Paper Mill Sludge Volume Reduction by Vermicomposting

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public health and safety,
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Abstract

Paper mill sludge (PMS) is a solid by-product of paper-making process and produced in large quantities as waste. In this study, the volume of the PMS is aimed to be reduced by using vermicomposting process. This vermicompost process reduces the organic constituent's ratio of this waste and the volume reduction is analyzed by feeding in two forms namely raw and sterilized. Test beds with six compositions of samples are with a base of 30 Grams of earthworm soil having five numbers of Lumbricus terrestris, a deep-burrowing anecic earthworms. It is observed that digestion with fruit peel,cow-dung, sterilized paper mill ,Earthworm and Earthworm soil .sludge rate at samples is having maximum digestions of 20 percentage,

1.Introduction

Bajpai, P. et al. [1] discusses the various types of sludge generated by pulp and paper mills, which collectively constitute paper mill sludge (PMS), a secondary waste of the paper industry. Ahmadi & Al-Khaja (2001) [2] also illustrated the challenges associated with PMS disposal and provided detailed explanations of various techniques for its management. According to the findings of Quaye et al. [3], it is recommended to carbonize PMS under optimal conditions before blending it with an appropriate amount of soil for increased agricultural yield, eliminating the need for supplementary minerals. In their study, Likon & Trebˇse [4] examined different strategies for efficiently utilizing PMS. They empHasized the importance of considering the economic aspects when implementing waste management procedures. Monosi et al. [5] innovated lightweight ash derived from de-inking sludge, demonstrating its efficacy as an improved binder material. Pitroda et al. [6] utilized hypo sludge from paper mill industries in concrete mix production, assessing

concrete's compressive and split strengths across different hypo sludge proportions. Buruberri et al. [7] produced beatific and Portland clinkers by utilizing industrial wastes from paper pulp. Cupido et al. [8] detailed the pHysicochemical characteristics of binary clay and paper sludge mixtures. Azrizal et al. [9] examined the pHysical, chemical, and reactive attributes of ash derived from PMS, concluding its suitability for various building industry applications, including bricks, concrete, and more. Baneviˇciene et al. [10] subjected PMS to a temperature of 900°C, assessing its influence on the pHysical-mechanical properties of the cementitious matrix and exploring its potential applications in cementitious materials. Astrauskas & Grubliauskas (2020) [11] created composite panels utilizing PMS and clay as the binding agent, specifically designed for sound absorption purposes. Their findings suggested that the sound absorption coefficient is contingent upon the density of PMS. In a recent report by Haile et al. [12], it was revealed that PMS can be utilized to produce a range of value-added materials, including carbon fiber, bioplastic, fibers, and eco-friendly composites. Soucy et al. [13] pioneered the creation of wood-plastic composites by incorporating paper mill sludge. Their research focused on examining how the inclusion of paper mill sludge affected the pHysical and mechanical characteristics of high-density polyethylene (HDPE). Jele et al. [14] discussed the diverse array of products derived from three distinct types of pulp and paper mill sludge materials. Abushammala et al. [15] have recently generated a range of energy and high-value materials from paper waste materials. Healthcare-associated infections (HAIs) refer to infections that develop in patients within a hospital or other healthcare facility, which were not present or in the incubation stage at the time of admission [16]. Surgical site infection (SSI) stands as the most common healthcare-associated infection (HAI) in developing nations, with occurrences ranging from 1.2% to 23.6% of procedures between 1995 and 2010, compared to a notably lower incidence of 1.2% to 5.2% in developed countries [17]. Furthermore, the incidence of hospital-acquired neonatal infections in developing countries has been documented to be 3-20 times greater than that in developed nations [18]. DipHtheroids, Bacillus species, Gram-negative rods, fungi, and yeasts have been documented in studies [19-23]. Globally, the reporting of healthcare-associated infections (HAIs) linked to medical devices is notably inadequate, with relatively few examinations conducted on device-associated infections [24].Autoclaving stands as the predominant method for sterilization worldwide, renowned for its robustness and cost-effectiveness in ensuring the sterility of medical devices [25,26].Biological indicators are widely recognized as the most reliable means of monitoring sterilization effectiveness [27,28]. These indicators rely on microorganisms, such as Geobacillus stearothermopHilus spores, which are rendered inactive at the standard autoclave temperature of 121°C. During sterilization, Following the completion of the sterilization cycle, the indicator is removed and incubated in a culture medium optimized for the growth of the indicator organism. If growth occurs, it signifies an ineffective sterilization cycle, rendering the medical devices unsterile as well.Organic vermicompost, rich in various enzymes, stimulates microbial activity, consequently augmenting microbial biomass within the soil [29]. Certain foods and household waste are preferred by worms and do not harm them, such as cardboard and various dye-free leaves, which serve as essential bedding material and a carbon source. Additionally, dry and green tree leaves, vegetable and fruit peels including cucumbers, potatoes, lettuce, apples, bananas, melons, squash, carrots, eggplant, strawberries, and eggshells, as well as grains like oats, rice, and corn, are suitable for vermicomposting. Kitchen waste, except for citrus, onions, and garlic, can also be utilized.The vermicompost is the result of worms consuming and

excreting organic waste [30,31,32]. The findings revealed that the vermicomposting process led to an increase in pHospHorus (31.38-55.89%) and potassium (33.40-63.15%) concentrations, accompanied by a decrease in total organic carbon (38.24-43.49%) and total nitrogen (9.01-32.52%). Additionally, there was a notable rise in earthworm growth rate. Rice straw and kitchen waste were identified as suitable feed materials for worms due to the expedited vermicompost production process, resulting in a reduced C/N ratio and increased nutrient content compared to the initial material. [33]. In another experiment, containers were set up and populated with worms, followed by the addition of paper waste, sludge, and regular compost. Measurements of pH, electrical conductivity (Ec), C/N ratio, total nitrogen, available pHospHorus, total potassium, and total calcium were taken before and after the conversion of materials into vermicompost by earthworms. The results demonstrated a decrease in pH, Ec, and C/N ratio to 6.01, 1.89 dSm-1, and 10 respectively, while concentrations of total nitrogen, available pHospHorus, total potassium, and total calcium were recorded as 1.8%, 284.4mgkg-1, 242.7mgkg-1, and 0.034% respectively [34].

2.Materials Required: The primary material utilized in the project is Paper Mill Sludge (PMS), a waste by-product generated in the paper industry. This sludge is typically in a semi-solid state and contains moisture. Sourced from Sri Krishna Paper Mills in Sivakasi, Tamilnadu, India, the sludge underwent sun drying to eliminate its moisture content. Subsequently, the dried sludge was finely powdered using a mixer, and the resulting powdered paper mill sludge was employed in the project's processes.

3Method: The PMS undergoes autoclaving at standard operating conditions, including temperature, pressure, and duration, to ensure effective eradication of pathogens while preserving the organic integrity of the waste material. The effectiveness of autoclaving is assessed through microbial load analysis, which encompasses the overall bacterial count and the presence of indicator species. Furthermore, a nutritional analysis is conducted to evaluate the retention of essential nutrients in the sterilized PMS.

After sterilization, the sterilized PMS is inoculated with composting earthworms to facilitate vermicomposting. The rate of decomposition, earthworm activity, and nutrient dynamics throughout the vermicomposting process are continuously monitored. Control tests using untreated PMS are carried out to assess the efficacy of vermicomposting with sterilized and unsterilized PMS.

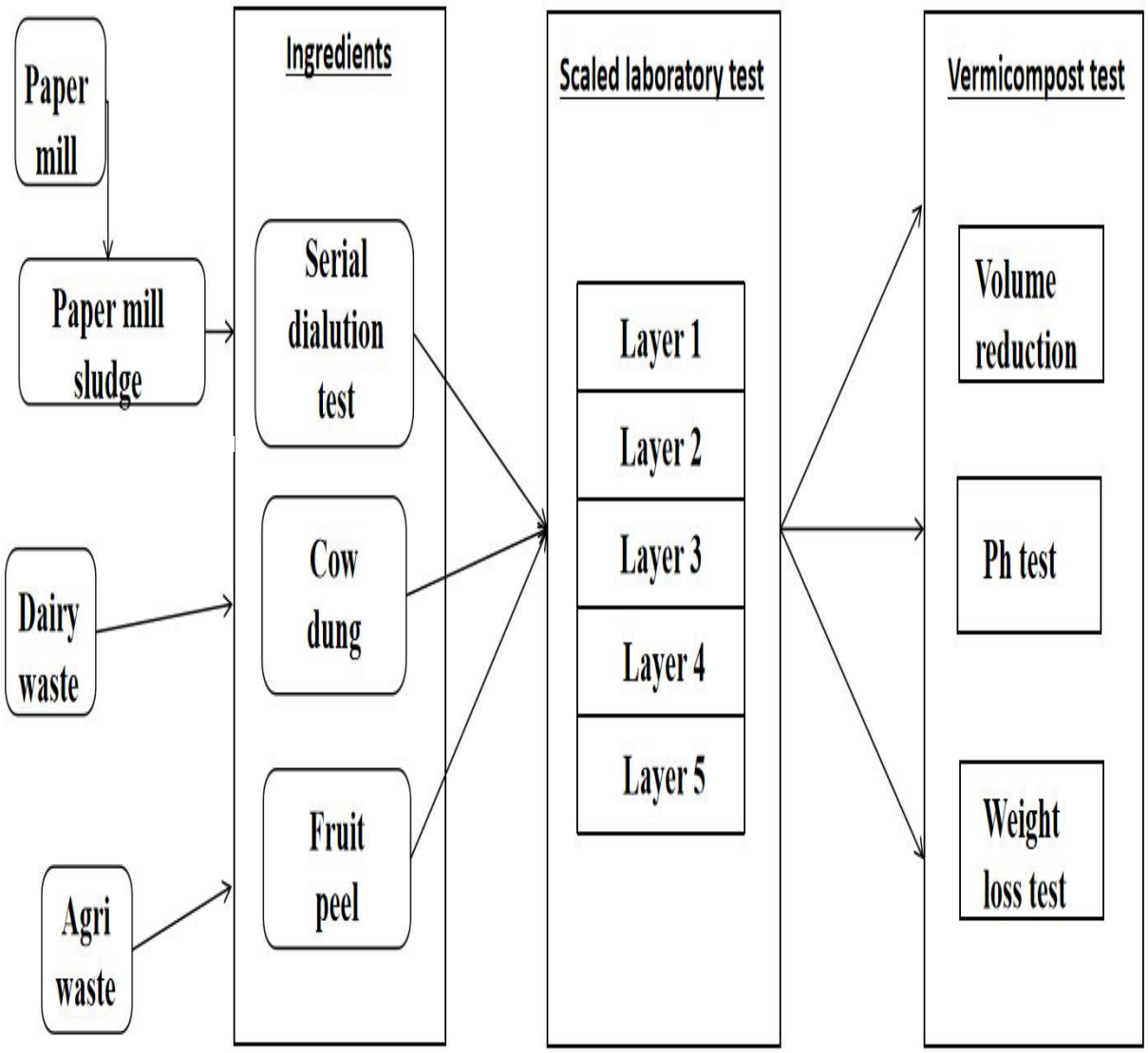

Fig No .1Process Flowchart

to remove the organic components from the sludge we are going to do a vermicomposting process For doing the vaccine we are collecting the earthworms that must be 0.5 to 1 kg per meter square or in the ratio of 1:1 or 1:3. To do very composition in a faster manner you are going to try sterilization the sterilization process not only kills the microbes in this condition yet also going to breakdown the complex glucose structures into simple glucose so that it helps the digestion process and makes use for quick results. For this we are going to use the process of autoclaving which uses a stream at 121 degrees Celsius of 1.023 bar this autoclaving is done for about 20 minutes and we have fabricated a boiler that makes the specification that is required for the autoclave. For doing proper autoclaving the device must have a Teflon coating of at least 3 MM within the autoclave region To prevent microbial growth in that region

4. methodology: The paper sludge waste from the Sri Krishna Paper Mills in Sivakasi, Tamilnadu, India.The paper sludge is separated into two half's one half is left untreated the another half undergoes treatment process, this treatment process involves adding 5 parts of water to 1 part of sludge in 1:5 ratio.then this mixture is heated to 121 degree celcius for a period of 30 minutes, after that this is let to cooled for some period of time.Then the cow dung from the dairy industry is collected and let to be dried in sun for required time to form cow dung cakes.Then fruit peel on form of agro waste especially banana peels are collected and chopped taken.Six 250 ml glass beakers are taken.Each samples are then put in their beaker in their respected compositions

5.Materials Required: Thermal hydrolysis breaks down complex organic compounds in sludge into smaller, biodegradable ones. This procedure increases the biodegradability of the sludge and makes following treatment processes easier.

5**.1 Characteristics of PMS:**Below are descriptions of the different tests conducted to characterize the paper mill sludge (PMS).

5.1.1Serial dilution Test: Serial dilution testing is the systematic assessment of a system's or process's scalability or robustness by serial expansions or adjustments, with the goal of understanding its performance at various pHases of development or deployment. This approach enables researchers to discover possible bottlenecks, assess the efficacy of scaling solutions, and optimize the system for increased performance and dependability.

5.1.2Volume Reduction Test: A volume reduction test determines how much a material, such as paper mill sludge, can be decreased using various treatment techniques, such as de-watering or compaction. This test determines the efficiency of volume reduction approaches in handling and disposing of waste items more efficiently.

Table 2 sample composition

Sn.No	Contents				
	N.O.W	Soil (in grams)	Sludge (in grams)	Cow Dung (in grams)	Fruit Peel (in grams)
1	5	30+60	30	-	-
2	5	30+30	30	30	-
3	5	30	30	30	30

N.O.W = Number of Earthworms

5.1.3 Weight Loss Test: The weight loss analysis is performed with the objective of quantifying the reduction in weight of the waste material subsequent to heating. This analytical procedure serves to ascertain the extent of water evaporation that occurs during the heating process. Furthermore, water is introduced to the PMS in order to achieve dilution and subsequently assess the resultant weight loss.

5**.1.4 pH Test:** In fields such as chemistry, biology, medicine, and environmental studies, researchers frequently conduct pH tests on various solutions like water, soil, and biological fluids. By utilizing a scale ranging from 0 to 14, these tests ascertain whether the solutions are acidic or alkaline A pH level of 7 indicates neutrality, whereas values less than 7 suggest acidity and those more than 7 indicate alkalinity.

6.Preparation: The method we are going to use for the digestion process is vermicompost preparation methodology to make a small-scale setup of six beakers of 250 ml are taken and each beaker is taken to do a separate process first beaker of 250 ml is taken and 30 ml of soil 30 ml of paper mill sludge 60g of soil and 20 g waters added on it. second beaker is taken and it's also filled with 30 g of soil 30 g of paper mill sludge 30 g of cow dung 30gof soil and 20 g of water The third beaker is taken the same with again 30 g of oil 30gof paper mill sludge 30gof cow dung 30 g of fruit pill and 20 g of water added to it these are done for unsterilized paper mills sludge. for sterilizing paper mill sleds and Sludge We are going to design a reactor for the specifications of the Autoclave we need a reactor with an interior Teflon coating of at least 3 mm thickness this must withstand the pressure of one bar at 1 bar pressure or one bar atomic pressure and And it also must withstand the heat of up to 150 degree Celsius because auto claiming is done at degrees of 122 degree Celsius to 132 degrees Celsius.

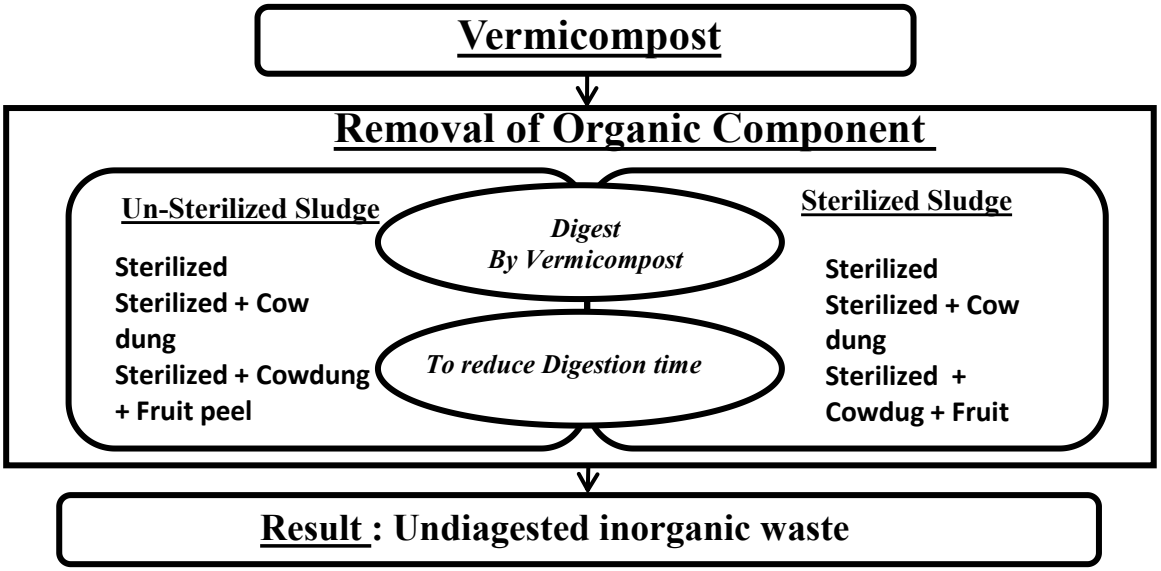

Fig No .2 Vermicompost Flowchart

7.Product testing

7.1Serial dilution testing

Serial dilution testing entails the methodical examination of a system or process's scalability and resilience by means of successive expansions or adjustments, with the objective of evaluating its efficacy across distinct developmental or deployment stages. This technique enables researchers to pinpoint potential constraints, assess the efficacy of scaling strategies, and refine the system to bolster its performance and dependability.In the forthcoming experiment, a pHospHate buffer will serve as the diluent medium. The dilution regimen will encompass dilutions of 10, 10^2, 10^3, 10^4, and 10^5 . Initially, 1 ml of the sample (PMS) will be blended with 9 ml of the pHospHate buffer to yield a 10 ml dilution, which will be meticulously mixed. Subsequently, 1 ml of this tenfold diluted solution will be transposed and amalgamated with 9 ml of buffer to engender a 10^2 dilution. This sequential process will be iteratively executed, with 1 ml from each subsequent dilution being transferred and blended with 9 ml of buffer to engender the subsequent higher dilution, culminating in the targeted 10^5 dilution level. Through this systematic methodology, our objective is to comprehensively scrutinize the scalability and efficacy of the system across various dilution factors, thereby enabling the identification of probable constraints and the optimization of procedures to enhance operational efficiency and reliability.

Table 3 :Serial dilution testing

Sn.No	sample prepared (ml)	no.of.colonies	Buffer (ml)	volume Plated (ml)	CFU/ml
1	10	402	9	1	Too numerous
2	10^2	256	9	1	2.56×10^5
3	10^3	125	9	1	1.25×10^6
4	10	0	9	1	Too less
5	10^2	0	9	1	Too less
6	10^3	0	9	1	Too less

$$\text{CFU} = \frac{\text{Number of Colony} * \text{Total Dilution}}{\text{Volume Plated}}$$

Total Dilution : 10^n ml
Volume Plated : 0.1ml

Fig no. 3 Serial Dilution

7.3Volume Reduction Test

Initially normal paper mill sludge is taken and soil is added to form the SS1 mixture and 5 lumbricus terrestris are added to that mixture and this mixture is monitored.SCS1 consists of sludge,cow dung and soil with 5 lumbricus terrestris.SCFS1 consists of sludge,cow dung,fruit peel and sand with 5 lumbricus terrestris.meanwhile sterilized sludge and soil is added to form the SS2and 5 lumbricus terrestris are added to that mixture and this mixture is monitored .SCS2 consists of sterilized sludge,cow dung and soil with 5 lumbricus SCFS2 consists of sterilized sludge,cow dung,fruit peel and sand with 5 lumbricus terrestris.

Table 5 Vermicomposting digestion laboratory pit

Sample 1

parts	components	quantity
1	earthwormsoil	->60 grams
1	earth worm	->5 worms
1	sludge	->30 grams
1	earthworm soil	->30 grams

Sample 2

parts	components	quantity
2	earthwormsoil	->30 grams
	cow dung	->30 grams
1	earth worm	->5 worms
1	sludge	->30 grams
1	earthwormsoil	->30 grams

Sample 3

parts	components	quantity
2	Fruit peel	->30 grams
	cow dung	->30 grams
1	earth worm	->5 worms
1	sludge	->30 grams
1	earthwormsoil	->30 grams

Sample 4

parts	components	quantity
1	earthwormsoil	->60 grams
1	earth worm	->5 worms
1	Sterilized sludge	->30 grams
1	earthwormsoil	->30 grams

Sample 5

parts	components	quantity
2	earthworm soil	->30 grams
	cow dung	->30 grams
1	earth worm	->5 worms
1	sterilized sludge	->30 grams
1	earthwormsoil	->30 grams

Sample 6

parts	components	quantity
2	Fruit peel	->30 grams
	cow dung	->30 grams
1	earth worm	->5 worms
1	sterilized sludge	->30 grams
1	earthwormsoil	->30 grams

This table no 5 shows us the composition set up of our very own laboratory pit. This Sample 1 consists of 30 Grams of earthworm soil in the base 30 Grams unsterilized paper mill sludge then 5 earth worms are added then 60 Grams of earthworm soil is

put `together to form the sample 1.but the same is done in sample 2 but the top earth worm soil is reduced to 30 Grams but 30 grams of cow-dung replaces the reduced earthworm soil.the sample 3 is similar to sample 2 but the top earthworm soil is totally replaced with fruit peel.This Sample 4 consists of 30 Grams of earthworm soil in the base 30 Grams unsterilized paper mill sludge then 5 earth worms are added then 60 Grams of earthworm soil is put `together to form the sample 4..but the same is done in sample 5 but the top earth worm soil is reduced to 30 Grams but 30 grams of cow-dung replaces the reduced earthworm soil.The sample 6 is similar to sample 2 but the top earthworm soil is totally replaced with fruit peel.

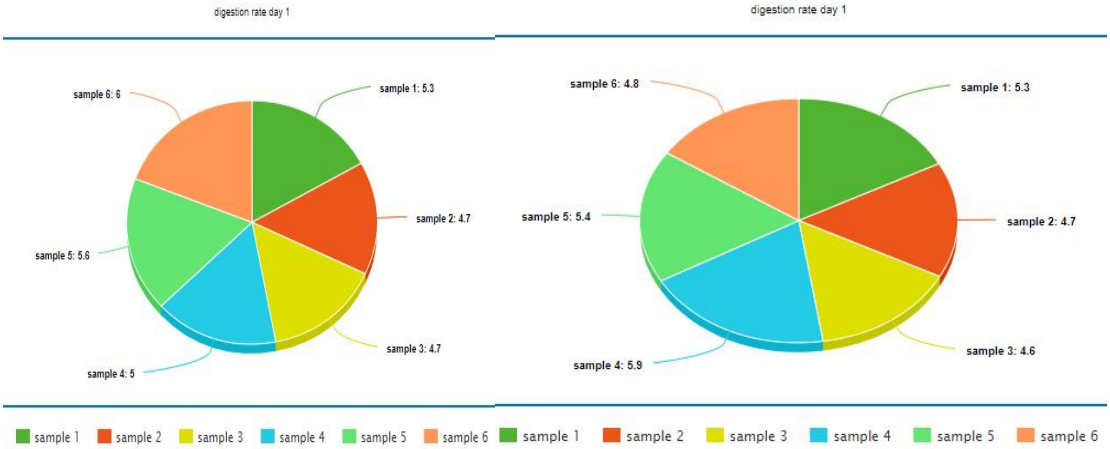

Fig 4 a) day 1&2 digestion rate

This 2 grapHs shows us the inference of the day 1 and day 2 digestion rate of all our laboratory pit samples .graph1 has our initial height of our laboratory pit sample.and graph2 shows us the digestion rate of our sample and the comparative digestion between our sample.

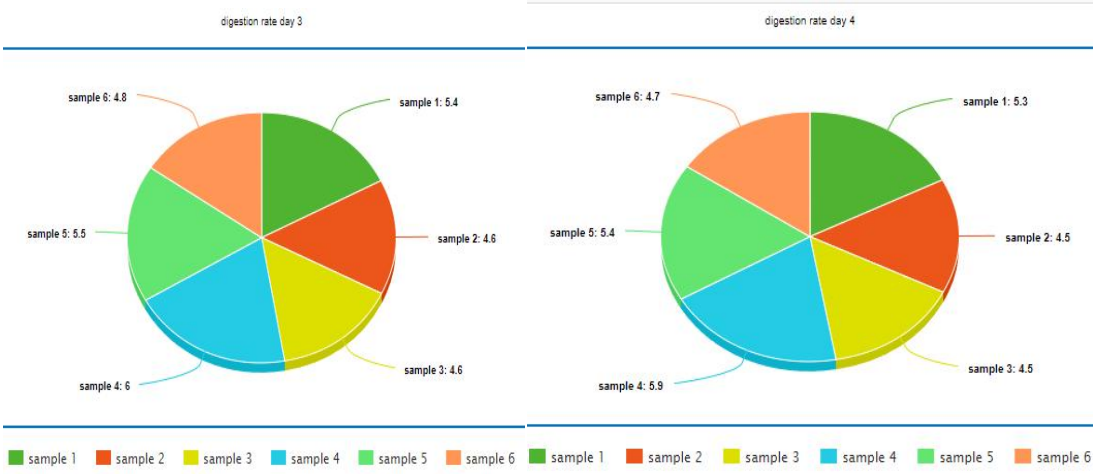

Fig 4 b) day 3&4 digestion rate

This grapHs shows us the digestion rate of our samples at day 3 & day 4 this also shows the comparative digestion rate among our samples .we can see some good rate of digestion from our sample 3,5& 6.

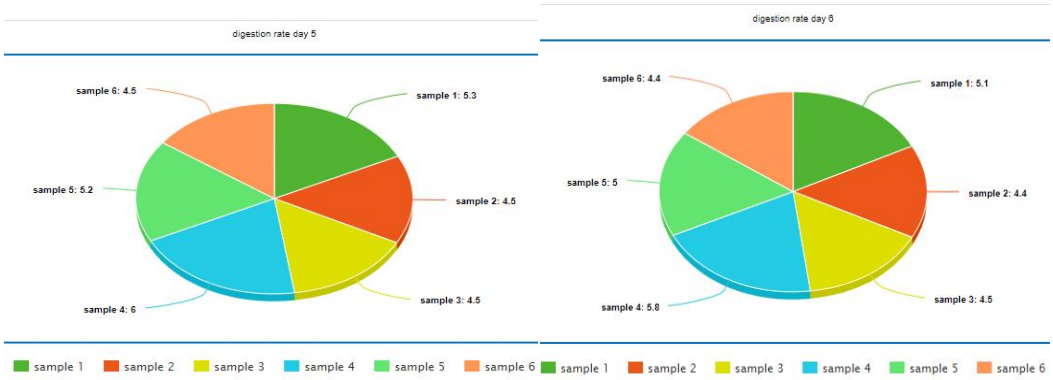

Fig 4c) day 5&6 digestion rate

This graph shows us the interference between the digestion rate on day 5 & day 6 this also shows high difference between our graph1 and graph6 this shows us that the digestion is going in much smother manner.

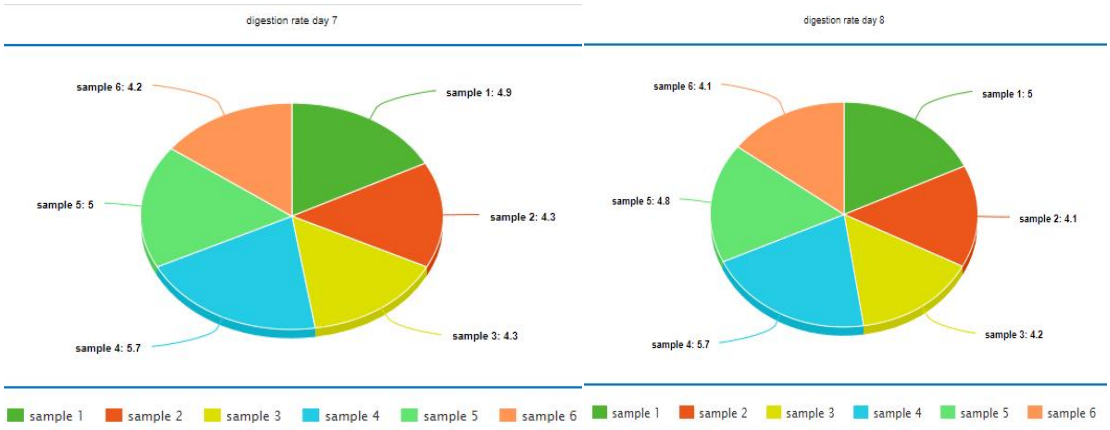

Fig 4 d) day 7&8 digestion rate

This two graphs shows us the rate of digestion on our samples at day 7 & day 8 this shows us greater difference from start this shows us grater digestion rate in our sample 6.

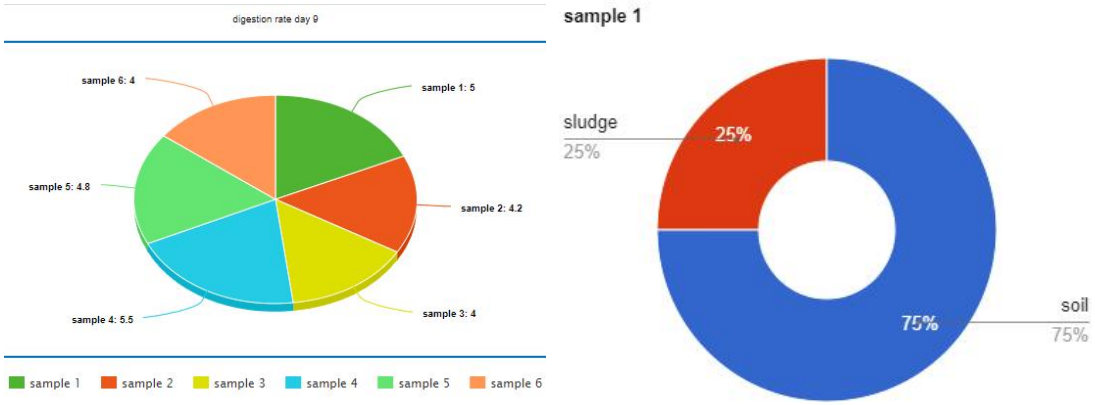

Fig 4 e) day 9digestion rate & sample 1 compositions

This pie chart in left shows us the final record value of our samples at day 9 . This give us required digestion value .This doughnut chart in the right shows us the composition rate of our sample 1.

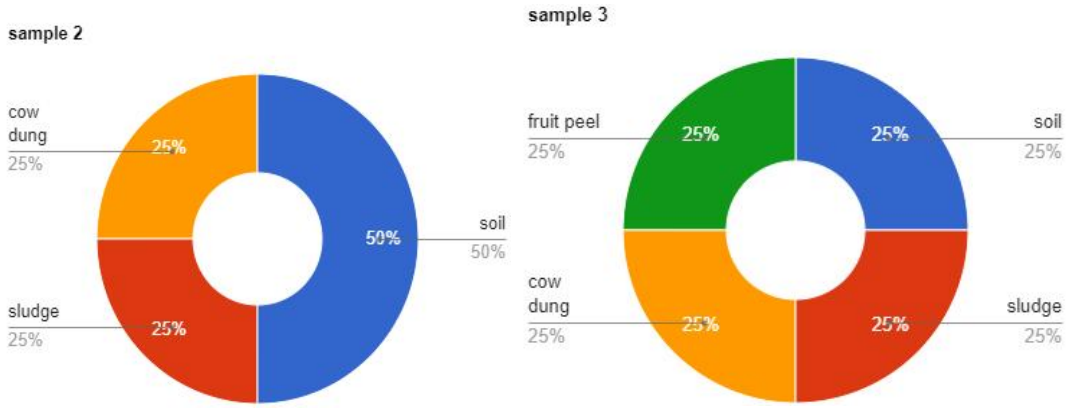

Fig 4 f) sample 2 & 3 compositions

This doughnut chart shows us the composition of our sample 2 & 3 .This tells the percentage ratio of our sample this 25 % repents presence of 30 Grams of the in that composure .

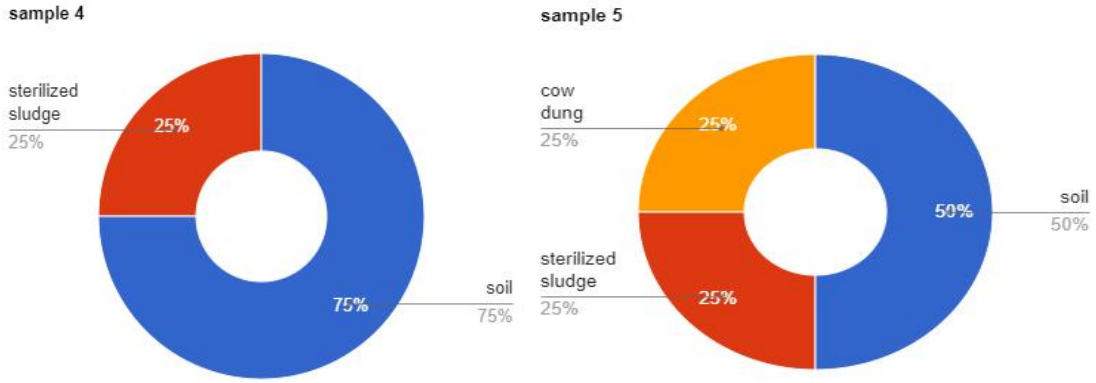

Fig 4 g) sample 4 & 5 compositions

This two doughnut graphs shows us the composition ration of sample 4 & 5 .We can also see that this is much similar to the sample 1 & 2 but the sludge content of sample 1 & 2 are replaced with sterilized sludge to form sample 4 & 5.

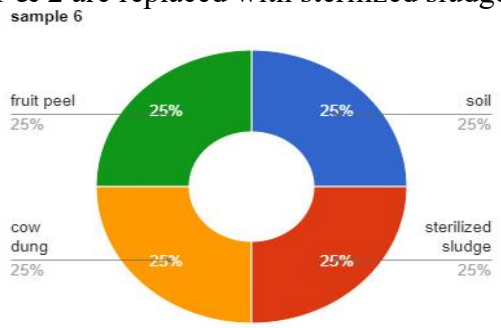

Fig 4 h) sample 6 compositions

This doughnut graph represents the composition rate on the sample 6 this also similar to sample 3 but the sludge content of sample 3 is replaced with sterilized sludge on sample 6.

8.Result

8.1. Paper mill secondary waste

Paper Mill Sludge (PMS) from Sri Krishna Paper Mills in Sivakasi, Tamilnadu, India undergoes a systematic process for utilization. Initially collected, it is sun-dried to reduce moisture, then pulverized for uniformity. A portion is used directly, while the rest is sterilized. Sterilization involves mixing the sludge with water and autoclaving for over 30 minutes to eliminate pathogens.

Fig 5.a paper mill sludge

8.2. Cow dung

Cow dung sourced from dairy industries is systematically collected for further processing. Upon collection, the cow dung undergoes a drying process to reduce its moisture content. Following this, the dried cow dung is molded into standardized cow dung cakes,These cakes are then subjected to crushing, resulting in finely granulated particles. These granules are precisely measured and added to laboratory pit samples in accordance with predetermined quantities, ensuring the controlled introduction of organic matter into the samples

Fig 5 b.cow dung

8.3 Fruit peel

The process involves the systematic collection of agro waste, specifically banana peels, from multiple sources. Subsequently, these banana peels are meticulously chopped into smaller pieces. Following this, the pieces are accurately weighed and incorporated into laboratory pit samples in accordance with predetermined quantities, ensuring precision and consistency in experimental procedures.

Fig 5 c.Fruit peel

8.4 Scaled laboratory pit

8.4.1. Unsterilized samples

Fig no 6.a Unsterilized samples

8.4.2. Sterilized Samples

Fig no 6.b Sterilized samples

This table no 5 shows us the composition set up of our very own laboratory pit. This Sample 1 consists of 30 Grams of earthworm soil in the base 30 Grams unsterilized paper mill sludge then 5 earth worms are added then 60 Grams of earthworm soil is put `together to form the sample 1.but the same is done in sample 2 but the top earth worm soil is reduced to 30 Grams but 30 grams of cow-dung replaces the reduced earthworm soil.the sample 3 is similar to sample 2 but the top earthworm soil is totally replaced with fruit peel.This Sample 4 consists of 30 Grams of earthworm soil in the base 30 Grams unsterilized paper mill sludge then 5 earth worms are added then 60 Grams of earthworm soil is put `together to form the sample 4..but the same is done in sample 5 but the top earth worm soil is reduced to 30 Grams but 30 grams of cow-dung replaces the reduced earthworm soil.The sample 6 is similar to sample 2 but the top earthworm soil is totally replaced with fruit peel

9.Output:

9.1 Vermicompost test :

the inference of the day 1 and day 2 digestion rate of all our laboratory pit samples .Day1 has our initial height of our laboratory pit sample;and Day 2shows us the digestion rate of our sample and the comparative digestion between our sample.Day 3day 3 & day 4 this also shows the comparative digestion rate among our samples .we can see some good rate of digestion from our sample 3,5& 6.digestion rate on day 5 & day 6 this also shows high difference between our day 1 and day 6 this shows us that the digestion is going in much smother manner. at day 7 & day 8 this shows us greater difference from start this shows us grater digestion rate in our sample 6. the final record value of our samples at day 9 . This give us required digestion value .This doughnut chart in the right shows us the composition rate of our sample 1.

Table no 6 .Vermicompost test						
Days	**1**	**2**	**3**	**4**	**5**	**6**
1	5.3	4.7	4.7	6	5.6	5
2	5.3	4.7	4.6	5.9	5.4	4.8
3	5.4	4.6	4.6	6	5.5	4.8
4	5.3	4.5	4.5	5.9	5.4	4.7
5	5.3	4.5	4.5	6	5.2	4.5
6	5.1	4.4	4.5	5.8	5	4.4
7	4.9	4.3	4.3	5.7	5	4.2
8	5	4.1	4.2	5.7	4.8	4.1
9	5	4.2	3.4	5.5	4.8	4

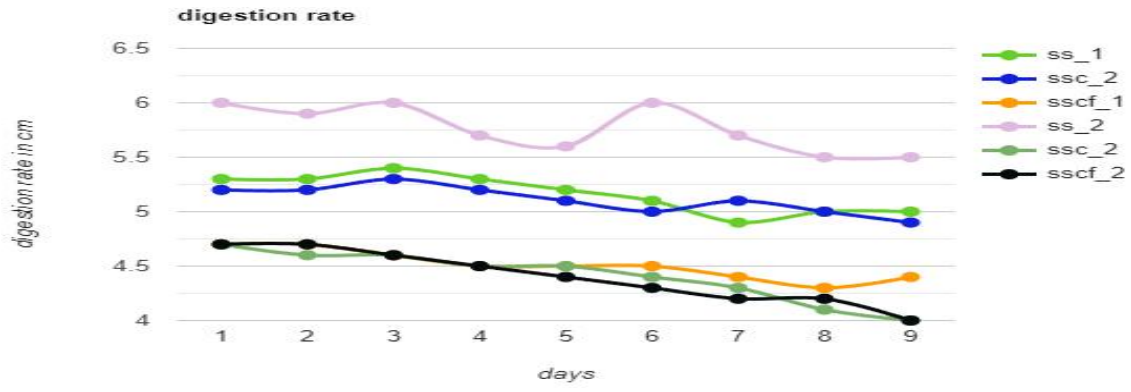

Fig 7 overall digestion rate

9.2 Weight loss test:

Paper-mill sludge is taken 50 grams and diluted with 250ml water to form a slurry consistency and then heated at 125 deg celsius for 30 minutes and then filtered and the weight of dry sludge and water left behind is calibrated . Another sample of 50 gram paper mill sludge and 500ml of water is mixed till a slurry formation is attained and then it's heated at 125 deg celsius for 50 minutes and then filtered and he weight of dry sludge and water is calibrated.

Table 7.a weight loss tables

30 minutes of sterilization

Weight of PMS (g)		Weight of water (g)		pH	
Before	After	Before	After	Before	After
50	48	250	62.5	7.56	8.13
50	47	500	125	7.56	8.13

50 minutes of sterilization

Weight of PMS (g)		Weight of water (g)		pH	
Before	After	Before	After	Before	After
50	47.35	250	31.25	7.56	8.13
50	45.4	500	61.79	7.56	8.13

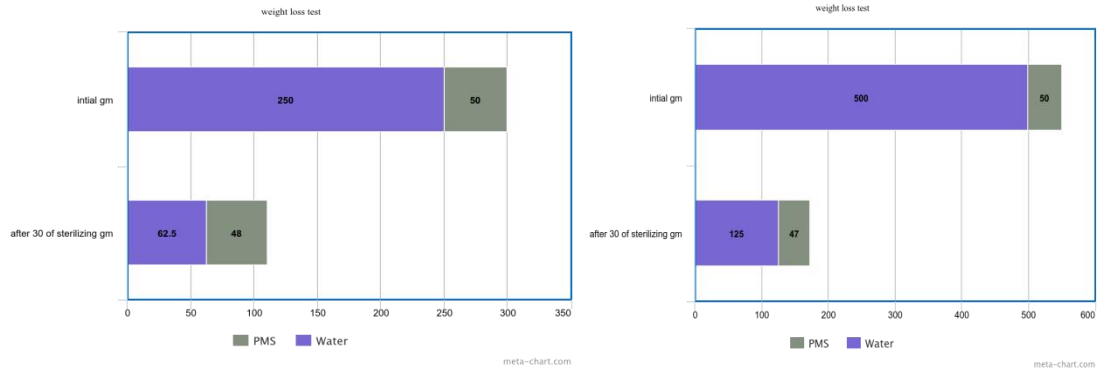

Fig 8.a weight loss at 30 of sterilization

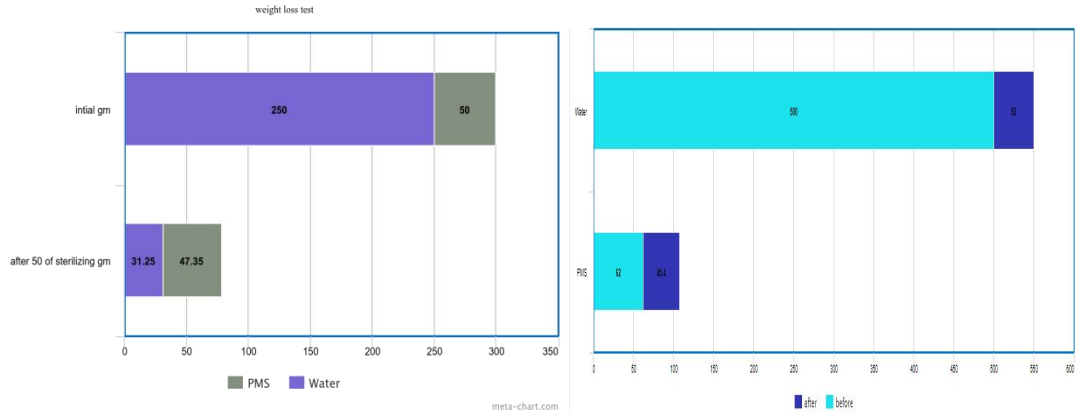

Fig 8.b weight loss at 50 of sterilization

9.3 pH test:

Fig no 9.pH test pit

In fields such as chemistry, biology, medicine, and environmental studies, researchers frequently conduct pH tests on various solutions like water, soil, and biological fluids. By utilizing a scale ranging from 0 to 14, these tests ascertain whether the solutions are acidic or alkaline A pH level of 7 indicates neutrality, whereas values less than 7 suggest acidity and those more than 7 indicate alkalinity.

Table 8 pH test	
pH	
Before	After
7.56	8.13
7.56	8.13

10.Conclusion

From this laboratory pit observance and our test inference we ca clearly see that that the sample 6 which consists of 25% of earthworm soil (30 Grams); 25% of sterilized paper mill sludge(30 Grams); 25% of fruit peel (30 Grams); and 25% of Cow-dung (30 Grams)gives us the maximum digestion rate .This proves that when this earthworm soil is replaced by M sand we can used which can directly used as construction materials.

11.Reference

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