

Design and Thermal Analysis of a Low-Cost FDM Based 3D Printer

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Abstract

Three-dimensional (3D) printing has emerged as one of the most important technologies in modern manufacturing. Unlike conventional subtractive manufacturing methods, additive manufacturing builds objects layer by layer directly from digital models, reducing material wastage and enabling rapid prototyping. Among the various additive manufacturing technologies, Fused Deposition Modelling (FDM) is widely used due to its simplicity, affordability, and ease of operation.

This paper presents the design, fabrication, and thermal analysis of a low-cost FDM-based 3D printer developed using readily available components. The complete printer assembly was designed using SolidWorks software and fabricated to provide an economical solution for educational and prototyping applications. Thermal analysis of the extruder nozzle was carried out to evaluate temperature distribution, heat transfer characteristics, and extrusion performance during ABS filament printing. Brass was selected as the nozzle material due to its high thermal conductivity and cost-effectiveness. Simulation results indicated a maximum temperature of 508 K and a minimum temperature of 416 K across the nozzle. The analysis confirmed uniform heat distribution and efficient thermal behavior, leading to improved extrusion quality and dimensional accuracy. The study demonstrates that a reliable and efficient 3D printer can be developed at low cost without significantly compromising performance.

Keywords: 3D Printing, Additive Manufacturing, FDM, Thermal Analysis, ABS Filament, Nozzle Design, Rapid Prototyping.

1. INTRODUCTION

Additive Manufacturing (AM), commonly known as 3D printing, is a process of creating three-dimensional objects by depositing material layer by layer according to a digital model. Unlike conventional manufacturing methods that remove material through machining operations, additive manufacturing builds components directly from CAD models, minimizing material wastage and production time.

The increasing demand for rapid product development, customization, and complex geometries has accelerated the adoption of additive manufacturing technologies across various industries. Applications of 3D printing are found in aerospace, automotive, healthcare, architecture, defense, and education.

Among all additive manufacturing techniques, Fused Deposition Modelling (FDM) is one of the most popular because of its low cost and compatibility with thermoplastic materials such as PLA, ABS, and PETG. In FDM technology, a filament is fed through an extruder, heated to its melting temperature, and deposited through a nozzle onto a print bed layer by layer.

Commercial 3D printers often have high acquisition costs, limiting their use in educational institutions and small-scale industries. Therefore, the development of a low-cost and reliable 3D printer is important for expanding accessibility and promoting innovation.

The objective of this study is to design and analyze a low-cost FDM-based 3D printer and investigate the thermal performance of its nozzle assembly.

2. LITERATURE REVIEW

Lalit Kumar, Qamar Tanveer, and Vineet Kumar developed a low-cost 3D printer with a build volume of $20 \times 20 \times 20$ cm and printing accuracy of 0.1 mm. Their work demonstrated that affordable printers can be manufactured using economical components while maintaining satisfactory performance.

Limei Yuan described 3D printing as a significant contributor to the third industrial revolution. The study emphasized the role of additive manufacturing in reducing transportation costs, inventory requirements, and manufacturing complexity.

Suraj Takale, Siddharth Singh, and co-researchers designed and analyzed an FDM-based 3D printer using SolidWorks software. Their study highlighted the feasibility of producing economical printers using locally available materials.

Shishir Kumar Singh and Rajesh Satankar performed analytical and numerical investigations on FDM extruders. Their research demonstrated the importance of thermal management in improving print quality and extrusion efficiency.

Yong Zhou and co-researchers analyzed temperature distribution in the FDM process and concluded that thermal behavior significantly affects filament bonding and mechanical properties.

Recent studies from 2024–2026 focus on AI-enabled printers, IoT-based monitoring systems, smart process control, and sustainable manufacturing using biodegradable materials.

3. DESIGN AND DEVELOPMENT OF 3D PRINTER

The developed printer consists of the following major components:

3.1 Extruder Assembly

The extruder is responsible for feeding, melting, and depositing filament material through the nozzle. It consists of a feed mechanism, heat sink, thermal barrier tube, heater block, and nozzle.

3.2 Print Bed

The print bed provides a flat and stable platform for material deposition. Proper bed leveling is essential for achieving dimensional accuracy and good layer adhesion.

3.3 Controller Board

The controller board acts as the brain of the printer. It interprets G-code commands and controls motors, heaters, sensors, and cooling fans.

3.4 Stepper Motors

NEMA-17 stepper motors are used due to their high positioning accuracy and reliable torque characteristics.

3.5 Base Frame

The frame provides rigidity and vibration resistance, ensuring accurate movement and improved print quality.

4. MATERIAL SELECTION

4.1 Brass Nozzle

Brass was selected because of its excellent thermal conductivity and ease of machining.

Property	Value
Thermal Conductivity	109 W/m-K
Specific Heat	380 J/kg-K
Density	9490 kg/m ³

4.2 ABS Filament

ABS was selected because of its strength, durability, and thermal stability.

Property	Value
Filament Diameter	1.75 mm
Glass Transition Temperature	108°C
Extrusion Temperature	230–260°C
Bed Temperature	80–130°C

5. THERMAL ANALYSIS OF NOZZLE

Thermal analysis was performed using SolidWorks Simulation to study heat transfer and temperature distribution within the nozzle assembly.

Objectives

- Determine temperature distribution.
- Ensure uniform filament heating.
- Reduce heat loss.
- Improve extrusion quality.
- Prevent thermal deformation.

The nozzle diameter considered was 0.4 mm, while the ABS filament diameter was 1.75 mm.

The heat transfer through the nozzle is governed by Fourier's Law of Heat Conduction:

$$q = -kA(dT/dx)$$

where:

q = Heat transfer rate (W)

k = Thermal conductivity (W/m-K)

A = Cross-sectional area (m²)

dT/dx = Temperature gradient

The simulation generated temperature distribution, heat flux, and thermal gradient plots for evaluating nozzle performance.

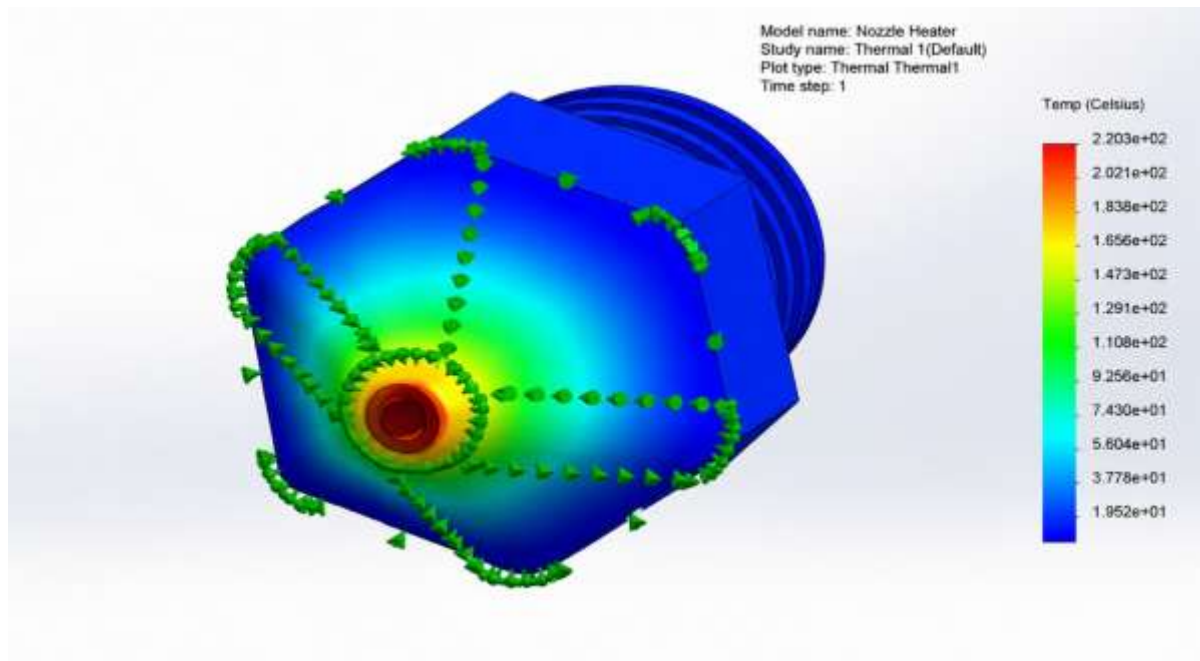


Fig.1 Analysis on Nozzle

The objectives of thermal analysis are:

- To determine the temperature distribution over the nozzle surface.
- To ensure uniform heating of the filament material.
- To minimize heat loss to surrounding components.
- To prevent overheating and thermal deformation of the nozzle.
- To improve printing quality and extrusion efficiency.

In thermal analysis, parameters such as thermal conductivity, heat flux, convection, and operating temperature are considered. Proper thermal management helps maintain stable extrusion temperature, resulting in smooth material flow and better print accuracy.

6. RESULTS AND DISCUSSION

The thermal simulation demonstrated efficient heat transfer within the nozzle assembly.

Observations

- Maximum temperature occurs near the heater cartridge.
- Temperature decreases gradually away from the heat source.
- Uniform heat distribution ensures proper filament melting.
- Thermal gradients help identify heat loss regions.

Results

Parameter	Value
Maximum Temperature	508 K
Minimum Temperature	416 K
Temperature Drop	92 K
Average Temperature	462 K
Heat Transfer Rate	5.014 W

The results indicate that proper thermal management significantly improves extrusion quality, dimensional accuracy, and layer adhesion.

7. APPLICATIONS OF 3D PRINTING

Aerospace

3D printing enables lightweight component manufacturing and rapid production of complex aerospace structures.

Automotive

Automotive industries use additive manufacturing for prototyping, customized components, and lightweight structures.

Healthcare

Applications include prosthetics, implants, surgical models, and personalized medical devices.

Defense

3D printing is used for mission planning models, spare parts production, and rapid deployment of customized components.

Education

Educational institutions use 3D printing for practical learning, engineering models, and research activities.

8. FUTURE SCOPE

Future developments in additive manufacturing include:

- Artificial Intelligence (AI)-based print monitoring.
- Internet of Things (IoT)-enabled remote operation.
- Smart self-calibrating printers.
- Cloud manufacturing systems.
- Bioprinting of tissues and organs.
- Sustainable and biodegradable materials.
- Industry 4.0 integration.

These advancements are expected to improve efficiency, automation, and sustainability in manufacturing.

9. CONCLUSION

The graph is plotted by taking 20 nodes along a straight line on the nozzle surface to study the temperature variation across the nozzle body. From the thermal analysis results, it is observed that the temperature gradually decreases from 508 K at the nozzle tip to approximately 416 K at the outer region of the nozzle.

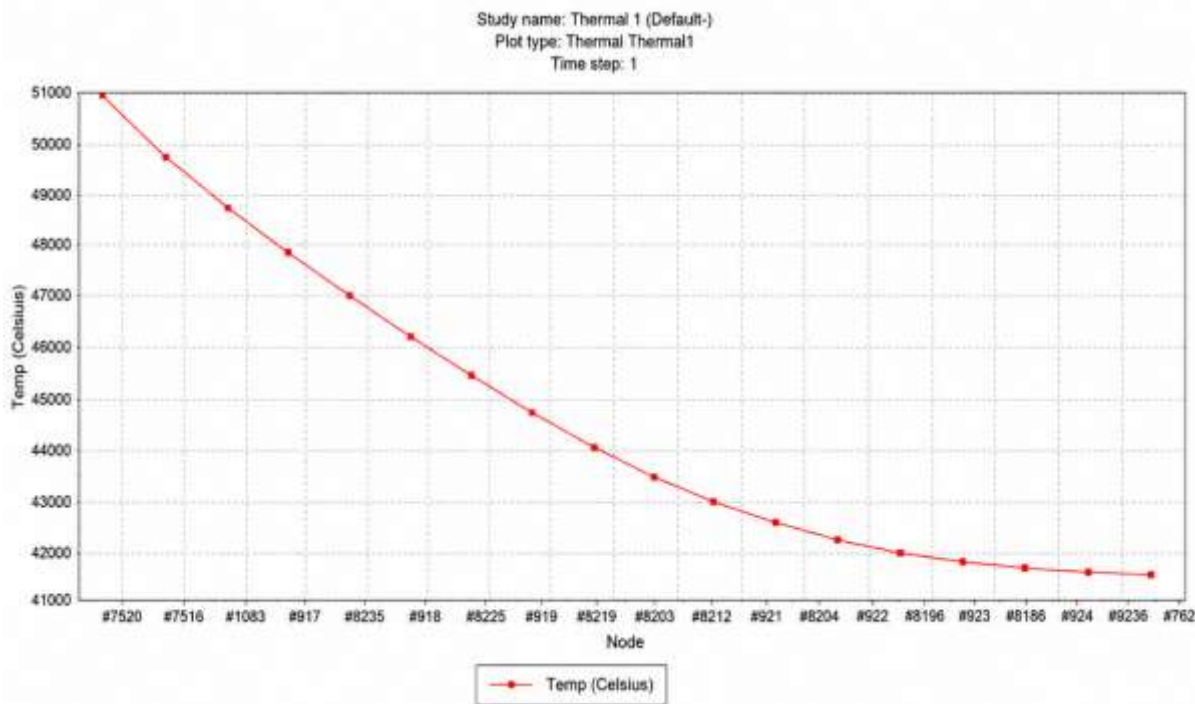


Fig: 2 Temperature Distribution Curve for 20 Nozzle Nodes

A low-cost FDM-based 3D printer was successfully designed and analyzed. Thermal analysis of the brass nozzle confirmed efficient heat transfer and uniform temperature distribution. The developed system provides an economical and reliable solution for educational institutions, research laboratories, and rapid prototyping applications. Future integration of AI, IoT, and smart manufacturing technologies can further enhance printer performance and process automation.

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