Recycling Waste Plastic Bottles Into 3D Printer Filament: A Sustainable Approach Using FDM Technology

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Abstract- *The global surge in plastic production and consumption has led to an alarming increase in plastic waste, threatening ecosystems, public health, and environmental sustainability. A substantial portion of this waste arises from single-use plastic water bottles, which often find their way into landfills and oceans. This study proposes an innovative, eco-conscious solution by designing and developing a 3D printing filament making machine that recycles PET-based plastic bottles into usable 3D printing filament. The machine integrates a custom-built extrusion setup, cooling system, and winding mechanism to convert shredded bottle pieces into uniform filament. Experimental trials demonstrate that the machine is capable of producing high-quality filament suitable for Fused Deposition Modeling (FDM) 3D printing applications. Through a systematic exploration of materials, processes, and sustainability impacts, this project contributes to addressing plastic waste challenges while promoting circular economy principles.*

Keywords- Plastic recycling, PET bottles, 3D printing, FDM, filament extrusion, sustainable manufacturing, circular economy, environmental impact, additive manufacturing, waste valorization

I. INTRODUCTION

1.1 Background

The extensive use of plastic materials in contemporary society has brought forth a dual-edged sword—while plastics provide invaluable benefits in terms of versatility, affordability, and durability, their persistence in the environment poses serious ecological and health threats. According to the Central Pollution Control Board (CPCB) of India, nearly 9.4 million tonnes of plastic waste are generated annually, with only 60% being recycled. PET (Polyethylene Terephthalate) bottles, widely used for beverages, account for a significant portion of this waste due to their single-use nature.

1.2 The Plastic Dilemma

Plastics are non-biodegradable; depending on the type, it can take hundreds of years to degrade. PET bottles, for instance, can take up to 1000 years to fully break down. Meanwhile, microplastics resulting from degradation contaminate soil, groundwater, and marine ecosystems. Ingested by aquatic organisms, these particles bio accumulate and ultimately impact human health.

1.3 Rationale of the Study

Despite several initiatives, plastic waste continues to accumulate due to ineffective collection, poor waste management infrastructure, and limited recycling capacity. Recycling plastics into useful products such as 3D printing filament represents a promising solution. The goal of this project is to create a low-cost, accessible system that repurposes discarded PET bottles into high-quality filament compatible with FDM printers. The study aims to foster a culture of recycling and innovation in material utilization.

II. LITERATURE REVIEW

The environmental concerns surrounding plastic waste and its harmful impacts have been well documented. Previous researchers, including KhileshSarwe and Pramod S. Patil, emphasize the urgent need for advanced recycling mechanisms. Sarwe highlights that despite efforts to limit plastic use, its consumption continues to rise due to the lack of alternatives. Patil focuses on the utility of recycled plastics in various engineering applications and advocates for broader implementation of recycling technologies.

Recycling of plastic bottles into 3D printer filament has gained traction due to the growth of the additive manufacturing sector. However, challenges remain in achieving uniform filament diameter, maintaining melting temperature, and ensuring consistent mechanical properties.

Most existing methods rely on virgin polymers, making recycled alternatives crucial for achieving sustainable development goals.

III. METHODOLOGY

The filament-making process involves several stages:

1. The Extruder Successfully Melted PET and Formed Continuous Filament

This observation confirms the fundamental capability of the filament-making machine: melting PET and extruding it into a continuous, usable filament.

PET (Polyethylene Terephthalate) has a melting temperature in the range of 230–250°C. The extruder's hotend was capable of reaching and maintaining this temperature range, enabling the plastic to transition from a solid state to a viscous flowable form suitable for extrusion.

A standard 1.75 mm nozzle was used for extruding the molten plastic. The PET smoothly passed through this nozzle, demonstrating that the extrusion force (likely provided by a screw or plunger system) was sufficient to handle the material's viscosity.

Continuous filament formation means that the melted PET cooled and solidified uniformly after extrusion, without interruptions, clogs, or breaks — a crucial requirement for high-quality 3D printing filament.

This indicates that the core functionality of the machine (melting and extruding) is well-designed and compatible with recycled PET as feedstock.

2. Filament Consistency Improved with Precise Speed and Cooling Control

One of the most important quality factors in 3D printer filament is diameter consistency (usually targeted at 1.75 ± 0.05 mm). Variations can lead to clogs, print failures, or uneven extrusion during 3D printing.

Speed Control: By adjusting the rotation speed of the motor-driven spool, the system can regulate the rate at which filament is pulled from the extruder. Pulling too quickly can thin the filament (or even snap it), while pulling too slowly can cause thick spots or material backflow.

Use of a 60 RPM, 1.95 Nm torque motor with a speed controller allowed for fine-tuning of this extrusion-pull rate balance.

Cooling Control: A 12V DC cooling fan was positioned right after the nozzle to rapidly solidify the extruded filament. This cooling is critical because:

It prevents filament from sagging or stretching due to gravity or momentum before it sets.
It locks in the diameter and roundness before the filament gets wound onto the spool.

With both precise motor control and effective cooling, the filament had significantly fewer deviations in diameter and maintained a more circular cross-section, which is ideal for FDM printers.

3. Manual Cutting Introduced Variability in Feedstock, Affecting Initial Output Quality

The plastic bottles were manually cut into strips before being fed into the extruder. This manual process introduced several inconsistencies:

- Strip Thickness and Width: Variability in size affected the feed rate and melting rate. Thicker strips took longer to melt, while thinner ones melted too quickly, leading to flow rate fluctuations.
- Foreign Matter: In some cases, pieces of labels or glue residues remained on strips, polluting the filament or clogging the nozzle.
- Feeding Mechanism: Since the feedstock wasn't uniformly shaped, it required manual monitoring to ensure it entered the extruder smoothly.

As a result, during early runs, the filament showed:

- Diameter inconsistencies due to fluctuating extrusion pressure.
- Color or texture inconsistencies from contaminated feedstock.
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This issue can be mitigated in future versions by:

- Introducing automated shredders or grinders that create uniformly sized PET flakes.
- Adding pre-processing steps like washing, drying, and quality screening.

4. Proper Temperature and Fan Placement Reduced

Warping and Bubbles

Warping and bubbles are common problems during filament extrusion and directly affect print quality.

- Warping occurs when the filament cools unevenly, leading to internal stresses. This can make the filament curve or twist, making it unusable.
- Bubbles are formed when trapped air or moisture in the PET expands during melting, creating voids or bumps in the filament.

These issues were tackled as follows:

- **Proper Temperature Control**: The extruder was operated in a narrow optimal range (around 230–240°C for PET). Temperatures above this could cause thermal degradation (yellowing, gas formation), while lower temperatures risked under-melting and clogging.
- **Fan Placement**: The fan was mounted **immediately downstream of the nozzle**, ensuring that:
- The filament was rapidly cooled before it could sag or deform.
- Volatile gases from overheating were minimized.
- Surface finish was smooth and consistent.

Result: This reduced the occurrence of:
- Bubbles (from outgassing or moisture).
- Warping (from uneven or delayed cooling).
- Surface imperfections.

IV. EXPERIMENTATION AND SETUP

4.1 Machine Components and Functions

1. Extruder
- Function: Heats and melts PET plastic.
- Description: The extruder includes a hotend, nozzle, and heater. The shredded plastic strips are introduced and melted uniformly before being pushed out through the nozzle.

2. Cutter
- Function: Cuts plastic bottles into thin strips.
- Description: A hand-operated or motorized blade assembly is used to cut cleaned PET bottles into manageable pieces for extrusion.

3. Motor
- Type: 60 RPM, 1.95 Nm torque.
- Function: Drives the winding disk.
- Purpose: Ensures smooth and controlled spooling of extruded filament.

4. Cooling Fan
- **Specification**: 12V DC.
- **Function**: Rapidly cools down the extruded filament to maintain uniformity and prevent deformation.

5. Speed Controller
- **Function**: Manages the motor speed for both extrusion and filament winding.
- **Benefit**: Allows fine control over filament tension and diameter.

6. Adapters
- **Specifications**: 12V 3A and 12V 2.5A.
- **Purpose**: Provide regulated power supply to various electronic components.

7. Stand, Holder, and Accessories
- **Function**: Structural support and secure mounting of components.
- **Description**: Holds the extruder, motor, and winding system in place for precise operation.

4.2 Filament Fabrication Process

- **Bottle Collection and Cleaning** Used PET bottles are collected, labels removed, and washed thoroughly to eliminate contaminants and adhesives.
- **Cutting into Strips** Bottles are manually cut into thin strips using the cutter. Uniform strip width is essential for consistent extrusion.
- **Feeding into Extruder** Strips are fed into the extruder manually or with a feeder mechanism. The heater element melts the plastic at approximately 230°C (optimal for PET).
- **Filament Extrusion** Molten PET is pushed through a nozzle with a diameter of 1.75 mm (standard for most 3D printers). The speed of extrusion is controlled via the motor and speed controller.
- **Cooling Phase** The filament passes beneath a 12V DC cooling fan, which rapidly cools it to retain shape and avoid stretching or sagging.
- **Winding and Spooling** The cooled filament is wound onto a spool using a rotating disk connected to the motor. Proper synchronization is necessary to maintain even spooling.
- **Testing and Quality Control** The filament diameter is checked using calipers to

ensure tolerance of ±0.05 mm. improperly extruded filament is remelted.

4.3 Material Used

- **PET (Polyethylene Terephthalate)**: Derived from used plastic water bottles.
- **Electrical Components**: Motors, adaptors, speed controllers.
- **Mechanical Components**: Extruder, stand, cutter, spooling disk.

V. RESULTS AND OBSERVATIONS

- The extruder successfully melted PET and formed continuous filament.
- Filament consistency improved with precise speed and cooling control.
- Manual cutting introduced variability in feedstock, affecting initial output quality.
- Proper temperature and fan placement reduced warping and bubbles.

Observational Highlights

- **Diameter Consistency**: Achieved 1.75 ± 0.07 mm.
- **Spooling Uniformity**: Improved with synchronized speed control.
- **Material Use Efficiency**: 95% of plastic strips successfully converted.

VI. DISCUSSION

This experiment validates that PET bottles, typically discarded as waste, can be efficiently recycled into filament suitable for FDM 3D printing. The machine provides a low-cost, decentralized recycling solution, especially useful in educational institutions, makerspaces, and local communities.
Challenges encountered included:

- Inconsistent melting due to bottle thickness variation.
- Manual feeding limiting throughput.
- Occasional nozzle blockages requiring maintenance.

However, these issues are manageable through automation upgrades, improved sensors, and consistent feedstock processing.

VII. ENVIRONMENTAL IMPACT AND SUSTAINABILITY

The project supports several sustainability goals:

- **Waste Reduction**: Diverts plastic bottles from landfills and oceans.
- **Resource Conservation**: Reduces reliance on virgin polymers.
- **Energy Efficiency**: Recycling consumes less energy than producing new plastic.
- **Educational Value**: Serves as a model for awareness-building in schools and colleges.

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VIII. CONCLUSION

This study demonstrates a practical and impactful way to repurpose plastic bottle waste by converting it into filament for 3D printing. The machine developed is both cost-effective and sustainable, aligning with circular economy principles. It not only mitigates environmental damage caused by plastic waste but also empowers individuals and communities to actively participate in waste reduction.

By scaling this technology and introducing further automation, this concept can evolve into a commercially viable solution for local manufacturing, prototyping, and educational projects. It stands as a testament to how engineering and innovation can directly address environmental concerns.

IX. FUTURE SCOPE

- Integration of automatic bottle feeders.
- Use of sensors for real-time filament diameter monitoring.
- Compatibility testing with other plastics like HDPE and LDPE.
- Development of hybrid filaments by mixing recycled PET with additives.
- Commercializing the unit for schools and startups.

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