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Resource Recovery from Food Waste Fraction of Municipal Solid Waste by Mechanical Heat Treatment

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Abstract: *Currently, open dumpsites are used to dispose of the majority of municipal solid waste (MSW) produced in Nigerian cities and towns, which has detrimental effects on the environment. Combining mechanical and heat treatment for municipal solid waste is known as mechanical heat treatment. Food waste (FW) was gathered for this study, sorted, and then fed into a shredding machine to reduce the particle sizes. A portion of the shredded FW weighing 10 kg was fed into an autoclave. For one hour, the autoclave was kept at the required pressure range of 17 psi to 21 psi and temperature range of 121 °C to 127 °C. The wet digested slurry was transferred to a laboratory oven and dried at 105°C for 24 hours to eliminate all moisture after the autoclaving procedure. Physical and chemical properties of the FW were also evaluated, such as bulk density, weight, volume, pH, C/N ratio, total organic carbon (TOC), and total Kjeldahl nitrogen (TKN). The bulk density of the food waste was discovered to be nearly constant both before and after shredding. Moreover, the thermal hydrolysis of organic matter caused the pH of the treated FW to drop. Additionally, it was found that the autoclaving process increased the TOC content of FW.*

Keywords: *Municipal Solid Waste, Food Waste, Autoclaving, Shredding, Bulk Density*

INTRODUCTION

Waste that is household or similar to a household is known as municipal solid waste (MSW). It includes some commercial and industrial wastes, such as those from offices, schools, shops, etc., that may be collected by a commercial company or the local authority. It also includes household wastes collected by local authorities. The timely and safe collection, treatment, and management of generated waste is known as municipal solid waste management (MSWM). By reusing and recycling materials that would otherwise be sent, MSWM contributes significantly to the sustainable management of materials, economic growth, and employment creation while taking into account the positive effects on the environment (US EPA, 2022; What a Waste, 2023). As cities struggle to keep up with the increasing waste streams, the rapid urbanization process exacerbates the municipal solid waste (MSW) crisis.

This is due to the ongoing development of urban and rural construction, as well as the continuous increase in population density. With the world population predicted to reach 9.8 billion by 2050 (World Bank Group, 2023), there will undoubtedly be a greater need for basic services like food, housing, and transportation. Consequently, there will be a significant increase in MSW generation because of the interplay between urbanization, industrialization, and population growth (Orhorhoro *et al*., 2017; US EPA, 2023). Urbanization and population growth will inevitably lead to the generation of MSW, which poses a serious threat to the environment and public health globally (Orhorhoro *et al*., 2017; Onyebanji *et al.*, 2022). The environment and public health are greatly impacted by the mishandling of MSW resulting from urbanization and population growth. Inadequate MSW disposal can lead to land pollution, which produces dangerous pollutants that contaminate soil and hinder the growth of agriculture (Azike *et al.*, 2022; Portelinha *et al.*, 2022). Inadequate management of dumpsites can seriously damage aquatic habitats and put human health at risk and it can as well lead to water pollution. Since the amount of greenhouse gases released during the disposal of MSW can exceed 700 kg per ton, it is important to address these emissions (Orhorhoro and Oghoghorie, 2019; Khan *et al.*, 2021). According to estimates, 2.24 billion tons of MSW are generated annually worldwide, or 0.79 kg of MSW per person per day (World Bank Group, 2023). Given the detrimental effects of MSW, sustainable and appropriate MSWM techniques are essential for both environmental governance and public health. The majority of waste generated in Nigerian cities is dumped in open landfills; very little is recovered for recycling, and very little is subjected to procedures like anaerobic digestion, incineration, or composting (Owamah *et al.*, 2015; Orhorhoro and Oghoghorie, 2019; Orhorhoro *et al.*, 2022). Untreated waste disposal leads to a low rate of recoverable material reincorporation into productive chains, meaning that materials like paper, cardboard, plastic, metals, and glass lose their potential for recycling, reuse, and energy recovery. Additionally, it causes the release of harmful substances into the atmosphere, including leachates and greenhouse gases (GHG), which are primarily made up of carbon dioxide (CO_2) and methane (CH_4) (Saier, 2007; Trulli *et al.*, 2012; Wilson *et al.*, 2012; Menikpura *et al.*, 2013; Torretta *et al.*, 2017; Orhorhoro *et al.*, 2017). Many technologies, including anaerobic digestion, pyrolysis, gasification, incineration, composting, and mechanical heat treatment (MHT), have been developed to lessen the environmental effects of disposing of municipal solid waste (MSW) (Archer *et al.*, 2005; Di Lonardo *et al.*, 2012; Trulli *et al.*, 2012, Orhorhoro *et al.*, 2022).

The term "mechanical heat treatment" (MHT) is somewhat new. It is used to characterize mechanical and thermal technology configurations, including steam-based systems. These procedures are generally used to divide a mixed waste stream into multiple constituent parts in order to provide additional options for recovery, recycling, and, in certain cases, biological treatment. The procedures also lessen the waste's moisture content and sanitize it by eliminating any bacteria. Combining mechanical and thermal treatment methods, MHT technology aims to separate fuel fractions (fuel derived from refuse) and/or relatively high-quality recyclables from waste. Additionally, and depending on the technology used, they extract organic fibre for use as a raw material or alternative fuel and reduce the volume of waste produced. Thermal drying is a non-pressurized method of heat treatment, while autoclaving is a pressurized method. Their respective purposes are to stabilize and sanitize waste feedstock. MHT offers advantages for handling, storing, and transporting the sanitized outputs. Additionally, it significantly reduces the volume of waste and lessens odor issues (DEFF, 2023). As shown in Table-1, the most popular system being promoted for the MHT treatment of MSW is built around a thermal autoclave. Using steam and pressure, autoclaving has been used for many years to sterilize medical and surgical equipment. Prior to being dumped in a landfill, this technology is also frequently used for the sanitization treatment of some clinical wastes and for specific rendering procedures for animal wastes. Its application to MSW, however, is a relatively recent innovation, and commercial experience with this feedstock has advanced significantly in recent years and is currently growing in the UK. A non-pressurized heat treatment process, which involves heating waste in a revolving kiln before mechanical separation, is the second kind of MHT system.

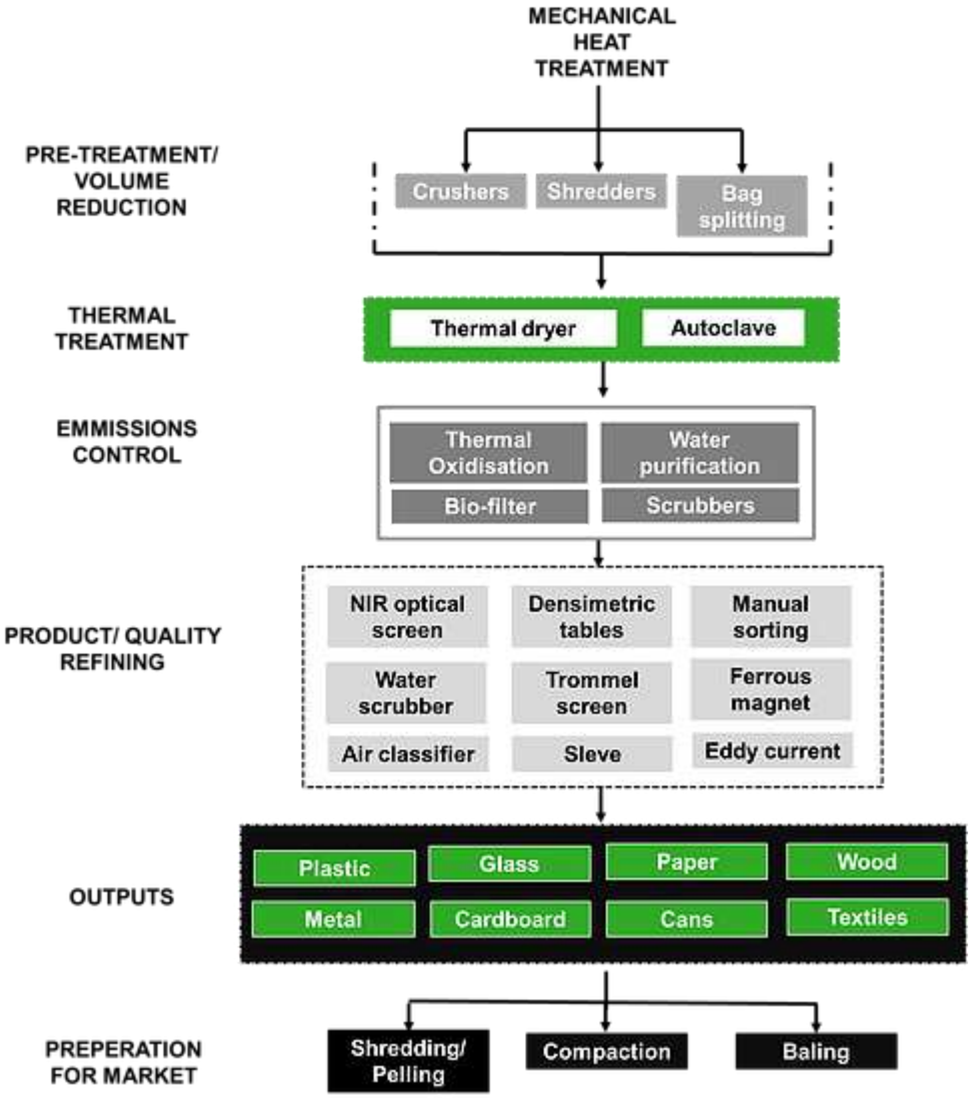


Fig. 1 Process chart of mechanical heat treatment (DEFF, 2023)

Table-1 Municipal solid waste mechanical heat treatment process

Heat Treatment Process	Description
Autoclaving is the process of processing steam in a vessel in batches while applying pressure.	After the waste is pressure-steamed, it is mechanically sorted and separated to render it sterilized. This is a batch process, meaning waste is fed into a sealed vessel, treated for about an hour, and then released before another batch of waste is fed in.
Continuous Heat Treatment: Not requiring pressure; done inside a vessel.	After heat is applied externally to dry the waste, the sanitized waste is separated and sorted mechanically. Waste is continuously fed into the process, traveling along the thermal vessel, and passing through the system.

MATERIALS AND METHODS

Food waste (FW) was separated from household solid waste that was collected from Okada for this study. Paper, plastic, metal, glass, and other waste (ashes, leather, cloth, etc.) are additional solid waste components that are collected with FW. The FW was sorted and then fed into the shredding machine (Fig. 2), which reduced the particle sizes. An autoclave was fed with 10 kg of the shredded FW (Fig. 3). This research employed an electric pressure steam sterilizer autoclave with a 50-liter capacity. Water was added to the autoclave primarily to facilitate the creation of steam during the treatment procedure. The autoclave's inner container held the 10 kg portion of FW, which was sealed with a cover unit. The system was brought up to the necessary pressure of 17 psi to 21 psi and temperature range of 121 °C to 127 °C. For one hour, this pressure and temperature were maintained. After the autoclaving process, the wet digested slurry was moved to a laboratory oven and dried at 105°C for 24 hours to remove all of the moisture. A grinder was used to reduce the size of the dried products into smaller particles. As advised by Mohamad *et al.* (2017), the Walkey-Black method was used to determine the content of total organic carbon (TOC), and the semi-micro Kjeldahl method was used to determine the total Kjeldahl Nitrogen (TKN). An electronic pH meter was used to measure the pH in solution condition.

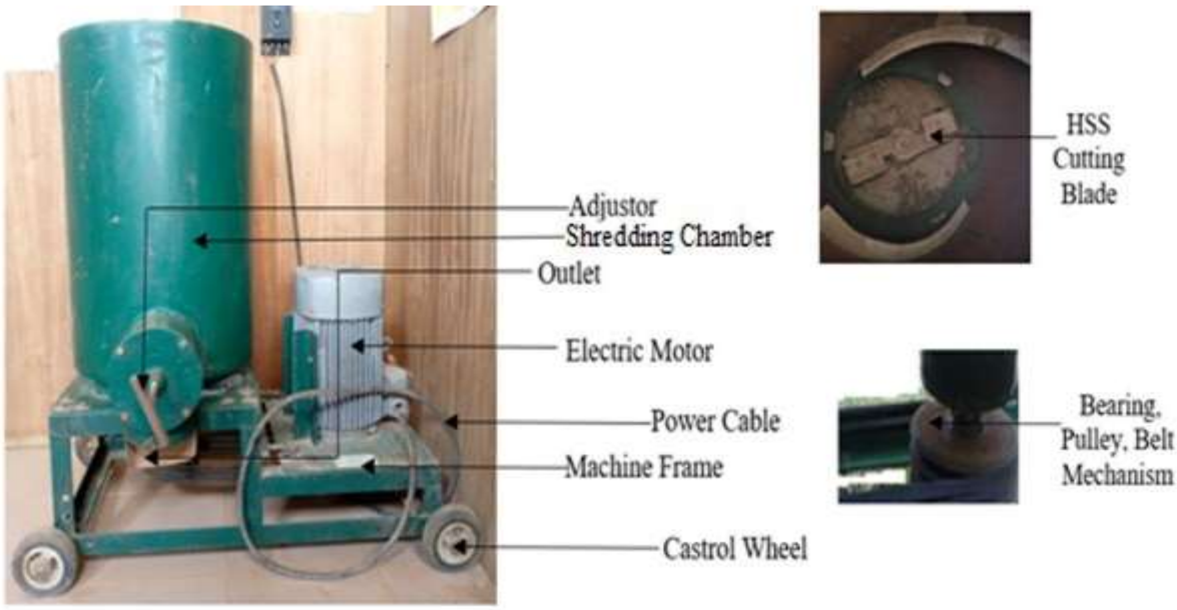
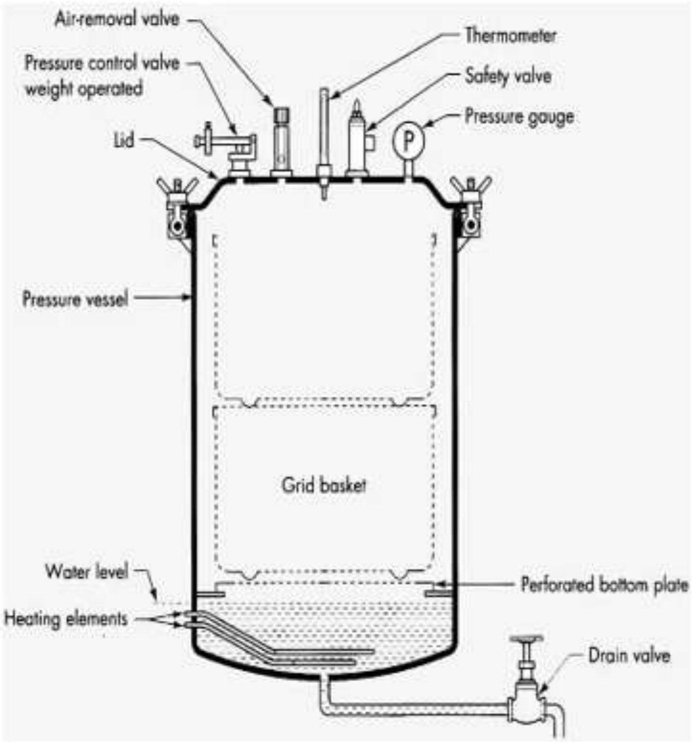


Fig. 2 Shredding machine



i. Component parts

ii. Pictorial view

Fig. 3 Autoclaving machine

RESULTS AND DISCUSSION

The dry weight change, volume and bulk density, as well as the characteristic size of the processed waste components, were used to evaluate the mechanical treatment of the FW fraction of MSW using a specially designed shredding machine. The FW's physical and chemical characteristics, including bulk density, weight, volume, pH, C/N ratio, total organic carbon (TOC), and total Kjeldahl nitrogen (TKN), were also assessed. A known dry weight of FW is fed into the shredder and treated in a brief cycle of roughly five minutes. The treated FW component was found to maintain its original characteristics following treatment, resulting in a characteristic particle size of 10 mm.

Table-2 Physical properties of food waste

S/N	Parameters	Before Shredding	After Shredding
1	Dry weight (kg)	180.45	178.20
2	Volume (m^3)	3.24	3.20
3	Bulk density (kg/m^3)	55.694	55.687

This makes it possible to treat small food wastes like bones, but not materials with a high hardness level, like fruit pits. However, the shredder does not require the use of water during treatment, which resulted in a minimal change in the material's weight after processing. The tiny percentage of waste that sticks to the shredding inside the shredding chamber is the only reason for the weight loss. The fact that the waste takes up less space after shredding makes it easier to package products for sale and recycle them later for future use.

Fig. 4 displays the analysis of the bulk density result. The dry weight of food waste per volume unit is known as the bulk density. The bulk density takes into account the pore space in addition to the solids. It was found that the bulk density of the food waste was approximately the same before and after shredding.

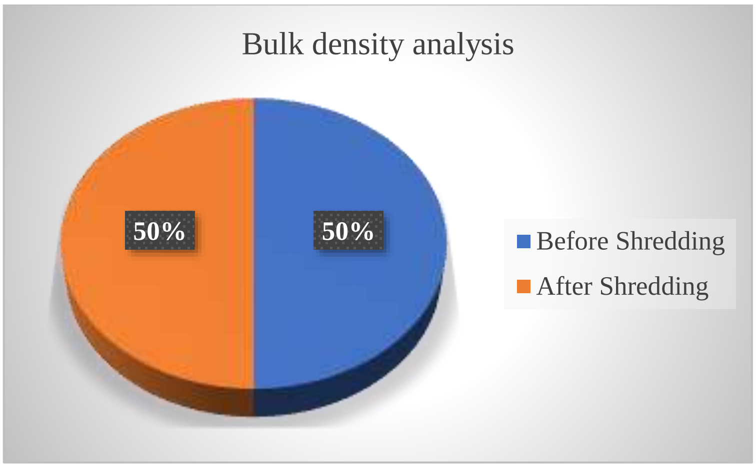


Fig. 4 Result of bulk density analysis

Fish and chicken bones, vegetable peel skin, and leftovers (beans, garri, yam, rice, and fufu) made up the components of the FW generated. Table-3 presents an overview of the chemical properties of FW that have been determined. The properties both before and after the autoclaving process were displayed in the analysis. As suggested by Papadimitriou *et al.* (2009), the results showed that the pH of the treated FW had decreased as expected. This decreased pH was caused by the thermal hydrolysis of organic matter. According to Chang and Hsu (2008), the chain's variation in carbon content also affected pH and acidity. However, as the degradation process progressed, the pH value began to drop because the rate at which acid was produced outpaced the rate at which it decomposed, resulting in an accumulation of acid (Chang and Hsu, 2008). On the other hand, following FW's autoclaving procedure, it was discovered that the TOC content had increased. There was an increase in the TOC concentration from 22.55 to 38.55 percent. According to Kumar *et al.* (2010), the hydrolysis of organic matter into soluble matter was primarily responsible for the changes in TOC. As a result of protein mineralization into nitrate, the concentration of TKN (sum of ammonium and organic nitrate), which was measured from the autoclaved sample, dropped from 0.98 to 1.15% after autoclaving. The C/N ratio is a widely used indicator of the nitrogen content of organic matter (Weindorf *et al.,* 2011). As can be seen from Table-3 result, the C/N ratio increased from 19.51 to 35.27%.

Table-3 Chemical properties of pre-treated and autoclave treated food waste

S/N	Parameter	Pre-treated	Autoclave treated
1	TKN (%)	0.98	1.15
2	TOC (%)	22.55	38.55
3	C/N	19.51	35.27
4	pH (m)	5.45	5.01

CONTRIBUTION TO KNOWLEDGE

This study has demonstrated that MSW generated in Nigerian towns and cities can be managed through mechanical heat treatment. According to the study, the autoclaving process raises the TOC content, lowers the pH, and increases the C/N ratio.

CONCLUSION

The investigation into the mechanical processing of municipal solid waste was completed effectively. The study shown that the bulk density of the FW was roughly the same before and after shredding. Furthermore, the outcomes demonstrate that the FW's C/N ratio could be raised through autoclaving. Conversely, after FW's autoclaving process, it was found that the TOC content had gone up. The concentration of TOC increased from 22.55 to 38.55 %. After the sample was autoclaved, the concentration of TKN (sum of ammonium and organic nitrate) decreased from 0.98 to 1.15% due to protein mineralization into nitrate. All these are indications that FW waste can be mechanical heat treated for organic rich fertilizer thereby reducing the volume of MSW dump indiscriminately in Nigeria towns and cities.

CONFLICT OF INTEREST

The study was carried out by all authors listed and there is no conflict of interest associated with it.

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