

Sustainable Plastic Waste Management During the Arbaeen Pilgrimage: Cost-Effective Strategies for Recycling PET Water Bot- tles

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Abstract

This plastic recycling project seeks to minimize environmental pollution resulting from the accumulation of plastic waste by collecting, sorting, and processing it for reuse in the production of new, usable products. This project aimed to contribute preservation of natural resources, by accumulating plastic in landfills and oceans and reduces dependence on virgin raw materials, in addition to decreasing carbon emissions. Moreover, it raises environmental awareness while also providing employment opportunities in recycling factories through fields of collection, processing, and manufacturing. The project constitutes a crucial step toward achieving sustainable development and a circular economy.

Large quantities of plastic waste have been observed during the Arbaeen pilgrimage in the holy city of Karbala, one of the world's largest human gatherings. This waste primarily consists of water bottles and plastic utensils utilized by pilgrims and Hussaini service processions. While a portion of this waste is sorted and collected systematically by service and volunteer entities, a large portion ends up in general waste without being utilized.

This creates a genuine opportunity to capitalize on these large quantities of plastic through more efficient organization of collection and sorting processes, in collaboration with municipal authorities and environmental initiatives. These materials can be directed toward recycling facilities to be transformed into new, usable products such as household items, benches, storage boxes, or even eco-friendly construction materials.

Keywords: Renewable Energy, Arbaeen Pilgrimage, the Holy City of Karbala, Plastic Recycling, Environmental Pollution, Recycling Factories, Sustainable Development.

Introduction

The extensive use of plastic bottles during the Arbaeen pilgrimage is expected to generate tons of plastic waste, which can significantly impact the environment. This substantial plastic waste can lead to environmental disasters, contributing to pollution. Pollution continues to be one of the most enduring and harmful environmental issues of our time (air and ocean pollution). Despite growing awareness and recycling efforts, most plastic waste ends up in landfills or is incinerated, contributing to ecosystem degradation and climate change (Mohsenzadeh et al., 2023). To address this, the concept of “plastic reborn” (plastic recycling) through distributed recycling and additive manufacturing has emerged. The recycling effort contributed to reduce the carbon emissions to 41.8% lower than that of virgin PET (Junaid et al., 2023). This approach involves converting post-consumer plastic waste directly into 3D printing filament, enabling local reuse of materials while reducing environmental impact (Kumar et al., 2022). This paper proposes that plastic can rebirth in communities or in households, therefore aiming to provide cost-effective, eco-friendly 3D printing filament alternatives while fostering circular economy principles through local recycling efforts. The project aims to design a recycling device from 3D-printed components and produce plastic filament, using a thermal extruder, coil, motors and nozzle.

1.3D Printer Filament

3D printing filaments are primarily composed of thermoplastics. Common types include acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). Other materials used include polycaprolactone (PCL), polycarbonate (PC), polystyrene (PS), polyetherimide (PEI), and various forms of polyethylene (PE), including LDPE (low-density PE), LLDPE (linear low-density PE), and HDPE (high-density PE). These materials are used to print automotive parts, surgical instruments, prototypes, packaging, toys, and many other products that are in everyday use. Figure 1 shows the shape of filament that used to print 3D parts (Muthuraman et al., 2021).



Figure 1: 3D printer filament

2. 3D Printer

A 3D printer is a device used to convert plastic filament to three-dimensional parts. Three-dimensional (3D) printing, also known as additive manufacturing, is a transformative technology that enables the layer-by-layer fabrication of physical objects directly from digital models. Over the past two decades, 3D printing has expanded from prototyping applications to full-scale production across diverse industries, including healthcare, aerospace, automotive, construction, and education. This technology offers significant advantages in terms of customization, material efficiency, and design flexibility. Recent advancements in materials science, printing resolution, and multi-material printing have further broadened its capabilities, allowing for the creation of complex geometries and functional components (Hunt et al., 2015). Figure 2 shows the 3D printer device used in this research.

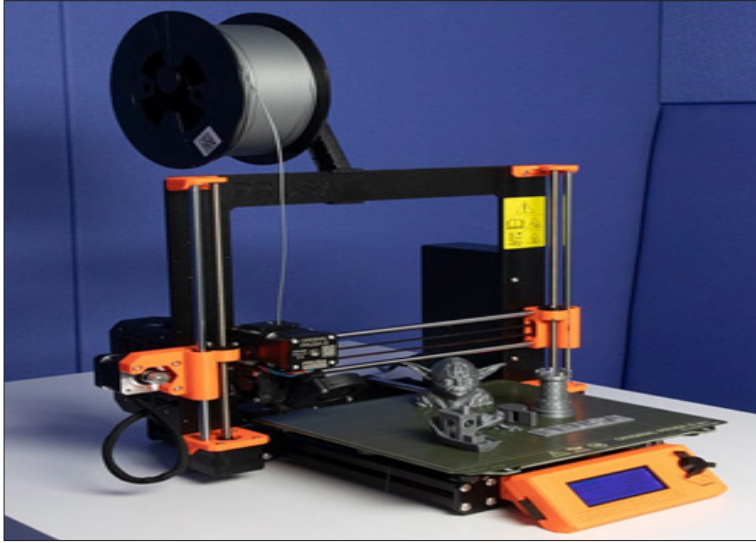


Figure3 :2 D printer

2. Design of the Recycling Device

To manufacture the recycling device, each component was designed using SolidWorks software. The designs were then 3D printed and assembled into the final system (Hopewell et al., 2009).

Step 1: SolidWorks Design

SolidWorks is a leading computer-aided design (CAD) software widely used in engineering, product design, and manufacturing industries for creating precise 3D models and detailed technical drawings (Andrady, 2011). SolidWorks provides an integrated environment that supports the full product development lifecycle—from conceptual design and simulation to manufacturing documentation and analysis. Its parametric modeling approach allows for efficient design modifications, while its simulation tools enable structural, thermal, and motion analysis to optimize product performance before physical prototyping. Figure 3 illustrates the CAD model of the recycling device, where each part is designed for 3D printing.

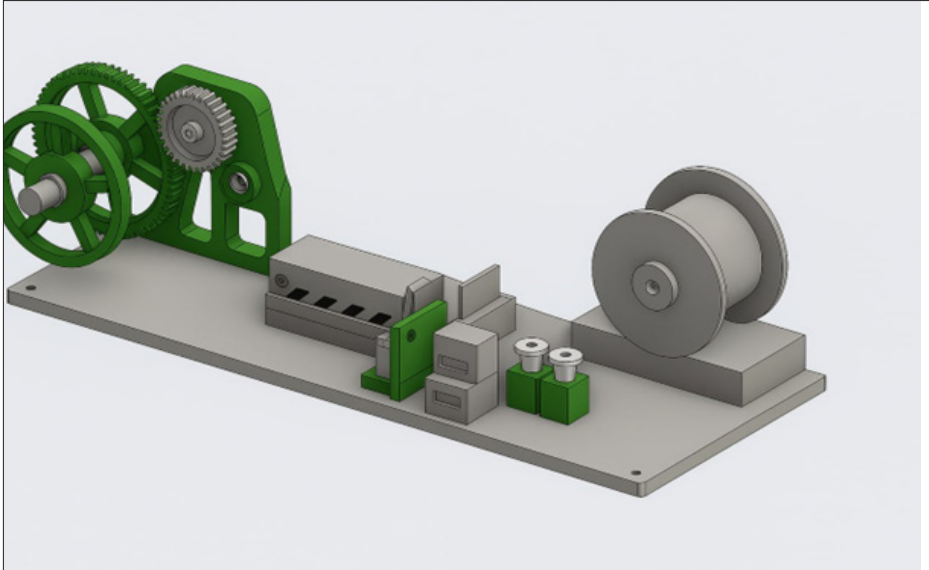


Figure 3: Recycling device model in SolidWorks

Step 2: 3D Printing

Once the components were designed in SolidWorks, they were printed using a 3D printer. Figure 4 shows the parts prepared for printing, and Figure 5 displays the printed components.

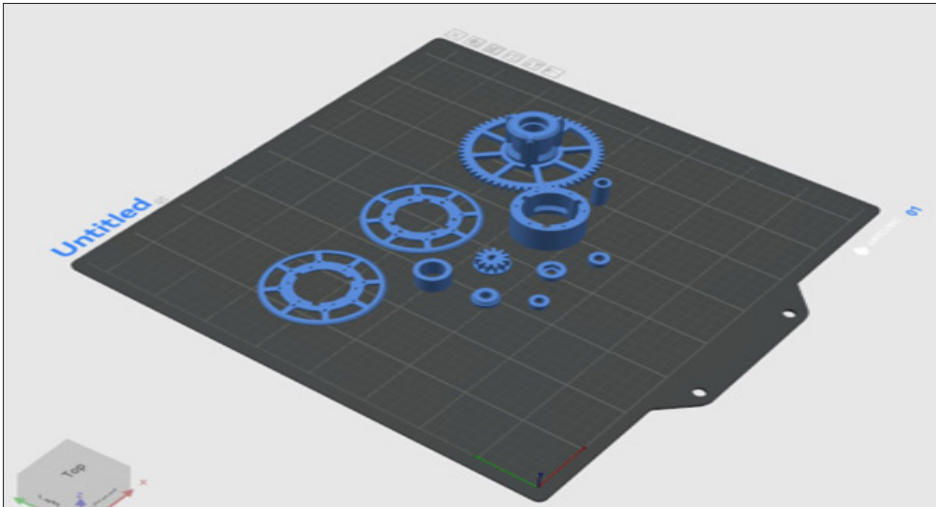


Figure 4: 3D part before printing in 3D printer.

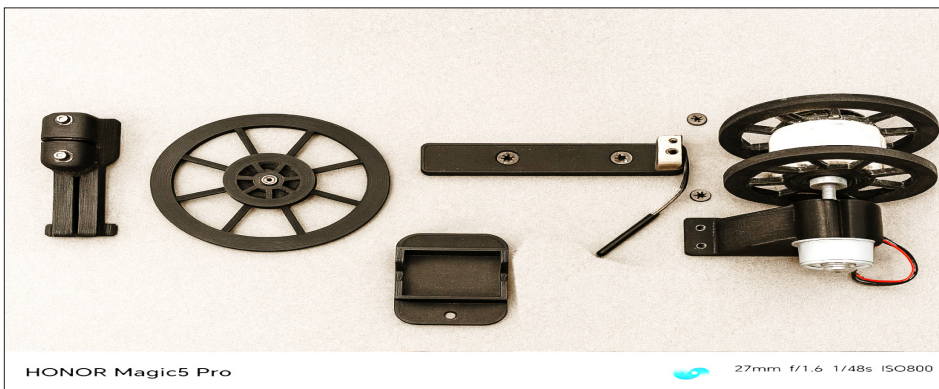
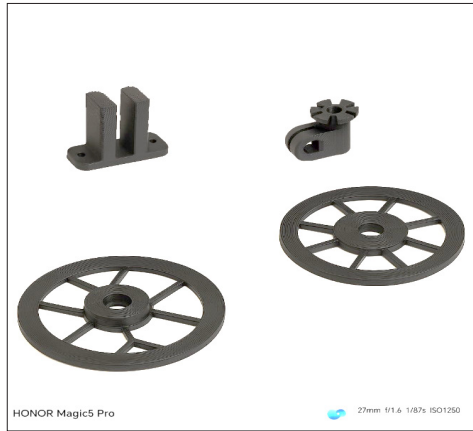


Figure 5: 3D printer devices after printing

Step 3: Other Components Used in the Device

Additional components required for the device include:

- Nozzle (V6 Volcano): Inlet diameter 3mm- entry size for feeding the PET strip, Outlet diameter: 1.2 mm – extrusion opening for melted filament, Material: Brass or stainless steel for durability and thermal conductivity, Drilling: 1.2 mm outlet is drilled into a 1.6 mm hole to support 1.75 mm.



Figure 6: Nozzle

- Ceramic Heater: A 12V DC, 40W ceramic heating element for efficient and consistent heating. This is made of ceramic material. It features a threaded screw-on connector for heater block compatibility (Singh et al., 2017).



Figure 7: Ceramic heater

- Aluminum Heater Block: Made of Aluminum material for efficient transfer of heat from the heater to the nozzle. Designed to fit the V6 Volcano nozzle and securely hold it in place (Zander et al., 2018).

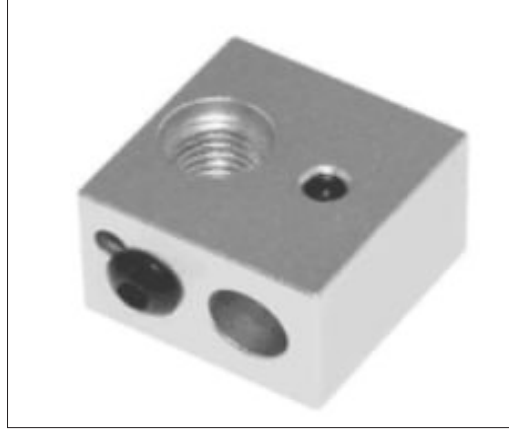


Figure 8: Aluminum heater block

- Thermo Controller (TC 49P or TEX C100): Regulates temperature using a K-type thermocouple and solid-state relay



Figure 9: Thermo controller TC 49P

- High-Torque Motor and PWM Controller: Enables smooth filament pulling and precise speed control (Jambeck et al, 2015).



Figure 10: High torque Motor

- 10A 12V SMPS (Switched Mode Power Supply): Powers the system with overvoltage and overcurrent protection, delivering a stable 12V DC output. Capable of supplying at least 10A for safe operation of all components.

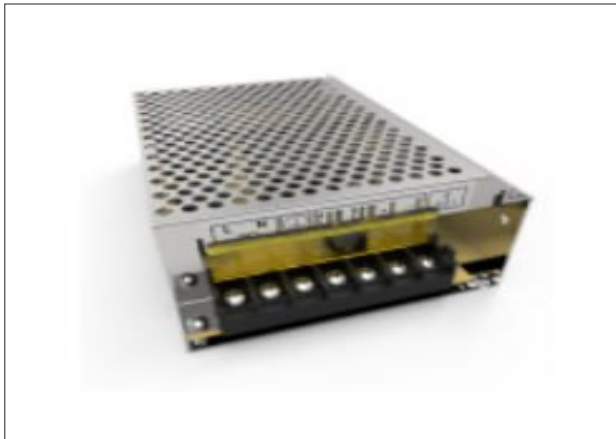


Figure 11: SMPS

Step 4: Assembly

After printing the components and sourcing the electronic parts, the recycling device was assembled. Figure 12 shows the fully assembled device.

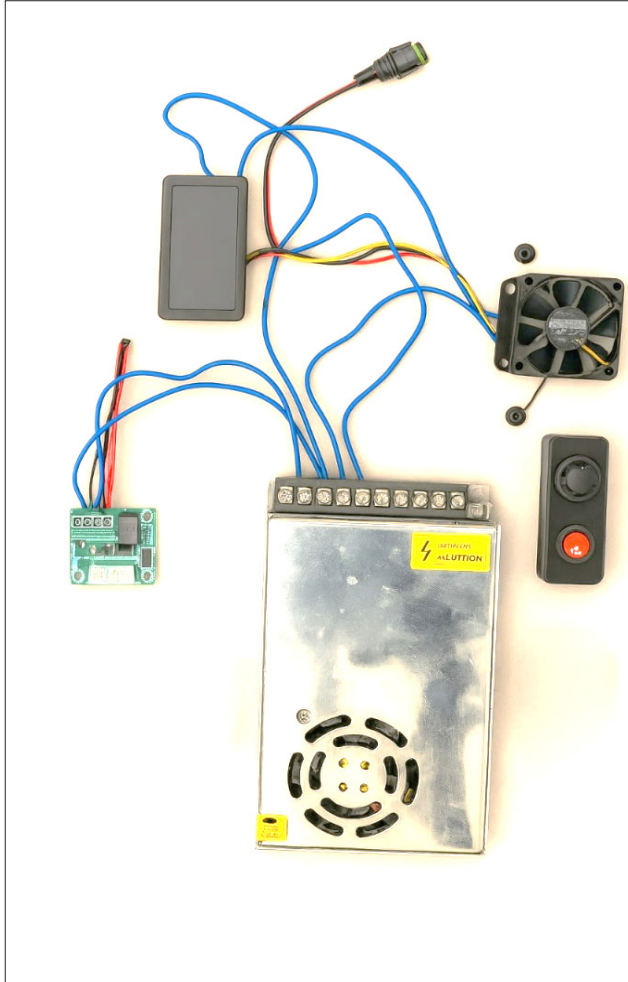


Figure 12: Gathering device parts

3.Process Methods

The following steps describe the recycling process used to convert waste plastic bottles into 3D printing filament.

Step 1: Used plastic cups and bottles are collected after thorough cleaning to ensure high-quality filament. In this project, the plastic waste was primarily sourced during the Arbaeen pilgrimage. Figure 13 shows the collected plastic waste.



Figure 13: Plastic cups and water bottle waste

Step 2: A small amount of water is added to each bottle, and the bottle is then heated using a gas burner. This softens the plastic, making it easier to cut. Figure 14 shows the heating process.



Figure 14: Water added to bottle while heating

Step 3: After softening, the plastic is cut into strips using a manual cutting tool. Figure 15 shows the cutting tool used.



Figure 15: cutter tool

Step 4: The plastic strips are fed into the heater at approximately 220°C. The heated plastic is extruded through a nozzle to produce a thin filament. Figure 16 displays the filament being extruded.

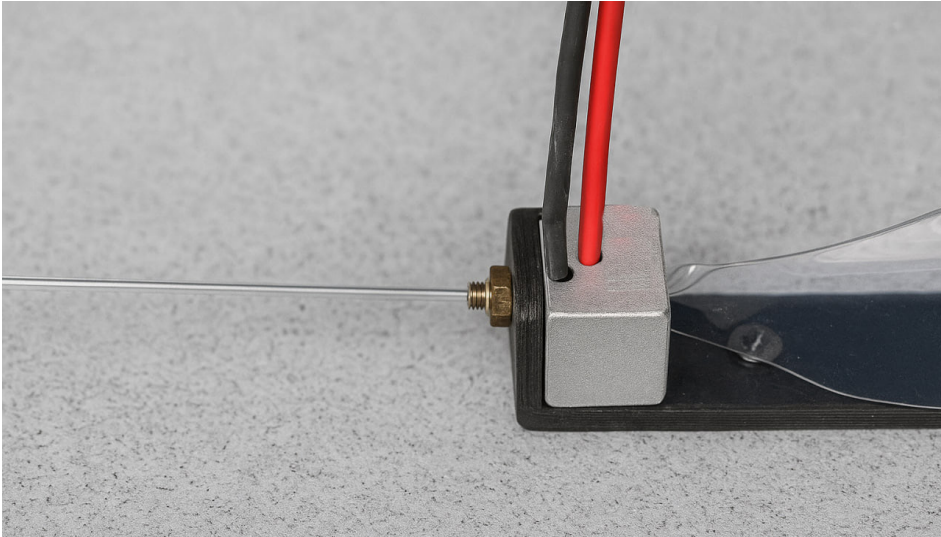


Figure 16: Filament produced from plastic strips

Step 5: The filament is pulled using a high-torque motor and cooled in ambient air. It is then wound onto a roller for storage. Figure 17 illustrates the pulling mechanism.

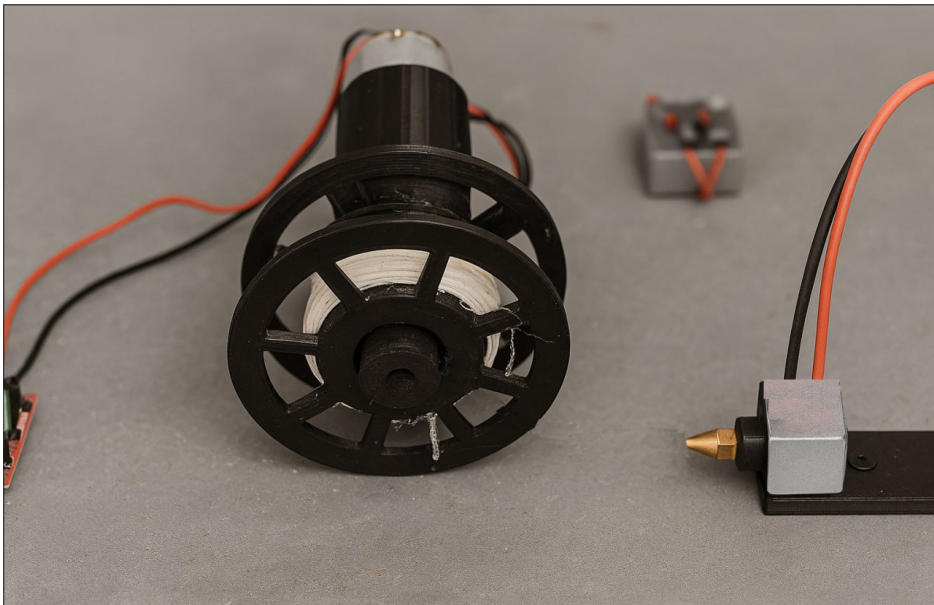


Figure 17: Filament pull using high torque motor

Result

The heating subsystem, consisting of a heater block and nozzle, was used to convert plastic strips into filament. The device operates at a temperature range of 200°C to 220°C. Figure 18 illustrates the heating block that converts strips to manufacturing filament.

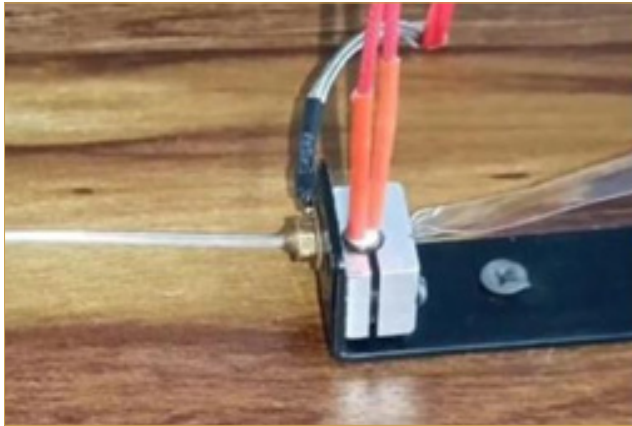


Figure 18: Extract filament from plastic bottle strips

The pulling mechanism existing, where using high Torq motor are used for this purpose. As the filament exited the heater block, it was cooled by open air and solidified into a strand of approximately 1.75 mm in diameter. Figure 19 shows the pulling mechanism.



Figure 19: Pulled mechanism