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EcoComposter: A Compact Household Composting Solution

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***Abstract* – The increasing amount of household biodegradable waste has created a demand for effective and environmentally friendly waste management solutions. In this paper we present Eco Composter: A Compact Household Composting Solution, an automated system to convert kitchen and vegetable waste into nutrient rich compost in 8 days. The system is an Arduino based controller with inbuilt temperature and moisture sensors, heating mechanism, and mixing system for automatic monitoring and control of compost. The experimental results showed a successful breakdown of organic waste into dry soil-like compost with decreased manual labor and improved efficiency. The developed system is compact, cost effective, hygienic, and useful for urban households. The proposed solution promotes decentralized waste management and eco-friendly environmental practices.**

Keywords: Composting, Biodegradable Waste, Arduino, Waste Management at Household, Automation, Temperature Monitoring, Moisture Control, Sustainable Environment.

I. INTRODUCTION

The increasing generation of biodegradable household waste like kitchen scraps, vegetable peels, fruit waste and garden waste has become a major environmental concern in urban and semi-urban areas. When disposed of improperly in landfills, such waste causes bad smells, pest problems, methane gas releases, and adds to the unnecessary strain of municipal waste collection system [1], [2]. Therefore, there is an increasing need for efficient, eco-friendly, and sustainable waste treatment methods at the household level.

Composting is the natural biological process of microorganisms breaking down organic waste into nutrient rich manure to be used as fertilizer for plants and gardens [3], [4]. Traditional composting is a great option, but it's usually slow and requires continuous monitoring, manual mixing, proper aeration, and controlled temperature and moisture conditions [5], [6]. These drawbacks limit its practical application in today's households in which time, space, and convenience are critical factors. To address these challenges, this project presents the design and development of a Automated Compact Household Biodegradable Waste Composting System.

The system is developed using Arduino microcontroller integrated with DS18B20 temperature sensor, capacitive moisture sensor, Silicone heating pad, DC gear motor, fan and LCD display. The proposed system monitors the environmental parameters continuously and automatically controls the process of composting for improving decomposition efficiency and to reduce human effort [7], [8]. The system operates in several stages of composting: initial decomposition, thermophilic heating, and maturation/cooling. The controller, using sensor feedback, regulates the heating, moisture level, and mixing process to maintain favorable composting conditions. The LCD screen provides real-time data for the user to monitor the status of the system conveniently.

The purpose of this project is to achieve a compact, low-cost, and user-friendly composting solution for household applications, particularly for apartments and urban homes. The developed system encourages waste segregation at source, reduces dependence on landfill disposal and promotes sustainable environmental practices [9]. In this report, the full design methodology, hardware implementation, control logic, mathematical modeling, simulation results, experimental observations, and performance evaluation of the automated composting system are discussed.

The proposed automated composting system also goes hand in hand with the growing concept of smart homes, sustainable living, and decentralized waste management. The system combines sensor monitoring and automatic control to maintain the key composting parameters, such as temperature, moisture content, and aeration, within the desired operating range. This leads to a more stable process, faster microbial activity, and a better quality of the final compost product [10]. The automated system also creates less odor and is less attractive to pests than traditional methods of composting and requires far less user intervention.

The compost generated by the system can be effectively reused for home gardening, terrace farming, nurseries, and

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landscaping, supporting a circular waste-to-resource approach. The unit's compact design makes it ideal for urban living spaces where space is at a premium. In the long term, the widespread adoption of such household composting systems can contribute to reduction of municipal solid waste loads, reduce transportation and landfill costs, and increase environmental awareness among the citizens [11], [12]. The project is therefore a major step towards cleaner cities, conservation of resources, and smart waste management solutions for future communities.

II. RELATED WORK

To understand microbial degrading processes and improve system performance, several studies have worked on mathematical modeling of composting processes. To more accurately show substrate consumption, new methods included microbial kinetic formulas, where earlier models primarily relied on empirical connections [6], [13].

In composting systems, substrate-limited microbial growth has been mostly described by Monod-type kinetics. By including natural parameters of adjustment like temperature, moisture content, oxygen availability, and nutritional balance, researchers have made these models large [6], [11]. Due to these operational conditions, it has improved prediction accuracy.

It has been noticed that temperature and moisture have a main impact on microbial activity, with ideal levels encouraging faster breakdown. Aerobic stability depends on oxygen availability. Carbon–nitrogen ratio has a great impact on composting performance and particle size [3], [5]. Current composite models aim to incorporate these features while maintaining mathematical simplicity [14].

However, the majority of research focuses on single ways and large-scale composing systems. Nowadays mix household waste and small automated composing systems have come into attention [7]. therefore, there is need for integrated Kinetic models that are useful for small-scale home composting.

Recent research has focused on the importance of scenario waste analysis to determine composting efficiency under different waste compositions. These methods show how adding organic materials can mostly improve nutritional balance, moisture retention, and microbiological stability [4], [15]. This finding state that system design and waste combination selection are equally important for composting efficiency.

Moreover, traditional composting models rarely include real-time monitoring and control applications. Most of the models are used only for offline simulation and performance estimation. Simplified composite kinetics models are essential for automated composting systems and for future integration with sensors, controls, and intelligent optimization techniques [7], [9].

III. GENERAL COMPOSTING PROCESS

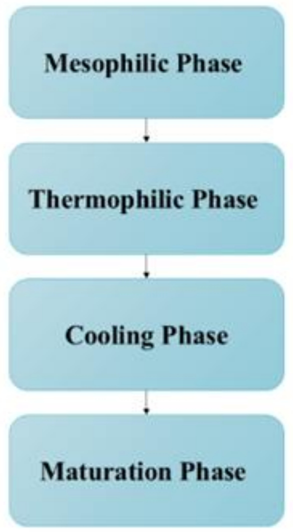

Fig -1: Composting stages

Fig.1 shows the different stages of the composting process as described below. It represents the sequential progression from mesophilic to maturation phase during organic waste decomposition.

A. *Mesophilic Phase*

- Composting starts with materials that are easy to break down being eaten by microbes that are like moderate temperatures (~20–40°C).
- These microbes need a lot of oxygen, and they make heat as they work.
- The right amount of moisture is important; if it's too dry, the microbes slow down, and if it's too wet, it can become smelly and lack oxygen.
- The mix of carbon and nitrogen is high at first, because the materials are fresh and not yet broken down [11], [13].

B. *Thermophilic Phase*

- As the microbes work harder, the temperature goes up to ~55–65°C.
- Different microbes that like heat take over, and they break down tough parts like proteins, fats, and plant fibers.
- At these high temperatures, harmful germs and weed seeds get destroyed.
- The compost becomes lighter quickly, and the mix of carbon and nitrogen starts to go down because carbon is released as carbon dioxide [6], [13].

C. *Cooling Phase*

- After the temperature peaks, it slowly goes back to normal (~30–40°C).
- More kinds of microbes return, including the ones that like moderate temperatures [11].
- The need for oxygen slows down, and the moisture stays around 40–50%.
- The compost keeps breaking down, but not as fast as before.

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D. *Maturation Phase*

- The compost becomes stable with a final mix of carbon and nitrogen around 12:15, showing it is ready.
- The organic matter is black in colour. This matter is crumbly. It serves the soil in some way or other. The organic matter ensures that the soil has the right nutrients and structure [5], [15].
- The temperature is back to normal, and the microbes are working on balance.
- The compost is dark, crumbly, and has no smell it's ready to use in farming.

IV. SYSTEM DESIGN

The objective of the suggested system will be to ensure proper disposal of biodegradable waste generated in homes in an eco-friendly manner. The Automatic Compact Household Biodegradable Waste Composter is an electromechanical system based on the use of a microcontroller to grind, heat, aerate, and control the process of decomposing organic waste material to make compost [8]. The system is to be compact, sanitary, and efficient in urban domestic setting [1], [7].

A cover has been provided to increase user convenience and to allow for introduction of biodegradable waste into the system. In order to reduce smell during loading and decomposing, a carbon filter is also introduced. The matter is shredded by machines within a large rotating drum. The blades that do the shredding and mixing are located within this drum, powered by an electric motora [3], [5].

In order to maintain the temperature required for optimal composting within the composting drum, a silicone heating strap should be put around the drum. The composting time is reduced due to the heating stage, while pathogens and excess moisture are eliminated in this way [10], [15]. Several sensors are used to monitor important operational parameters, such as temperature and process condition. The microcontroller that is used as the control system center receives data from the sensors continuously. To ensure optimal operation, the microprocessor regulates the operation of the motor, heating strap, and lid system depending on sensor data and internal algorithms. Information regarding system operation and composting process can be obtained through the display panel located on the system base [7], [8]. This simple signal, without increasing operational complexity, increases the ease-of-use aspect of the design.

Overall, this system presents an environmentally friendly choice for biodegradable waste in domestic settings because the system focuses on automation, compactness, odor management, energy efficiency, and minimal user intervention.

The display panel of the composting machine shows the real-time temperature and moisture levels of the composting chamber on the front panel, enabling continuous monitoring of the composting process, as shown in Fig. 2.

Fig-2: Display Panel of Composting System

V. MODEL CREATION AND PROCESS OVERVIEW

Composting of household bio-degradable waste is a combination of biological and physical processes [11], [13]. The micro-organisms break down the waste, but their activity is dependent on physical factors such as the flow of oxygen, the level of moisture, heat, and the mixing of waste. For example, oxygen passes through the waste, moisture spreads around, heat is generated by microbial activity, and mixing helps break down the waste into smaller pieces. All these things help microbes break down waste more quickly.

At the same time microorganisms convert complex waste into stable compost through biological reactions [4], [11]. Sometimes the rate of composting is limited by the speed at which these biological reactions take place, and sometimes it is limited by physical factors such as the movement of oxygen or moisture.

In this project, different approaches to modeling the composting process for a household composting system were studied. It was found that the waste decomposition follows a smooth S-shaped (sigmoid) curve, which means that the process starts slow; it becomes fast and then slows down again [16]. This indicates that composting is predominantly controlled by biological activity rather than by drastic physical constraints.

Furthermore, when the oxygen supply was altered, the composting rate did not change much [11]. This means that oxygen is easily available to microbes and is not a limiting factor.

So, the composting process is considered reaction-controlled, meaning the speed mainly depends on microbial activity (biological reactions), not on oxygen supply. Other factors like temperature, moisture, particle size, and carbon-nitrogen ratio do not directly stop the process but affect how efficiently microbe's work [14], [15].

To represent this, a mathematical model is used where decomposition depends on the amount of waste and follows Monod-type kinetics (microbial growth behavior).

Environmental factors are incorporated as simple correction factors:

- Temperature, C:N ratio is modeled using Gaussian functions (optimum range behavior)
- Oxygen and moisture are modeled via saturation functions (limited effect after a point)

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- Mixing and particle size are given to show that breaking up waste increases surface area and enhances decomposition.

In summary, this model offers a comprehensible and practicable comprehension of the composting process, which may be employed in performance improvement, system optimization, and designing automatic composting machines for domestic purposese [7], [16].

VI. SYSTEM EQUATIONS

A. *Substrate Mass Balance*

Let S(t) denote the biodegradable substrate concentration (kg or g/m³) at time t. The substrate mass balance for a batch composting reactor is expressed as [6], [10]:

$$S(t) = \frac{ds}{dt} = -r_s$$

Where,

r_s = rate of substrate degradation.

B. *Monod-Based Substrate Utilization Kinetics*

Microbial degradation of organic matter is limited by the availability of biodegradable waste products. This limitation is modeled using the Monod equation [10], [13], [14]:

$$r_s = k_{max} \frac{S}{k_S + S}$$

Where ,

k_{max} = maximum biodegradation rate
k_S = half-saturation constant
S = substrate

This formulation reflects saturation behavior at high substrate concentration and reduced activity when substrate availability is low [11].

C. Oxygen Availability Modeling

Aerobic composting requires continuous oxygen supply. Oxygen limitation is represented by a Monod-type modifier [11], [15]:

$$f_{O_2}(O2) = \frac{O_2}{k_O + O_2}$$

Where,

$f_{O_2}(O2)$ = Oxygen modifying factor
O_2 = Oxygen concentration.
k_O = Half-saturation constant for oxygen.

This term ensures that microbial activity decreases under oxygen-deficient conditions. In the proposed system, oxygen availability is regulated via controlled ventilation, making this modifier directly linked to the embedded equation [2], [7].

D. Moisture Content Modeling

Moisture is essential for microbial metabolism and nutrient diffusion. The moisture effect is modeled as [11], [15]:

$$f_M(M) = \frac{M}{k_M + M}$$

Where,

$f_M(M)$= Moisture modifying factor
M = Moisture concentration.

k_M= Half-saturation constant for Moisture

This expression penalizes extremely dry or saturated conditions, both of which inhibit aerobic microbial activity [5].

E. Temperature Dependency and Heat Effects

Temperature influences enzymatic reactions and microbial growth. The temperature effect is modeled using a Gaussian function [10], [14].

$$f_T(T) = \exp\left(-\frac{T - T_{opt}^2}{2\sigma_T^2}\right)$$

Where,

$f_T(T)$ = Temperature modifying factor
T = temperature

T_{opt}= Temperature obtained
σ_T =Temperature tolerance spread (variance).

This formulation captures:

- Reduced activity at low temperatures (mesophilic region) [3].
- Peak activity near optimal thermophilic conditions [5].
- Thermal inhibition at excessively high temperatures [10].

F. Carbon-to-Nitrogen Ratio Influence

The availability of carbon and nitrogen governs microbial metabolism. Nutrient imbalance reduces composting efficiency. The C:N ratio effect is modeled as [11], [15]:

$$f_{CN}(CN) = exp\left(-\frac{CN - CN_{opt}^2}{2\sigma_{CN}^2}\right)$$

Where,

$f_{CN}(CN)$ = CN ratio modifying factor
σ_{CN} = Spread of acceptable C: N balance.

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This Gaussian form penalizes deviations from the optimal nutrient balance [4].

G. Significance of the Proposed Model

The developed model [10], [14]:

$$\frac{ds}{dt} = \frac{k_{max\,.\,S}}{k_s + S} f_{O_2}(O_2).f_M(M).f_T(T).f_{CN}(CN)$$

- Provides scientific justification for system design choices [7].
- Enhances predictability and control of composting performance [9], [12].
- Bridges mechanical design, electronics, and biological processes [2], [7].
- It is suitable for household-scale decentralized waste management [1], [8].

VII. RESULTS

System performance was validated through mathematical simulation and real-time testing by means of a hardware setup using vegetable (cabbage) waste. The results were in good accordance, which indicated efficient composting, and hence successful production of compost.

Fig -3: Experimental result of stage 1

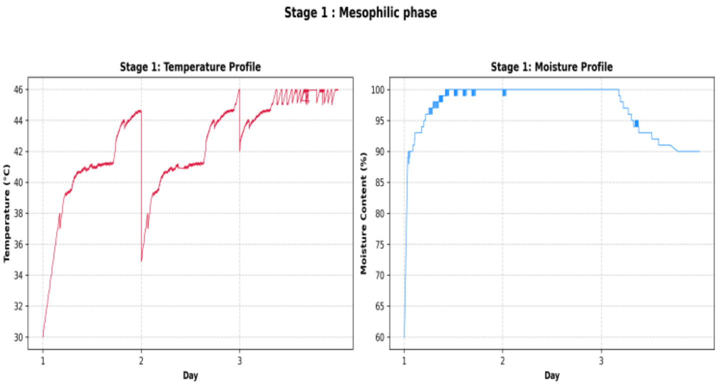

Fig-4: Mesophilic Phase

The plots of fig-4 shows temperature and moisture versus time are used to determine whether the system performs well, and the composting process takes place smoothly without any issues. During this stage, a steady increase in the temperature level was noted, moving from roughly 30°C to about 45-46°C within a period of three days. This clearly shows that there exists a system environment favorable enough for the performance of activities of mesophilic organisms contributing to the decomposition process. Moreover, moisture was controlled; there was an initial rise after which the optimal moisture levels, of around 90%, were maintained for three days. At this stage: The moisture content is too high. Microbial activity is minimal but begins naturally. The system initiates mixing through the motor to distribute waste evenly. Sensors start monitoring temperature and moisture continuously

Fig -5: Experimental result of stage 2

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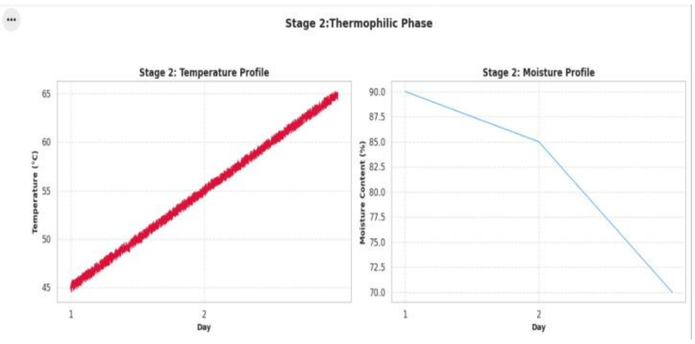

Fig-6: Thermophilic phase

The fig-6 shows the plot for thermophilic stage, the temperature increased continuously from about 45°C to 85°C, indicating robust and continuous microbial growth during the composting process. The increasing trend proved the successful establishment of thermophilic conditions, which were essential for the degradation of complex organic materials. The higher temperature range provided an effective mechanism to kill pathogens and break down lignocellulosic substrates efficiently, confirming the efficiency of the designed composting system in achieving desired thermal conditions. There was a gradual decrease in the values from around 91% to 70% in the thermophilic stage. This decrease resulted due to the substantial amount of heat produced during microbial respiration and evaporation. Maintaining such moisture content was crucial because it avoided anaerobic conditions while ensuring sufficient moisture content to sustain microbial growth and functioning.

At this stage: Microorganisms become active and generate heat. The temperature inside the chamber increases. Initial decomposition of organic matter begins.

Fig-7: Experimental result of stage 3

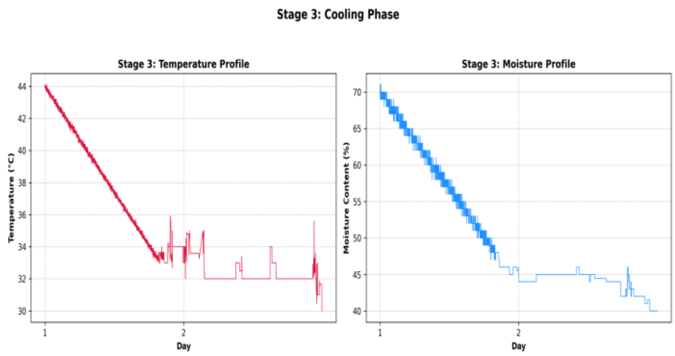

Fig -8: Cooling Phase

The fig-8 shows the plot for the cooling phase, there is a gradual decrease in temperature from 44°C to 31°C, representing the natural reduction in the metabolic activities of microorganisms due to the depletion of available organic substrates. The minor fluctuations witnessed during the last period of this phase point to the persistence of some microbial activity in isolated areas of the compost mass. This cooling pattern is indicative of the successful development of the material into the maturation process, which marks the end of the active decomposition stage and the start of compost stabilization. The moisture content falls from 70% to 41 % during the cooling phase, pointing to ongoing evaporative losses as the compost mass cools down. These stepwise decreases seen in the moisture content profile demonstrate the natural occurrence of moisture regulation and drainage in the composting system. It represents a milestone achieved, as it brings the moisture content close to the ideal percentage necessary for mature compost, signifying the successful maturing of the compost mass towards its curing stage.

Fig -9: Experimental result of stage 4 (Final compost)

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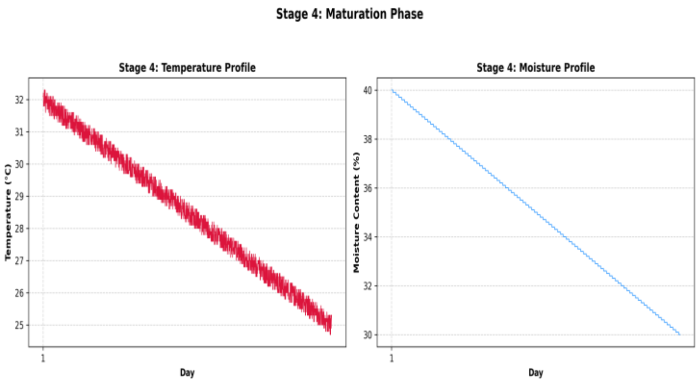

Fig -10: Maturation phase

The fig-10 shows the plot for the maturation phase, there was a gradual drop in temperature from about 32°C to 25°C, which was an indication of the complete depletion of readily degradable organic material and the cessation of microbial action. The slow cooling of the mixture to near ambient temperature was confirmation that the process had progressed to its last and successful stabilization phase. The attainment of mesophilic and nearly ambient temperatures was an indicator that the material had achieved biochemical stability, thus indicating that it was fully matured, safe, and could be applied without the danger of further heat production. As regards the moisture profile, the moisture level consistently dropped from approximately 40 % to 30 %, thus showing a natural drying pattern due to the cessation of microbial action and heat production. This was an important milestone in the drying of the mixture and ensured that it had reached its final ideal moisture levels. The steady decrease in the moisture level was an important indicator of proper moisture control in the mixture, which resulted in it reaching the required physical properties of the final product.

VIII. CONCLUSION

The paper describes the design and development of Eco Composter: A Compact Household Composting Solution for effective household organic waste management. The proposed system converts kitchen and vegetable waste into nutrient rich compost within 8 days using controlled heating, mixing, and monitoring mechanisms. Experimental results showed that wet organic waste could be efficiently decomposed into dry soil-like compost with less manual effort and better processing efficiency.

This system is compact, hygienic, affordable, and suitable for urban households compared to conventional composting methods. Real-time monitoring of temperature and moisture maintained suitable composting conditions during all decomposition stages. The proposed model offers an eco-friendly and sustainable approach to decentralized management of biodegradable waste, encouraging environmental conservation and waste reduction practices.

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