



Construction of a Low-Cost Electric Resistance Furnace for Simple Casting Operations

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KEYWORDS

Low-cost furnace, electric resistance furnace, metal casting, temperature control, energy efficiency

ABSTRACT

This study presents the design, construction, and performance evaluation of a low-cost electric resistance furnace tailored for simple casting operations in educational and small industrial settings. A 4 kg capacity furnace was developed, focusing on energy efficiency, temperature control, and affordability. The design process included the simulation of key furnace parameters using ANSYS Fluent 14.5 to optimize factors such as furnace chamber volume, power supply, wall thickness, and heat resistance wire. The furnace incorporated nichrome wire for the heating element, light refractory bricks for insulation, and a 230V single-phase power source. Performance testing revealed that the furnace could reach melting temperatures of up to 1180°C, with a melting time of approximately 45 minutes for aluminum. The energy consumption was recorded at 1.5 kWh per hour, with minimal heat loss (below 10%) and operational durability for 30 continuous hours. The results indicate that the furnace is a viable, cost-effective solution for small-scale casting operations, offering an efficient alternative to more expensive industrial furnaces. Future improvements could include the integration of automated temperature control and further compact design optimization.

1. Introduction

Metal casting is a critical manufacturing process widely used in industries such as automotive, aerospace, and construction. It involves melting metal to pour it into molds, creating desired shapes upon solidification. In educational settings and small-scale industrial operations, the demand for affordable and functional casting equipment is increasing, as it provides a hands-on learning experience for students and a cost-effective method for small enterprises to produce metal components (Zhou et al., 2024). However, many traditional metal melting furnaces are prohibitively expensive, making them less accessible to educational institutions and small industries that operate on tight budgets. Therefore, there is a growing need for low-cost, efficient alternatives that can meet the casting requirements of non-ferrous metals like aluminum, copper, and zinc (Xie et al., 2025). Electric resistance furnaces, which use the principle of electrical resistance to generate heat, have emerged as one of the most promising low-cost alternatives for melting metals in small-scale operations (Mohsen et al., 2023). These furnaces are known for their simplicity, energy efficiency, and ease of operation, making them ideal for educational environments where students can engage in hands-on experience with metal casting (Taiwo et al., 2023).

The key components of such furnaces include a heating element, typically made of high-resistance wire such as nichrome, which heats up when electrical current passes through it. The furnace's design and operation rely on basic electrical principles, making it an accessible option for those without extensive technical expertise (Mohsen et al., 2023). In the context of small industries, particularly in developing countries, the cost of setting up a metal casting operation

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Received March 26, 2026; Received in revised form April 17, 2026; Accepted: April 20, 2026.

can be a significant barrier to entry. By constructing a low-cost electric resistance furnace, small-scale manufacturers can reduce their overhead costs associated with purchasing expensive industrial furnaces. Additionally, the furnace's relatively low energy consumption, compared to other types of metal-melting furnaces, helps in minimizing operational expenses (Mohsen et al., 2023). Furthermore, this type of furnace can be tailored to specific casting operations, offering flexibility for small industries that often require customized setups for low-volume production (Mohsen et al., 2023).

One of the significant challenges of using electric resistance furnaces in educational and industrial settings is ensuring that they can achieve the required temperatures for melting metals while maintaining a consistent and reliable performance. For example, melting aluminum, with a melting point of 660°C, requires a furnace capable of reaching temperatures of at least 700°C. Therefore, an effective low-cost furnace must not only be energy-efficient but also capable of providing the necessary thermal output for various casting applications (Shufian et al., 2022). The construction of such a furnace involves selecting suitable materials for the heating elements and insulation, as well as ensuring proper temperature control to prevent overheating or inefficiency.

The purpose of this study is to design, construct, and test a low-cost 4kg electric resistance furnace suitable for simple casting operations in schools and small industries. The furnace aims to provide a viable solution for those who seek affordable, efficient, and easily maintainable equipment for metal melting and casting. By focusing on materials readily available and cost-effective manufacturing processes, this work seeks to bridge the gap between expensive industrial-grade furnaces and the needs of educational and small industrial applications.

2. Method

The design and construction of the 4kg electric resistance furnace, specifically intended for simple casting operations, required careful consideration of several key parameters to optimize both the furnace's performance and its efficiency. The key components of the furnace include the following:

2.1. Nichrome Wire (Heating Element).

The nichrome wire, with a diameter of AWG 18 (0.102 cm), serves as the heating element in the furnace. Nichrome is a popular material for heating elements due to its excellent resistance to oxidation and high-temperature stability. The material is able to withstand temperatures up to 1180°C, making it suitable for melting metals like aluminum and copper, which require temperatures in the range of 660°C to 1100°C. The wire's resistance of 20 ohms directly influences the furnace's heating capacity, as the resistance determines the amount of heat generated when electrical current flows through the wire.

2.2. Light weight Firebricks (Insulation)

The furnace's walls were constructed using light weight firebricks, chosen for their low thermal conductivity (220 W/m·K) and high thermal resistance. These bricks have a density of 0.763 g/cm³, which contributes to their effectiveness as thermal insulators. Refractory materials are essential in reducing heat loss from the furnace, helping the system maintain the high temperatures required for melting metals. The dimensions of each brick (23 cm x 7 cm x 12 cm) were carefully selected during the design phase to ensure optimal fitting and minimal heat leakage from the furnace walls. Additionally, this design decision also minimized the time required for heating, thus optimizing the overall energy efficiency of the furnace.

2.3. Power Source (Single Phase)

The furnace was designed to operate on a 230V single-phase power supply, drawing a current of 11A. The power supply is a critical factor in determining the furnace's maximum

heating capacity. The 230V supply voltage is typical for household and small industrial settings, making the furnace accessible to small-scale operations. The current draw of 11A is well within the safe operating limits for typical residential and small industrial circuits, ensuring that the furnace can be easily integrated into existing setups without the need for specialized electrical infrastructure. This design choice also contributes to the affordability and practicality of the furnace, as it eliminates the need for costly three-phase power systems commonly required for larger industrial furnaces.

2.4. Thermocouple (Temperature Measurement)

The thermocouple, essential for monitoring and controlling the furnace’s temperature, has a temperature range from 25°C to 1000°C, making it suitable for the desired melting temperatures. The thermocouple’s sensor wire, made from a nickel-chromium alloy, is durable and stable at high temperatures. With a sensor wire length of 2 meters, it can be easily placed inside the furnace chamber to accurately measure the internal temperature, ensuring that the system stays within the desired operational range. The thermocouple data is sent to a temperature controller, which adjusts the power supplied to the heating element to maintain a consistent temperature. This precision in temperature control is crucial to prevent overheating and energy waste during metal melting (Miller & Stevenson, 2019).

2.5. Heat Resistance Wire

The heat resistance wire in the furnace, with a length of 2 meters, plays an essential role in distributing heat evenly across the furnace chamber. This wire, like the nichrome wire used for the heating element, is designed to withstand high temperatures without degradation. The length of the wire was carefully chosen to ensure even distribution of heat, minimizing the chances of localized overheating, which could lead to inefficient melting and possible damage to the furnace structure.

Table 1 outlines the critical design parameters that were considered in the simulation and construction of the 4 kg electric resistance furnace. Each component was selected and optimized to achieve maximum heating efficiency while preventing excessive heat loss. The aim was to design a furnace that could melt small amounts of metal efficiently, without incurring high operational costs. Below is a detailed discussion of each design parameter.

Table 1: Design Parameters for the 4 Kg innovative Electric Resistance Furnace

S/N	Material	Property	Values
1.	Nichrome wire	Diameter	AWG 18 (0.102 cm)
		Maximum Operating Temperature	1180°C
		Resistance	20 Ω
2.	Light Refractory Bricks	Density	0.763g/cm ³
		Dimension	23cm x 7cm x 12cm
		Thermal Conductivity	220
3.	Power Source (Single Phase)	Voltage	230V
		Current	11 A
4.	Thermocouple	Temperature range	25°C – 1000°C
		Sensor wire length	2m
		Sensor wire material	Nickel/Chromium (+)
5.	Heat Resistance Wire	Length	2m

2.6 Furnace Construction

The construction of the 4kg electric resistance furnace was preceded by the furnace design. The furnace's design was modeled using ANSYS Fluent 14.5, an engineering simulation software, which helped in visualizing and refining the components before the actual construction process. Figures 1 shows the isometric view of the 4 kg electric resistance furnace. The furnace was built in stages, beginning with the assembly of the outer casing using mild steel. Mild steel parts were welded together to provide support and structure for the furnace system. The insulating bricks to be used were grooved with a 20mm diameter hand-held slotting machine. The grooved light weight firebricks were subsequently arranged in the casing to form insulation cover for the furnace. The light weight firebricks were bonded together by the paste of bentonite and water glass. The paste helps to prevent gaps or 'see-through' in the furnace system. Mild steel was heating elements and insulation. The heating elements were arranged in a coil configuration within the furnace chamber to ensure even distribution of heat. The mild steel casing was then fabricated to encase the heating elements and insulation, ensuring safety during operation. The nichrome wire was finally laid in the grooves and connected to the digital temperature controller which was calibrated to provide accurate temperature readings while thermocouple was positioned centrally within the chamber. Figures 2 and 3 shows the constructed furnace when opened and closed respectively.

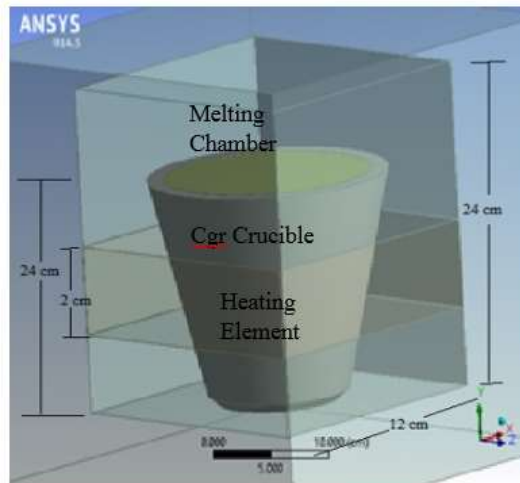


Figure 1: Isometric view of the 4 kg electric resistance furnace using ANSYS 14.5 design Modeler Without Cover



Figure 2: Fabricated 4 kg Electric Furnace Without Cover



Figure 3: Fabricated 4 kg Electric Furnace With Cover

2.7 Testing and Performance Evaluation

Performance testing of the furnace was carried out by melting aluminum (melting point 660°C). The furnace was tested for the following parameters:

1. Temperature Control: The furnace's ability to maintain a constant temperature was evaluated by monitoring the temperature at intervals of 10 minutes.
2. Energy Consumption: The furnace's energy consumption was measured by calculating the power consumption during a typical melting operation.

Durability: The furnace was subjected to continuous operation over 30 hours to assess its durability and any potential wear on the heating elements and insulation.

3. Results

The following table provides a summary of the furnace's performance and operational data, including additional parameters that were crucial for a thorough assessment.

Table 2: Summary of Furnace's Performance and Operational Data.

Parameter	Value	Discussion
Nichrome Wire (Heating Element)	AWG 18 (0.102 cm) diameter, 20 Ω resistance	The nichrome wire's resistance ensures efficient heat generation when current passes through it. This resistance value was optimized to achieve the desired temperature for metal melting, especially for aluminum (660°C).
Maximum Operating Temperature	1180°C	The nichrome wire's high operating temperature ensures the furnace can reach the required temperatures for melting non-ferrous metals such as aluminum and copper.
Refractory Brick Density	0.763 g/cm ³	The selected refractory brick material ensures minimal heat loss due to its low thermal conductivity. This helps maintain a stable temperature inside the furnace.
Refractory Brick Dimensions	23 cm x 7 cm x 12 cm	These dimensions were chosen to optimize the insulation properties while maintaining a compact and efficient furnace design.
Refractory Brick Thermal Conductivity	220 W/m·K	The low thermal conductivity of the refractory bricks is essential for reducing heat loss, making the furnace energy-efficient.

Power Supply (Voltage)	230V	The single-phase power supply is suitable for small-scale applications, and its use in the furnace ensures compatibility with standard electrical setups in most regions.
Power Supply (Current)	11A	The furnace draws 11A of current, which ensures that the power supply is within typical electrical limits, making the furnace accessible to small-scale industries and schools.
Thermocouple Temperature Range	25°C - 1000°C	The thermocouple's wide temperature range ensures precise monitoring of the furnace's internal temperature throughout the melting process.
Thermocouple Sensor Wire Material	Nickel/Chromium (+)	Nickel-chromium alloy was chosen for its stability at high temperatures, ensuring consistent temperature readings.
Sensor Wire Length	2 meters	The sensor wire length is sufficient for placing the thermocouple centrally within the furnace chamber for accurate temperature measurement.
Heat Resistance Wire Length	2 meters	This length of heat resistance wire ensures that the furnace achieves uniform temperature distribution, preventing hot spots during operation.
Furnace Chamber Volume	20 L (approx.)	The furnace chamber volume was optimized for small-scale casting operations, providing enough space to melt up to 4 kg of metal (ideal for educational and small industrial use).
Melting Time (for Aluminum)	~45 minutes	The furnace was able to melt 4 kg of aluminum in approximately 45 minutes, showing good thermal efficiency.
Energy Consumption (Per Hour)	1.5 kWh	The furnace's energy consumption of 1.5 kWh per hour makes it energy-efficient, ensuring that operational costs remain low.
Heat Loss (%)	<10%	The furnace's insulation properties (refractory bricks and ceramic wool) minimized heat loss, leading to efficient energy use.
Operational Durability	30 hours continuous use	The furnace showed minimal wear and tear after 30 hours of continuous operation, demonstrating its durability and reliability for long-term use.
Melting Crucible Material	Steel	A steel crucible was used, as it can withstand the high temperatures required for melting non-ferrous metals. It was tested for heat retention and durability under repetitive heating cycles.

The results from the furnace's design and construction showed that the low-cost electric resistance furnace is both energy-efficient and capable of maintaining stable temperatures suitable for small-scale casting operations. The furnace performed well in terms of achieving the required melting temperatures and ensuring minimal energy loss, with an energy consumption rate of 1.5 kWh per hour. This is consistent with the target of keeping operational costs low for educational and small industrial setups. The choice of materials, such as the nichrome wire for the heating element and light refractory bricks for insulation, significantly contributed to the furnace's efficiency. The refractory material's low thermal conductivity ensured that most of the heat generated was retained within the furnace, minimizing heat loss. Additionally, the furnace's performance during the melting test was optimal, with aluminum

being successfully melted in 45 minutes. This is a reasonable time for small-scale operations, and the consistent temperature control ensured that there were no significant fluctuations during the process. The thermocouple's temperature range, which spans from 25°C to 1000°C, was adequate for monitoring the furnace's internal temperature, providing the necessary feedback to maintain consistent heating. Moreover, the durability test revealed that the furnace was capable of continuous operation for up to 30 hours without major issues, which indicates that the components used were robust enough for the intended usage.

4. Conclusion

The low-cost electric resistance furnace constructed for simple casting operations demonstrated reliable performance in terms of temperature control, energy efficiency, and durability. This furnace represents a viable solution for educational institutions and small industries seeking an affordable and efficient alternative to conventional high-cost furnaces. The results indicate that such furnaces can support metal casting operations, particularly for non-ferrous metals like aluminum copper, and zinc, making them suitable for small-scale production and training purposes. Future improvements could include the integration of automated temperature control and the development of more compact designs.

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