigester,” Biogas and Bioenergy, vol. 35, pp. 3927-3935, 2011.

[2] U. Nations, “Sustainable development goals,” UNPD, 2015.

[3] M. T. Smith, J. L. Goebel and J. N. Blignaut, “The financial and economic feasibillity of rural household digesters,” Waste Management, vol. 34, pp. 352-362, 2014.

[4] E. Owusu-Sekyerea, H. Jordaan and H. Chouchaneb, “Evaluation of water footprint and economic water productivities of dairy products of South Africa,” Ecological indicators, vol. 83, pp. 32-40, 2017.

[5] F. Monnet, An introduction to anaerobic digestion, Scotland: Remade, 2003.

[6] National Non-Food CROPS cENTRE, “NFFC Renewable Fuels and Energy Factsheet,” 22 11 2011. [Online]. Available: htpp://www.nnfcc.com. [Accessed 18 02 2018].

[7] W. Fuchs and B. Drosg, “Assessment of the state of art of technologies for the processing of digestate residue from anaerobic digesters,” Water Science, vol. 67, pp. 1984-1993, 2013.

[8] F. Monlau, “New opportunities for agricultural digestate valorization,” Energy Environment Science, vol. 8, pp. 2600-2621, 2015.

[9] F. A. Shar, Q. Mahmood, Q. Rashid, A. Perves and I. A. Raja, “Co-digestion, pretreatment and digester design for enhanced methanogenesis,” Renewable and sustainable energy reviews, vol. 42, pp. 627-648, 2015.

[10] V. Bansal , V. Tumvesege and J. U. Smith, “Water for small-scale biogas digesters in sub-Saharan Africa,” GCB Bioenergy, vol. 10, pp. 1-18, 2016.

[11] A. O. Nyong and P. S. Kanaroglou, “Domestic water use in semiarid Africa: A case study of Katarko village in northeastern Nigeria,” Human ecology, vol. 27, pp. 537-555, 1999.

[12] G. Cocolo, “Assessment of different solid=-liquid seperation techniques for livestock slurry2,” University of Milan, Milan, 2013.

[13] C. E. Marcato, E. Pinelli, P. Pouech and M. Guiresse, “ Particle size and metal distributions in anaerobically digested pig slurry,” Bioresource Technology, vol. 99, pp. 2340-2348, 2009.

[14] Umited Nations Water, “Waste Water The Untapped Resource,” United Nations Educational, Scientific and Cultural Organization, Paris, 2017.

[15] E. U. Khan and A. Nordberg, “Membrane distilation process for concentration of nutrients and water from digestate rejected water,” Seperation and purification technology, vol. 206, pp. 90-98, 2018.

[16] F. Monlau, C. Sambusiti, E. Ficara, A. Aboulkas, A. Barakat and H. Carrere, “New opportunities for agricultural digestate valorization: current situation and perspectives,” Energy & Environmental Science, 2015.

[17] B. Drosg and W. Fuchs, “Biogas digestate and utilization,” in WIP Renewable Energies, Denmark, Woodhead publishing limited, 2013, pp. 267-270.

[18] B. Drosg, W. Fuchs, T. Al Seadi, M. Madsen and B. Linke, “Nutrient recovery by biogas processing,” IEA Bioenergy, London, 2015.

[19] J. Huang, Y. He, M. Chen, B. Jiang and Y. Huang, “Solar evaporation enhancement by a compound film base on Au@TiO2,” Solar Energy, vol. 155, pp. 1225-1232, 2017.

[20] A. I. Sifat and M. M. Uddin, “Water distilation method using solar power,” in International conference on mechanical engineering and renewable energy , Chittagong, Bangladesh, 2015.

[21] M. Vondra, V. Masa and P. Bobak, “The energy performance of liquid evaporators fpor liquid digestate treatment in biogas plants,” Energy, vol. 146, pp. 141-155, 2018.

[22] M. Ford and R. Flemming, “Mechanical solid-liquid seperation of livestock manure:Literature Review,” Ridgetown college for Omtario Pork, 2002. [Online]. Available: http://mie.esab.upc.es/ms/informacio/residus_ramaders/Separator%20manure.pdf. [Accessed 28 July 2018].

[23] G. Resch, A. Held, T. Faber, T. Panzer, F. Toro and R. Haas, “Potentials and Prospects for Renewable Energies at Global Scale,” Energy Policy, vol. 36, no. 11, pp. 4048-4056, 2008.

[24] N. Mao, “Nonwoven fabric filters,” in Advances in Technical Nonwovens, United Kingdom, Elsevier Ltd., 216, pp. 273-302.

[25] Marlin Steel, “7 Need-to-Know Polypropylene Material Properties,” Marlin Steel Wire Products LLC, 2018. [Online]. Available: https://www.marlinwire.com/blog/7-need-to-know-polypropylene-material-properties. [Accessed 24 August 2018].

[26] Textile Learner, “Polyester Fibre: Characteristics and uses,” Textile Learner, 2018. [Online]. Available: http://textilelearner.blogspot.com/2011/07/polyester-fiber-characteristics-of_11.html?m=1. [Accessed 24 August 2018].

[27] D. Christensen, “Nylon's Properties & Uses,” Sciencing, 16 April 2018. [Online]. Available: https://sciencing.com/nylons-properties-uses-8627049.html. [Accessed 24 August 2018].

[28] Wire Cloth, “Stainless Steel Mesh,” Wire Mesh Manufacturers, [Online]. Available: https://www.wire-cloth,net/stainless-steel-mesh/. [Accessed 25 August 2018].

[29] R. Singh, “Textile Learner,” Airlaid Web Formation Technique, 2018. [Online]. Available: http://textilelearner.blogspot.com/2013/07airlaid-web-formation-technique.html?m=1. [Accessed 25 August 2018].

[30] S. Singh, J. Verma, B. N. Rai and R. S. Singh, “Biodegradation of vapour phase bencene,toulene and xylene (BTX) using compost based modified biofilter medium,” Indian Journal of Biotechnology, vol. 14, pp. 216-220, 2015.

[31] Carbolite Gero, “Laboratory oven range,” Carbolite Gero , [Online]. Available: http://www.carbolite-gero.com. [Accessed 118 August 2018].

[32] Laboratory Testing Inc., “Macroscopic examination macrotech, grain flow, surface condition & more,” Laboratory Testing Inc., 2018. [Online]. Available: https://www.labtesting.com/services/materials-testing/metallurgical-testing/macroscopic-examination/. [Accessed 24 08 2018].

[33] S. Karastogianni, S. T. Girousi and S. Sotiropoulus, “pH: Principles and Measurement,” The Encyclopedia of Food and Health, vol. 4, pp. 333-338, 2016.

[34] Cole-Parmer Scientific Experts, “Thermo Scientific Orion 0520A1 benchtop pH/mV/temperatujre meter, 5200A, 220 VAC,” Cole-Parmer Instrument Company , 2018. [Online]. Available: https://www.coleparmer.com/i/thermo-specific-orion-520a1-benchtop-ph-mvtemperature -meter-model-520a-220-vac/5880805. [Accessed 21 August 2018].

[35] United States Environmental Protection Agency, “Total Solids,” United States Environmental Protection Agency, 06 March 2012. [Online]. Available: https://archive.epa.gov/water/archive/web/html/vms58.html. [Accessed August 24 2018].

[36] D. Q. Nykamp, “Parameter Definition,” Math Insight, [Online]. Available: http://mathinsight.org/definition/parameter. [Accessed 10 August 2018].

[37] Thought Co., “Independent Variable Definition and Example,” ThoughtCo., 23 October 2017. [Online]. Available: https://www.thoughtco.com/definition-of-independent-variable-605238. [Accessed 10 August 2018].

[38] A. M. Helmenstine, “Dependent Variable Definition and Examples,” ThoutCo., 12 April 2018. [Online]. Available: https://www.thoughtco.com/definition-of-dependent-variable-604998. [Accessed 10 August 2018].

[39] M. Lawrence and Y. Jiang, “Bioga-aggregates Based Buiding Porosity, POre Size Distribution, Microstructure,” in Biogas-aggregates Based Buiding Materials, Bath, Sommerset, United Kingdom, Springer, 2017, pp. 3971.

[40] K. Wegner, “Seperations II: Solid-Gas Systems,” in Micro-abd Nanoparticle Technology, Zurich, Swiss Federal Institute of Technology, 2018.

[41] M. Hjorth, K. V. Christensen, M. L. Christensen and S. G. Sommer, “Solid-liquid seperation of animal slurry in theory and in practice,” Argon Sustain Dev, vol. 30, pp. 153-80, 2009.

[42] A. A. Ogunmokun, O. D. Mwandemele and S. J. Dima, “Use of recycled waste water from biogas digesters for vegetable production in the Goreangab Dam Area of Windhoek Municipality. In: 1st WARFSA/WaterNet Symposium, Maputo Mozambique, pp. 1–2.,” 2000. [Online]. Available: http://www.thewaterpage.com/waternet_symposium.html. [Accessed 21 September 2015