Modelling and Analysis of a Solid Waste Composter for Urban Houses

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Abstract. Disposal of waste is an important issue faced by sanitation agencies, especially in India, where the volume of waste generated has been increasing rapidly over the last few years. According to the Ministry of Housing and Urban Affairs, as of January 2020, 147,613 metric tonnes (MT) of solid waste is generated per day in the country. Part of the waste that is expunged on a daily basis from homes, is food and other kitchen waste, which are biodegradable or compostable. In rural areas, such waste is disposed of in landfills, such that they get decomposed to form compost that is used as manure for crops. But this is not feasible in large cities where empty land, as well as the time required for waste to get converted into compost, is in short supply. Composting is a proven method to reduce the volume of waste, to almost 15-20% of its original amount. Therefore, this work is focused on designing an electric composter that could decompose waste artificially, and is compact, efficient, odourless, and easy to operate. This product can thus manage biodegradable waste at the source of its generation, and effectively supplant the wastebasket in a kitchen by occupying no greater space than the latter. The yield of compost would also provide nutritive natural fertilizer to homes wherein kitchen gardens or terrace farms have been set up, as well as promote the creation of the same wherever space is available. In this paper, the important parameters involved in the design of composter, including geometry parameters and the ones of operational significance such as speed and number of blades of agitator and bin temperature, have been discussed thoroughly, along with providing an understanding of the processes and considerations necessitated.

1. Introduction
Composting is a very attractive waste management method for communities that look out for efficient and safe ways to process domestic refuse. It recreates the lost value of the garbage, as well as reduces the quantity of it that needs to be disposed [1]. Composting is a procedure done in a specially-designed environment to disintegrate biological materials (mostly wastes) in the presence of O2, yielding compost, along with the by-products of heat, CO2, and water. In the Indian subcontinent, a large
fraction of the overall garbage is organic in nature, and so, a significantly beneficial consequence within the area of waste management can be brought about by dealing with at least the biodegradable waste from homes, at source. Though recycling waste materials in general is quite prevalent, treating the biowastes and reusing them effectively could prove to be very rewarding, especially at a juncture when farming practices are affected due to various geopolitical factors, and the time is ripe for setting up kitchen gardens wherever feasible. For generations, compost has broadly found use for conditioning and fertilizing soil, helping in plant growth. The widespread utilization of costlier controlled machines for managing organic wastes of late has led to the development of such products which grant increasingly more command over the parameters involved in the composting process [2].

A comprehensive survey of literature of microorganisms involved in several phases of natural composting in an exceedingly traditional agricultural landfill was presented by J. Ryckeboer et al [3]. In 2010, G. Irvine et al., investigated the heat generated during composting as a potential source of renewable energy [2]. They analysed the effectiveness of the compost as a fuel for electricity generation. In 2012, Francisco S proposed a small-scale electric composter with different settings and odour shield, followed by Nicholas Smith-Sebasto, who patented the design of a composter that shreds waste and aerobically composites it in a very rotating chamber [4,5]. Sailesh N elucidated the process parameters and output involved in creating a domestic composter designed for city households that runs using an inoculum for faster operation [6].

Composting facilitates the formation of simple chemical molecules (monomers) from complex molecules (carbohydrates), by means of their disintegration, so as to serve as food for the microbes, in addition to facilitating their growth [7]. Aerobic conditions are generally favoured over anaerobic conditions due to the faster nature of the process and the bacteria and fungi involved, generates heat as high as 80 ℃ [8]. This condition of excessive temperature expedites the breaking down of chemical compounds, which is associated with repulsive malodour. The compost output can be expected in a duration of 6 weeks, by when the aerobic decomposition would have been completed [9].

Artificial composters had been built to accommodate the organic waste generated and are sealed, in order to obviate unwarranted interactions with atmospheric agents, and improve the efficiency of the composter. The present work makes an effort to design a composter with the integration of drying, grinding and cooling stages.

2. Methodology
The design of the composter was carried out as described in the following paragraphs. In the drying stage hot compost piles are made to reach a maximum temperature of 50 - 80 ℃, which is desirable owing to it being noxious to disease-causing agents in plants [10]. Most composters are made to mimic this for its operation and thus made to be heated up to nearly 70 ℃ at the time of drying. An electric heater is used to raise the temperature, and distributed through an agitator or stirrer placed either on the horizontal or vertical axis of the compartment holding the waste to be processed. Aeration is also required and is provided through some provision that does not disrupt the internal process, and the controlled environment set at specific temperature, pressure and pH value. The drying stage essentially reduces the volume of the waste, by depriving it of moisture [11].

The grinding stage the composter has a mechanism of agitation which grinds the garbage and breaks them down into small, powder-like particles, which reduces the volume, sometimes even to about 90% of the initial quantity [11,12].

Though the cooling phase is essentially not critical to the production of compost, it is required for making it able to be handled and utilized productively. This may be done by using fans or specially created openings for this purpose.
An overall process flow was established and components required to facilitate the same had been constructed following theoretical calculations, with a safety factor associated with domestic use of any product. The processes taking place within the device, as viewed through the actions performed on the waste/compost have been illustrated in Figure 1.

![Diagram of Composter](image)

**Figure 1.** Process Flow Diagram of Composter.

### 2.1. Process Stages

Figure 2 and Figure 3 show the final CAD model depicting the composter and Figure 4 contains data pertaining to the parts used in the composter, which could be studied along with the information in Figure 1 as to which stage of operation they are employed in.

![Final CAD Model](image)

**Figure 2.** Final CAD Model.

![Interior view](image)

**Figure 3.** Interior view.

![Part Labelling](image)

**Figure 4.** Part Labelling.

#### 2.1.1. Input

In this stage, the waste generated in kitchens, including food waste containing both plant and animal matter, waste tissue papers, cartons and slime are added to the bin of the composter. The device is equipped with a lid operated by a hinge, that could be opened to append the waste, and closed to make sure the odour does not get out, and so that the composter could function properly. The
lid, which is made of fiberglass, has an inner lining of stainless steel so as to withstand the high temperature cycles inside. The lid has a gasket made of Ethylene Propylene Diene Monomer (EPDM) rubber, that facilitates in retaining the controlled environment for composting [13].

2.1.2. *Storage.* This stage occurs right after the input of refuse into the bin, and before the composting process begins. The bin has been designed using stainless steel as to accommodate a week’s (7 days) waste in it, therefore, the composting cycle has to be performed at the end of each week. The bin has a continuous groove on the outer side to hold the heating coil. The outer face of the bin is enveloped by a layer of insulation made of EPDM for safety. Within the bin a stirrer made of stainless steel performs the task of cutting and chopping the waste, in addition to ensuring the even spread of heat across the garbage, thus ensuring properly efficient operation [14].

2.1.3. *Composting.* Once the bin is filled to capacity, (ideally at the end of a week), the lid is closed completely and the heater is turned on, along with the stirrer. The composting is carried out by microorganisms whose growth is promoted by the addition of an inoculum in the form of Bioculum [15]. It serves the purpose of the compost starter mixture and accelerates the process [6]. The stirrer is run by a servo motor, whose motion is transferred by means of a connector. The rotation of the blades of the stirrer ensures that an equal amount of heat and inoculum reaches all the contents without having to accumulate in certain regions. The heater, whose material is nickel chromium alloy, reaches a constant temperature of 80 °C. The user had to operate a switch each to turn on the heater and the stirrer once they are satisfied with the waste input and wish to proceed to decompose it. That operation initiates this stage, during when an estimated time of 24 hours would be taken up by the composter to do its chore, at the end of which, the operator needs to use the aforementioned switches to kill the power and eject the compost [16]. The reduction in volume happens due to the heating which removes moisture mostly, and the high temperature helps the bacteria to perform their task with maximum efficiency. The water vapour formed as a result, would have to pass out of the system through the air channels created near the outlet that provide enough clearance for draining steam without having to take much of air in to tamper with the internal conditions. This would normally produce a smell, but will be rendered odourless by the nature of the bacteria used in our composter, which is to suppress it.

2.1.4. *Egress.* This is the stage which follows the composting phase, where the end product is transferred onto another compartment for retrieval. To this end, a stopper had been designed which would be operated by a linear actuator, which works like a sleeve over a cylindrical rod-like extension provided at the bottom of the bin. The user could operate this mechanism by means of a switch.

2.1.5. *Collection & Retrieval.* The compost is made to fall onto the tray and get collected there so that it would provide an environment for it to cool down before the user could get their hands on it, while also enabling the bin to be cleaned out as this is happening, so that the user could start dumping garbage further into the bin for the next cycle.

2.2. *Design Parameters*

Before proceeding to model the components of the device on the Computer Aided Designing (CAD) software SolidWorks 2020, there had to be certain design considerations adhered to, as in the size and volume of containers. Those calculations have been explained in the following part of the paper.

2.2.1. *Bin Design.* To determine the dimensions of the bin, firstly the height of the garbage head had to be identified.

\[
\text{Approximate mass of garbage generated in a domestic kitchen per day} = 1 \text{ kg} \quad (1)
\]

\[
\text{Approximate mass of garbage generated in a domestic kitchen per week} = 7 \times 1 = 7 \text{ kg} \quad (2)
\]
This could be set as the maximum possible mass that the composter bin would need to accommodate, since it has been designed to process the refuse accumulated over a week’s time or less. The daily garbage value has been considered higher than the actual figure just for safety [17]. The next step was to calculate the volume to be occupied by this mass. The average density of kitchen waste, assuming an average composition of all possible articles to expect in it, was identified as 0.00000035 kg/mm$^3$ [18]. The volume of weekly waste input - calculated from the mass of the same and the density - would be 20000000 mm$^3$.

This volume exceeds the volume of waste filled in per week, and therefore avoids overflowing if composted at least once a week. In addition to the waste, the bin also needs to house the stirrer, the connector, compartment for the motor, and the top surface of the stopper which seals the openings at the bottom, all of which need to be found space for, within the capacity of the cylinder. In the final model, volume of the stirrer has been found to be approximately 1005000 mm$^3$. Therefore, it can be seen that the capacity of the bin would be sufficient enough to hold all the aforementioned components.

2.2.2. **Tray Design.** The collecting tray needs to be designed to hold the expected capacity of compost to be generated at the end of the composting cycle. Even though the expected volume reduction would be beyond 80%, a safe value of 60% reduction has been assumed, to account for unexpected overflow. The capacity of the tray measured from the created model is about 10780000 mm$^3$, which is capable of comfortably housing the reduced volume of waste at the end of composting.

2.2.3. **Body Design.** The body of the composter is the basic skeletal structure to which all other parts are appended. The top face of the body needs to have grooves for attaching the hinges and screwing them on. Additionally, facility for electrical accessories has been made. Therefore, the dimensions of this body made of fiberglass have been assigned keeping in mind these requirements.

2.2.4. **Electrical Design.** Figure 5 is a simple diagram of the circuit used to make the composter achieve its functionality. The circuit has pathways for powering both the heating coil and the motor to which the stirrer is coupled. The circuit does not have provision for speed control of the motor since it is not an essential feature (a constant value of 800 rpm would more than suffice). The input is AC voltage that is denoted by the symbol with the sinusoidal wave on the left of the diagram. The circuit is not in parallel because the resistance of the heating element is relatively low so it might act as a short circuit, and additionally, there is a chance that very little current might end up flowing through the motor. Therefore, the motor circuit and the heating coil circuits are in series to the input, and in parallel to a resistor “R” each. Both these resistors have the same resistance, so the voltage that the motor circuit and the coil get will be of the same amount. Also, it is to be noted that R is pretty high so that when both the switches are ON, most of the current flows through the motor and coil circuits instead of the resistor, (R>>R1). The switches that seen before resistor R1 is to either have the motoring and heating coil circuits ON or OFF. The motor circuit and coil circuits are independent of each other i.e., motor can be made ON when coil is OFF, and coil can be turned ON when motor is OFF, and obviously both can be ON/OFF simultaneously. The triangle with arrows coming out is a light-emitting diode (LED). We have provided a colour code to them, as per our needs. That is, when motor circuit is turned ON, the red LED gets illuminated as an indication, similarly when coil circuit is on, the yellow LED glows. The resistor R1 is included to essentially prevent the excessive current passing through the LEDs. The rectangular symbol on the top of the diagram represents the heating coil, while the symbol with “M” inside of a circle stands for the motor. However, if more sophisticated requirements are seen in the future, there is always the option to turn the AC input to DC and attach two potentiometers to control the speed of the motor or the temperature of the heater.
3. Design Validation

The components mentioned in the previous section had been constructed on CAD software SolidWorks according to the calculated dimensions. It had to be validated by means of simulation using the Finite Element Method (FEM) analysis software, Ansys 2019. The analysis had to be done in two steps, being the initial computation of the temperature profile using the Steady-State Thermal module, and the determination of corresponding mechanical stresses caused by this thermal loading through the Static Structural module [19]. The model containing geometry had been meshed with an element size of 10 mm overall and 5 mm in certain critical bodies to obtain a sufficiently viable mesh, as shown in Figure 6 using stainless steel with properties of 193 GPa Young’s Modulus, 0.265 Poisson’s Ratio, and 14 W/mK thermal conductivity. Figure 7 reveals how the thermal load conditions had been assigned to the model, based on the working conditions it will need to be subject to, during operation [20]. The maximum temperature produced by the heating coil (80 ℃) has been input with the heat spreading over to the components of the composter inside and outside the heater. The temperature variation across the device has been modelled and illustrated in Figure 8. The structural effect that would be arising out of the stress imposed on the components has been calculated and depicted on the plot shown in Figure 9. This reveals that the maximum possible stress experienced during operation would be a little over 32 MPa according to von Mises criterion, which is well under the working stress values of the materials used in the composter [21]. Figure 10 additionally showcases the total deformation for these conditions, which also turn out to be of a relatively insignificant order. These data clearly indicate that the operating parameters are able to be withstood by the model. Thus, the thermal and structural analyses show that the composter design is safe.

Figure 5. Diagram of circuitry employed in the composter.

Figure 6. Load Conditions for the FEA.

Figure 7. Model at the end of Meshing.
4. Conclusion
The solid waste composter design has up to 6 kg storage, compaction and retrieval, a three stage design that will be useful for domestic applications. The circuit is designed to take care of the heating coil and the motor to which stirrer is coupled. Apart from the composter design, the structural and thermal stability is also ensured with stresses within the yield limit. This would be an effective solution to the problem of waste management and useful for households with kitchen gardens or other forms of vegetation, for whom this compost would serve as invaluable natural fertilizer for plant growth. The future work envisages a composter design for apartments and restaurants.

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