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TITLE: STABILIZATION OF BIOWASTE THROUGH A NATURAL DEHYDRATION PROCESS AND THE INTRODUCTION OF THE BIOBIN

TÍTULO: ESTABILIZACIÓN DE RESIDUOS BIOLÓGICOS MEDIANTE PROCESO DE DESHIDRATACIÓN NATURAL E INTRODUCCIÓN DE BIOBIN

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ABSTRACT

Biowaste is an essential raw material for either Waste to Energy recovery or natural fertilizer production. Due to its structural instability; handling, and storage of biowaste is challenging, especially when it comes to prolonged storage and transportation. Freezing or drying of wet biowaste at source is the optimal method to retain physical and chemical structure of biomass. The currently applied energy intensive process shrinks the interest of applying these methods at the source of biowaste generation (i.e., small kitchens, Homes, and offices). This provokes the need for a device that facilitates biowaste stabilization at low energy demands and relatively lower purchase and operational costs. Biowaste is introduced into the waste-bins of the source of generation at a very early stage (i.e., before decomposition). However, it is easier to dehydrate the wet-biowaste at room temperature with small current of air circulation under controlled conditions. The following description is a short insight to a new concept of a domestic dehydrator (BioBin) dedicated to biowaste stabilization through dehydration. The present article has as **fundamental objectives**, to present the results of the evaluation of an experiment at a domestic scale of the drying of household waste, and from the results achieved in the evaluations at a domestic scale to propose a container called BioBin that could be generalized for drying of biological waste, mainly fruit and vegetable remains in the kitchens, in city homes.

Keywords: biowaste stabilization; waste management; waste to energy; BioBin.

RESUMEN

Los residuos biológicos son una materia prima esencial para la recuperación de residuos en energía o la producción de fertilizantes naturales. Debido a su inestabilidad estructural, el manejo y almacenamiento de residuos biológicos es un desafío, especialmente cuando se trata de almacenamiento y transporte prolongados. La congelación o el secado de los residuos biológicos húmedos en la fuente es el método óptimo para retener la estructura física y química de la biomasa. El proceso intensivo en energía que se aplica actualmente reduce el interés de aplicar estos métodos en la fuente de generación de residuos biológicos (es decir, cocinas pequeñas, hogares y oficinas). Esto provoca la necesidad de un dispositivo que facilite la estabilización de residuos biológicos con bajas demandas de energía y costos operativos y de compra relativamente más bajos. En la fuente de generación, los desechos biológicos se introducen en los contenedores de basura en una etapa muy temprana (es decir, antes de la descomposición). Sin embargo, es más fácil deshidratar los residuos biológicos húmedos a temperatura ambiente con una pequeña corriente de circulación de aire en condiciones controladas. La siguiente descripción es una breve introducción de un nuevo concepto de deshidratador doméstico (BioBin) dedicado a la estabilización de residuos biológicos mediante la deshidratación. El presente artículo tiene entre sus objetivos principales presentar los resultados derivados de la evaluación de un experimento llevado a cabo a escala doméstica sobre el proceso de secado de residuos del hogar, y a partir de los resultados alcanzados en esta escala, proponer un recipiente llamado BioBin cuyo uso se puede generalizar para el secado de residuos biológicos, principalmente restos de frutas y vegetales en las cocinas de los hogares de las ciudades.

Palabras clave: estabilización de residuos biológicos; gestión de residuos; residuos a energía; BioBin.

INTRODUCTION

Biowaste is the most prominent dual-purpose form of resource that is available in the modern world for either sustainable energy generation or mineral recovery for the soil. Inefficient techniques in handling biowaste make utilization difficult. Currently, the most largely practiced method is to enclose all kind of waste into a single plastic container or bag. At present, also in past, waste from urban regions (Municipal solid waste (MSW)) is among the most prominent issues faced. According to (Hoornweg, & Bhada-Tata, 2012), in the urban world, the waste statistics reflect to 1,2 kg pp-1d-1 with a population around 3 billion residents in urban regions and this numbers are expected to shoot up to 1,42 kg pp-1d-1 with an increased amount of residents (up to 4,3 billion) by 2025. This implies not only non-biodegradable material but also biodegradable biowaste (aprox. 50%) (European-Commission, 2020). This composition of biodegradable matter in large quantities (central waste bins, residential waste collection points, landfills, for example) undergoes an anaerobic decomposition process and emits methane at destructive rates. Since methane is 28 times more harmful as compared to carbon-di-oxide, it is considered as one of the major components of Green House Gases (GHG), and hence global warming (Zhao, Themelis, Bourtsalas, & McGillis, 2019).

Biowaste or biomass is one of the best sustainable energy sources that can reduce the dependency on fossil fuels and chemical fertilizers (Weiland, 2009). But biowaste containing moisture (wet waste) possesses a negative economic value (Parker, 2018) and the moisture makes the biomass even harder to handle due to its instability. The instable biowaste does not only impose direct emissions or negative environmental costs but also indirect carbon emissions through transportation of such bulky biowaste (Kemp, 2011). The property of unstableness of biowaste is caused solely from the moisture content within and temperature. To overcome this greatest hurdle, two methods are largely adopted to stabilize the biomass, i.e, freezing the biomass to sub-zero temperatures or drying it. Stabilizing the biomass features a great number of advantages, mainly storage, transportation, and handling (Vakalis, Yard, Sotiropoulos, & Xydis, 2019).

When biowaste is burnt or incinerated, wet biowaste decreases its burning efficiency (Verma, Loha, Sinha, & Chatterjee, 2017), hence drying of biowaste is largely incorporated in large scale energy extraction processes. Freezing is done only in special purpose applications such as laboratories for long-term experiments. Biomass drying in general is a very energy intensive process and it needs some special types of methods to reduce energy demand. In industrial applications, due its greatest barrier i.e, heat (over 2000kJ kg-1: latent heat of evaporation for water) the energy demand for drying is at most unavoidable and accounts up to 15% of total energy consumption of the industry itself (Kemp, 2011). This implies also from medium to low capacity dryers, which could be implemented as decentralized solutions.

The idea behind the topic here is to design a production-ready product for residential and partly commercial use. Since biowaste drying in large quantities needs huge temperature ranges, mechanical energy and some drying agents or additives, it is considered as an energy demanding operation. This is also considered a hazardous and unfeasible technique for household use (where waste quantities are relatively small). Although, there are ample household dryers and composters available on the market, the purchase and maintenance costs rockets to 4-digit numbers (Kemp, 2011). In contrast to the operational cost of these machines, it leads to a high valued output i.e., compost or dried biomass. The expectation for recovering the investment is lowered when such system is used in a location where there is no greenery around or limited space for application of generated compost (apartments in urban spaces for example). The limitations also extend for flexibility towards non bio and non-recyclable type of waste streams (scrapes of single use plastics for example).

For this reason, the present article has as **fundamental objectives**, to present the results of the evaluation of an experiment at a domestic scale of the drying of household waste, and from the results achieved in the evaluations at a domestic scale to propose a container called BioBin that could be generalized for the drying of biological waste, mainly fruit and vegetable remains in the kitchens, in city homes.

Limitations. The main limitations of the work are related to the lack of measuring equipment used in the experiments, so the results presented were obtained using organoleptic methods.

DEVELOPMENT

The concept: BioBin

The basic principle considered for biowaste stabilization here is “natural dehydration” instead of forced drying. At the source, biowaste is introduced into the trash-can or waste-bin at very early stages (i.e., before decomposition). After generation, it is easier to dehydrate the biomass at room temperature with a small current of air circulation. This leads to the concept of the BioBin.

The BioBin is a simple dehydrator that uses the natural principle of water flow from a higher potential to lower potential region. Here, biomass is considered as a high potential region and outer atmosphere as the lower potential region. The internal hydrodynamic force exerted due to moisture difference drives water out from the biomass naturally. The BioBin facilitates the acceleration of this naturally occurring process. The BioBin is featured with an absorbent jacket made of recycled paper-based material along with aspiration ports on the body of the bin. These design features are assisted with a combination of heating element and a ventilator, supplying a controlled air stream through external ducts depending on real time sensing data of internal humidity, temperature, and pressure. This real time sensing is integrated for a dual-purpose function: reduction in power consumption and optimization of dehydration.

The focus of the BioBin is to provide a product that consumes little amount of energy to produce rich, dehydrated, structurally stable energy and low weight biomass from wet biowaste that is highly suitable for applications like energy recovery, composting and also landfill, if applicable. The advantages of dehydrated biomass are enormous, being remarkable the handling of such unstable waste. Due to lower operational costs, the output from the BioBin is considered as a low value output (since less energy is spent on biowaste), the waste can be disposed to municipal waste bins for further handling. The dehydrated output from the BioBin also cuts down the disposal frequency helping to significant reduction in use of plastic disposal bags and other resources.

MATERIALS AND METHODS

Experimental work done

Since the prototype of the BioBin is under its creation process, two preliminary test sets were carried out under the room climatic conditions, without any external heating or ventilation. The focus of this experimentation sets is to simulate a conventional biowaste disposal pattern and fractional working conditions inside the BioBin. The test material used for the experiments was partially ripped banana shells. Each test set consisted of two variants; one (test material) packed inside a plastic dispose bag (figure 1) (simulating normal disposal pattern) and the other placed in a pre-assembled paper-based material container (figure 2a and 2b). The two test sets were conducted in different placement positions; in test set one, the open dehydration container was placed directly on the floor (figure 2a) and in test set two, the open dehydration container was placed at an elevated level (figure 2b) and vice versa for the test material packed in plastic bags. These two variants were considered to evaluate the effectiveness of dehydration process. The test duration was presumed to be till the stabilization of biomass and data was logged two times in an interval of approx. 12 hours a day. The logged data consists of the room climate conditions (Temperature, Pressure and Relative Humidity) and Weight of both test samples. Finally, data were tabulared and represented in a line graph to interpret the results with initial input weight.

Figure 1. Biomass packed inside disposable plastic bag (formation of fluids, flies, and odor)

Source: self-made

Figure 2a. Open dehydration container placed on the floor
Source: self-made

Figure 2b. Open dehydration container placed at an elevated distance
Source: self-made

EXPERIMENT RESULTS

The test one and two results were observed until 13.5 and 9 days respectively. The development of possible nuisances was regularly monitored, as well as the presence of flies, odors and fluid. As shown in the graphs (fig. 3 and 4), the end of dehydration process occurred at around day 5 and negligible amount of mass loss was recorded later. In the open dehydration variant, signs of small flies for a short time was observed during test one and disappeared after two days (between 1.5 and 3.5 days), later in the second test no traces of flies were found. However, in both open dehydration tests, no fluids or unpleasant odors were generated throughout the testing period. The weight of the obtained dehydrated biomass was 91.52 and 90.15% less than its initial record. In the same contrast, the obtained product was flammable (as illustrated in the figure 5). On the other hand, a second parallel variant of the test in plastic bags lost only 16.02 and 16.78% of its initial weight, also showing traces of odor and fluids in the plastic bag (see figure 1). This behavior implies directly an anaerobic digestion or decomposition of the biomass. As assumed, the biomass was unstable and prone to all kinds of difficulties that can be seen in conventional waste disposal practice. Whereas open dehydration process provided a proof of the advantages of dehydrated biomass, after the dehydration process, the retained biomass showed its lignocellulose properties for a prolonged time.

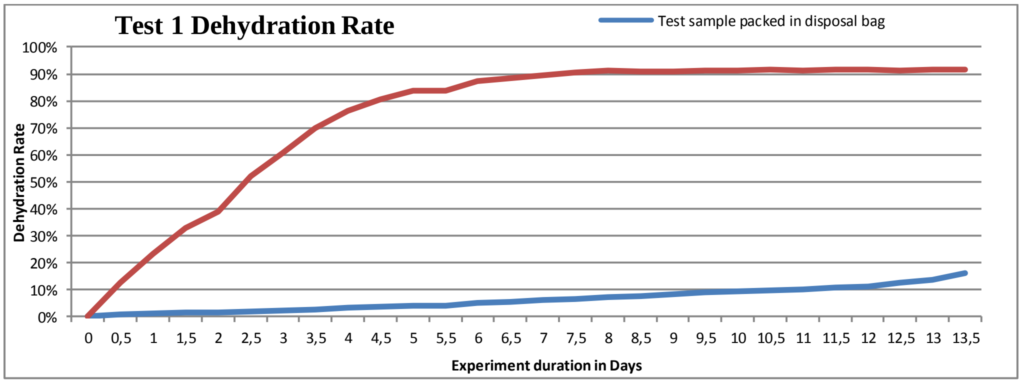

Figure 3. Comparison between open dehydration and enclosed storage of biomass Test-1

Source: self-made

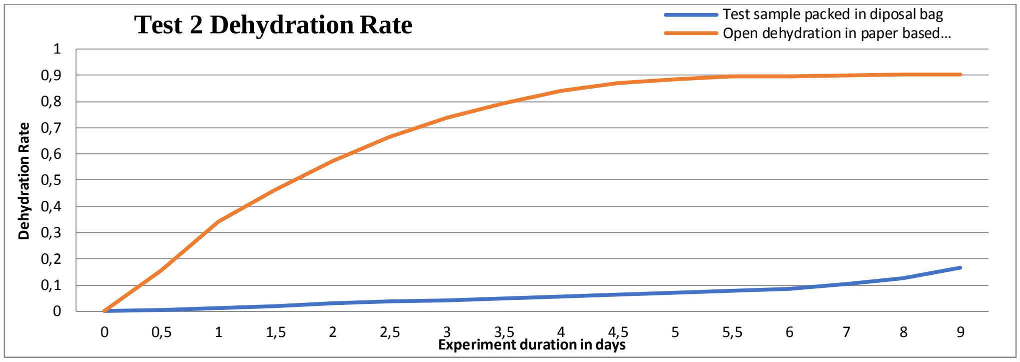

Figure 4. Comparison between open dehydration with enclosed storage of biomass Test-2

Source: self-made

Figure 5. Flammability test

Source: self-made

Proposal of the BioBin container for domestic waste drying

Problems associated with biowaste

Although biowaste is a sustainable resource, the uncontrollable degradation process makes it highly unstable. This is an alarming problem when the waste is subjected to storage. Additional additives are required to control or stop the degradation process.

The degradation (Anaerobic Digestion) process releases flammable gas but also undesirable odors, acids, and pathogens. When the degradation occurs in a non-concealed environment (dustbins and landfills for example), handling this type of waste will get more challenging.

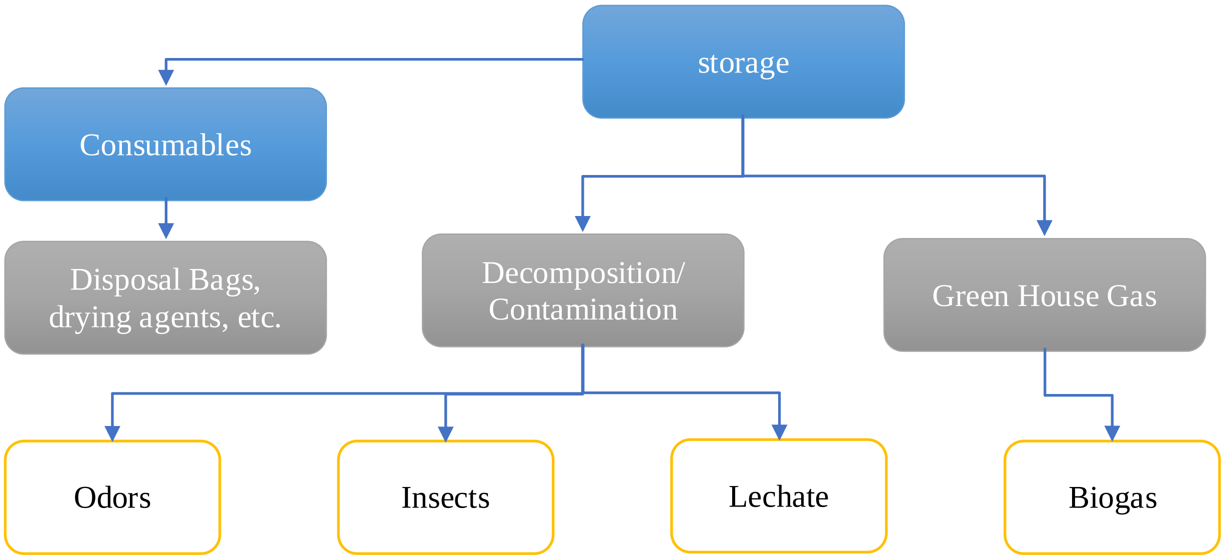

Figure 6. Problems associated with Biowaste

Source: self-made

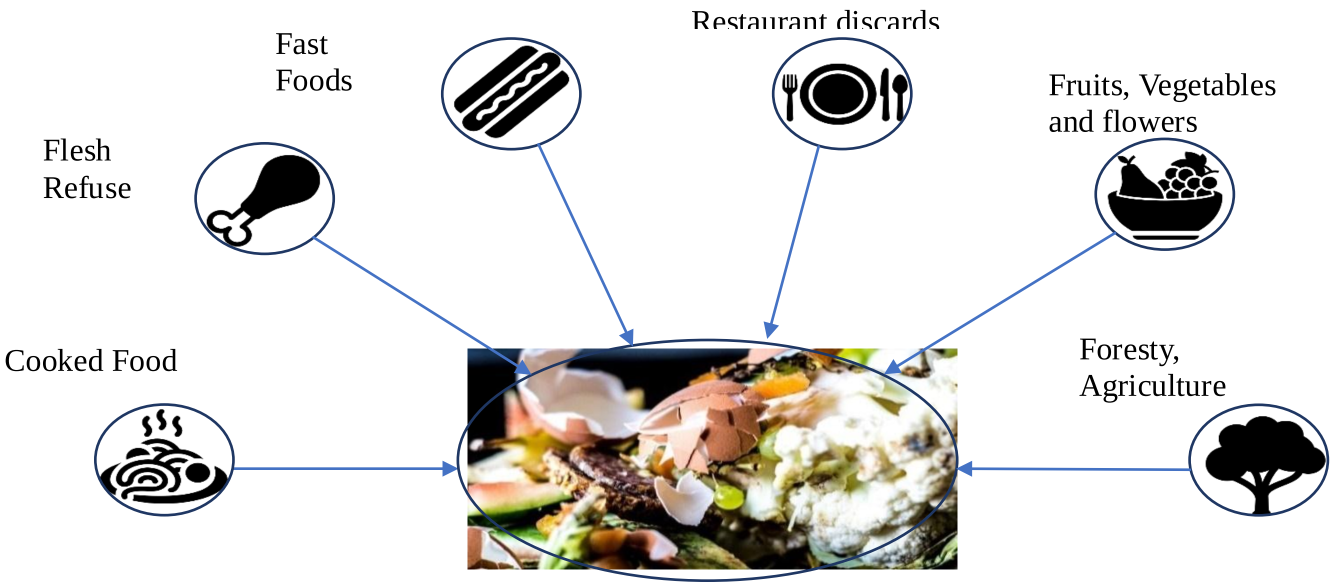

Figure 7. Categories of Biowaste

Source: self-made

Biowaste is an unused/unusable/ discarded organic matter from either a homogeneous or a combination of the above-mentioned categories. The focus of the BioBin is explicit on the waste portion that is generated in urban regions.

Biowaste is in turn considered as a sustainable resource by which energy and minerals could be extracted at the same time. Biowaste derived fuels are often storable and transportable in simple tanks or national gas grid systems (Biodiesel and biogas). Fuels derived from biowaste have the potential of replacing the dependency on fossil fuels and chemicals that are used for fertilizers.

Biowaste as a resource

1. Energy Recovery

2. Mineral Recovery

Figure 8. Biowaste as a resource

Source: self-made

Journey and Vision of the BioBin

- The journey of the BioBin started in 2016 in a vision to develop a product or service to solve one of the biggest problems: waste
- For the next 3 years and until now extensive testing has been done to confirm the functionality of the concept.
- Currently, continuous development on the design is a priority and market research is being conducted to find the potential customers and partners to work with.
- Soon, the BioBin with the required certifications will be launched as the first product of the company.

Needs

- In order to successfully launch the product, a wide variety of perspectives are necessary to interpret the demands and adjust the supply.
- Expert criteria on the topic are needed to refine the concept and develop a system with minimal chances of failure.
- Since the product is expected to enter the market, a multiple testing process is necessary to predict its functionalities.
- Financial interpretations are to be structured.
- An interdisciplinary team.
- The key entity-"Funding"

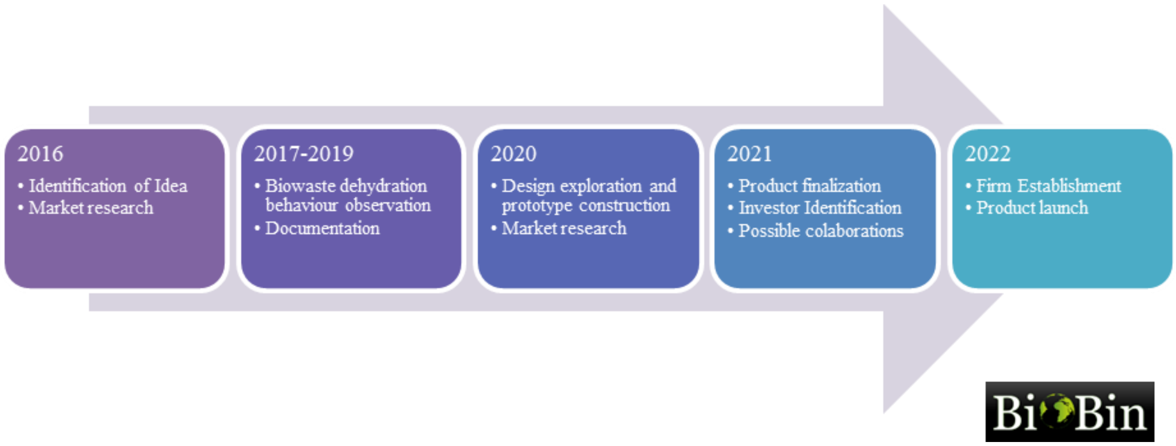

Figure 9. Journey and goals

Source: self-made

All efforts dedicated to improving waste management from the source will contribute to achieving the sustainable development goals of the 2030 agenda. Since the proper management of waste, specifically biological reduces the possibilities of water contamination; contributes to the generation of clean energy, to the creation of jobs, to a more sustainable management of cities, to a responsible consumption and to avoid the effects of climate change and therefore, to ensure aquifer and terrestrial life.

Figure 10. Possible sectors to contribute to

Source: Sustainability Goals UN

Based on international trends and experiments carried out by the authors on a domestic scale, a simple design of the BioBin is proposed. It can be placed in the kitchen for drying fruit, vegetable and other residues of biological origin.

The functionality of the BioBin is based on dehydration through a heated air circulation method. Figure 11 is a brief representation of a pilot model that is in construction. The system has been designed to work under a high moisture content environment but also restricted to dehydrate liquids. Hence, an overflow reservoir or bin is provided to collect excessive run-off fluids. The dehydration process is initially accelerated from heat and air circulation. Nevertheless, most of the dehydration depends on an absorbent jacket (that is made of a high porous structure with recycled paper-based material). Ventilation ports are provided all over the inner and outer wall surface of the BioBin body to ease the moisture flow to the outer atmosphere. A portion of the exhaust air from the bin is re-circulated back into the system to reduce energy consumption of the system and noise of the ventilator. The entire process will be controlled actively via an electronic circuit that drives the heater and blower depending on real time sensing information.

Assumed operative conditions of the BioBin

Over 3 years of extensive observations on the behavior of biomass and biowaste dehydration process, the following operating conditions are considered for the design of the BioBin. The operational temperature was considered to be at around 45-50oC with an airflow rate of around <60 l/min but the parameters are yet to be decided after pilot device experimentation. The temperature ranges are also selected in relation to the flexibility when using the Biobin for non-biowaste as well. The flow of air through the input biomass is also of paramount importance to minimize generation of flies inside the bin. Integration of real-time humidity and a temperature sensing system are also under construction process to optimize the power consumption. Two variants of the design are in process, to provide a version where photovoltaic cell provides additional energy for the device. In order to increase the usefulness of the BioBin, no additives were included in the design. However, an external absorption jacket was designed and integrated into the BioBin to enhance the natural dehydration process.

The BioBin outline:

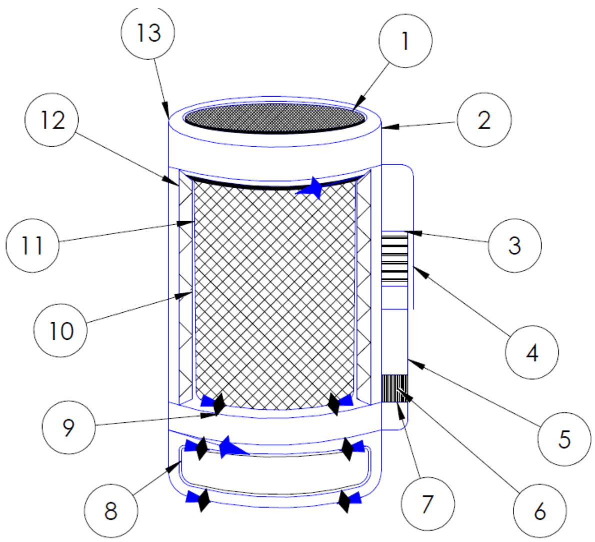

Figure 11. Basic outline of the BioBin pilot model

Source: self-made

Component list:

1. Lid with integrated carbon-filter
2. Top cover with exhaust air recirculation
3. Blower
4. Outflow air duct
5. Inflow air duct
6. Heating element

7. Heat exchanger
8. Fluid overflow bin
9. Air clearance
10. Absorbent jacket
11. Mesh-based bucket
12. Vents
13. Power management system

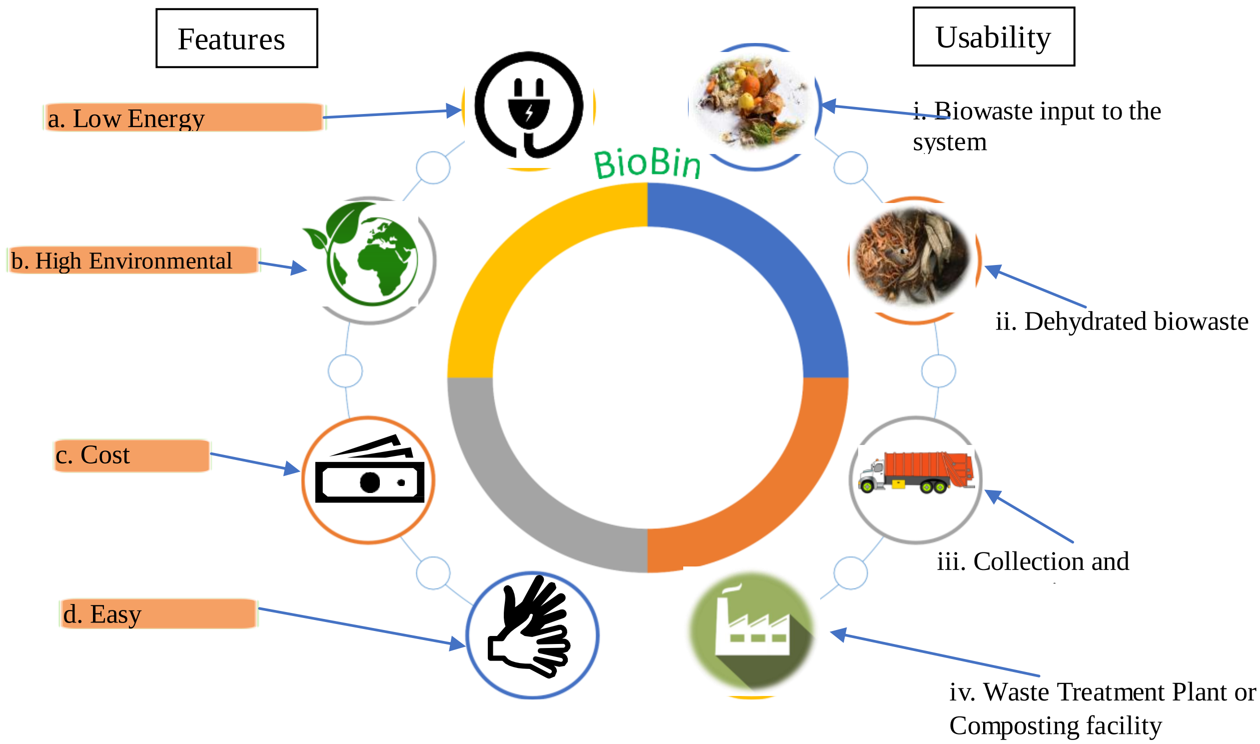

Figure 12. The BioBin features and usefulness

Source: self-made

The BioBin is an ordinary waste bin if analyzed in general terms, but the difference lies in its inner functional peculiarities. The BioBin design incorporates the natural dehydration principle along with a smart control system for biowaste stabilization.

Features:

a. Low Energy Consumption

i. The system is designed to run at very low temperature elevations (~45 °C)

ii. Power required for the operation is sketched within 40W el..

iii. Option to substitute the energy demand with a Photovoltaic module is available.

iv. Active monitoring of the internal climate makes the system more efficient.

b. High Environmental Benefits

i. Elimination of Green House Gases, odors, flies, and overflow fluids through dehydration process is possible.

ii. Harnessing dehydrated biomass as a bio-energy resource as well as the gross energy yield will be enhanced.

iii. Dehydrated biowaste can be stored and used as a raw material in the end. Thus, the necessity of landfills can also be avoided.

c. Cost Effective

i. Low cost device.

ii. Since operating conditions are held at the lowest possible energy demands, costs involved in processing waste are negligible.

iii. With a Photovoltaic module, it is possible to cut down energy cost up to 50%

d. Easy Maintenance

i. The low operative conditions facilitate flexibility to use the BioBin in different living spaces.

ii. The modular design provides easy maintenance.

iii. The nuisance free-dehydrated biowaste provides hassle free handling of biowaste

Social Impact

- ✓ The dehydrated biowaste is inert in nature that does not support pathogen formation. Therefore, biowaste do not decomposes in a short period. Thus, disposal frequency can be shortened.
- ✓ Dehydrated biowaste can be stored for a long term, likewise plastic or paper.
- ✓ The health condition of waste handling, waste disposal personnel and public, can be safeguarded.
- ✓ Less resources such as plastic or paper bags are required to dispose biowaste.

- ✓ The efficiency of Waste to Energy plants can be enhanced by utilizing dehydrated biowaste. Thus, producing higher energy from the biowaste.
- ✓ Nuisance and fluid overflow from open dumping and landfill can be eliminated.
- ✓ In recycling process less effort and resources such as water, cleaning agents are required for sorting and cleaning the valued material.
- ✓ The BioBin provides the greatest opportunity to separate waste categories efficiently at home.

Process Flow or Usefulness:

e. Biowaste Input to the System

i. Biowaste contains upto 90% of water in its total mass is disposed into the BioBin.

ii. Controlled heat and air will be supplied to remove moisture from biowaste.

iii. The process continues until the moisture level inside the BioBin reaches a preset safe level.

f. Dehydrated Biowaste

i. At this point biowaste contains water under 20% in its total mass and is ready to be disposed, stored or processed.

ii. The dehydrated inert biomass can now be either stored until the dispose bag fills or used for any other future needs.

g. Handling and Transportation

i. The light weight-dehydrated-biowaste makes handling easy and favors the reduction in specific fuel consumption for transport.

ii. Since there is almost no decomposition happening, there will also be no odor, fluids, and insects around the waste heap; it is easier to handle the waste at the collection points and disposal at the end as well.

iii. Separation of valuable resources like recycling material will be much easier and comfortable.

h. Energy recovery or fertilizer production

i. Well suited for storing longer periods without any major decomposition problem.

ii. No application of additives, therefore the physical and chemical properties of the biomass are retained.

iii. Biogas yield or fertilizer quality are not compromised.

iv. When incinerating there is no necessity for additional drying process.

v. Hindering of pathogen formation helps avoiding decomposition and hence the energy content of the biomass will be maintained.

CONCLUSIONS

The comparison between the final product from open dehydration and the plastic bag with packed biomass illustrates a high potential for a sustainable biowaste management perspective. Since there is a high-energy demand for the drying of biowaste, the loss of total energy yield is immense. In the described concept, removal of moisture from the biomass is held at relatively low temperatures; hence, the energy input is lower. When observing the results, in the second experiment set, dehydration time was shortened compared to the first set. Here, the pre-formed paper container with test material was placed at elevated positions, which lead to a micro flow of air throughout the container.

This approach can facilitate the development of an easy- to- use product "BioBin", which can be used at a household level or in low biowaste generating places (office spaces for example). The advantages of handling dehydrated biowaste in comparison to wet unstable waste are immense. This ensures also healthy living conditions of the waste disposal personnel.

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