



Design and Construction of a Simple Metal Melting Furnace

Muhammad Syarwali¹, Iqbal¹, Mahyuddin¹, Muhammad Faisal¹, Muhtadin¹

¹Departement of Mechanical Engineering, Universitas Abulyatama Aceh, Aceh Besar 23372, Indonesia

Corresponding Author: iqbal.mesin@abulyatama.ac.id

Abstract

The development of small-scale metal casting technology plays an important role in supporting industrial independence and reducing reliance on imported products. In particular, the use of recyclable metal waste, such as aluminium cans, offers economic and environmental benefits to local communities. However, the high cost and limited accessibility of conventional melting furnaces remain significant challenges for small industries. This study aims to design and develop a simple, efficient, and low-cost metal-melting furnace that uses locally available materials and alternative fuel sources. The research employed a Research and Development (R&D) approach, encompassing design, fabrication, experimental testing, and performance evaluation. The furnace was constructed using readily available materials, with used oil as the primary fuel supplied through a burner system and airflow from a blower. Performance testing included analysis of temperature, melting time, fuel efficiency, and material loss. The results indicate that the developed furnace is capable of melting aluminium efficiently, reaching a maximum temperature of 597°C within 8 minutes and 19 seconds. The combustion system using atomised used oil produced stable, concentrated heat, while the refractory lining effectively retained thermal energy within the furnace. In addition, the melting process resulted in uniform liquid metal with minimal residue, indicating good melting quality. From a performance perspective, using waste oil as fuel demonstrates high efficiency and cost-effectiveness compared to conventional fuels, while also promoting waste utilisation. The furnace design is simple, portable, and easy to construct and maintain, making it suitable for small-scale industries. In conclusion, the developed metal melting furnace successfully meets the requirements of efficiency, affordability, and environmental sustainability. It provides a practical solution for small industries by improving productivity, reducing operational costs, and promoting the use of alternative energy from waste materials.

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1. Introduction

Metal casting plays a crucial role in supporting industrial development in Indonesia, particularly in reducing dependence on imported products. The ability to independently produce metal-based components through local melting processes enables industries to meet domestic demands and strengthen national manufacturing capacity. The development of metal casting technologies,

especially in developing countries, has been widely recognised as a key factor in industrial sustainability and economic growth (Peterson, 1995; Al-Alimi et al., 2024). Furthermore, recycling-based metal production significantly reduces environmental impact and resource consumption (Capuzzi & Timelli, 2018).

The application of appropriate technology in small-scale industries is an effective strategy for creating employment opportunities and reducing youth unemployment. One practical implementation is the establishment of small-scale metal-melting businesses that use recycled aluminium waste, such as beverage cans. This approach not only provides economic benefits but also promotes environmental sustainability by reducing waste (Brough & Jouhara, 2020; Haraldsson & Johansson, 2019). The recycling of aluminium is particularly advantageous because it requires less energy than primary production (Nunes et al., 2023).

Metal waste, including iron, steel, and aluminium, is among the most abundant recyclable materials due to its widespread use in everyday applications. These materials can be efficiently reprocessed into high-quality products through remelting processes. Studies have shown that recycled aluminium scrap can retain good material properties when proper melting and treatment methods are used (Mashhadi et al., 2009; Sun et al., 2023). Therefore, scrap metal should not be treated merely as waste but rather as a valuable resource that can be transformed into products with added economic value (Bao et al., 2023).

To facilitate the adoption of metal casting technology in communities, particularly in small and home-based industries, it is necessary to develop affordable, compact, and easy-to-construct melting furnaces. The use of locally available materials is essential to minimise production costs and ensure accessibility for local artisans. Previous studies have emphasised the importance of low-cost, portable furnace designs for improving productivity and technological adoption in small industries (Madki et al., 2023). Additionally, furnace efficiency and energy consumption remain key considerations in their design and operation (Adeniji & Waheed, 2021; Faisal, 2026). This aligns with the need for simple furnace construction using locally available materials (Suarsana, 2017; Rosdi, Maghfirah, Erdiwansyah, Syafrizal, & Muhibbuddin, 202; Faisal & Iqbal, 2026).

Metal casting is a process in which solid metal is melted into liquid, poured into a mould, and allowed to solidify into the desired shape. The quality of the final cast product depends on several factors, including mechanical properties and defects that form during solidification. Various mould materials such as metal, sand, cement, and ceramics influence the quality of the final product. The relationship between solidification conditions and material properties has been extensively studied, showing that process parameters significantly affect casting quality (Ceschini et al., 2009; Hosseini et al., 2013).

Aluminium is one of the most widely used metals in casting due to its low density and excellent corrosion resistance compared to steel. During the casting process, aluminium undergoes phase transformations influenced by cooling rates and thermal conditions, which, in turn, affect its mechanical properties and microstructure. Previous research has demonstrated that the cooling rate plays a significant role in determining porosity, grain structure, and overall strength in aluminium alloys (Salarvand et al., 2021; Zhang et al., 2022). Proper control of melting and cooling processes is therefore essential to produce high-quality cast products (Setiawan & Nugroho, 2017).

Based on these considerations, this study aims to design and develop a simple, efficient, and cost-effective metal melting furnace using locally available materials and alternative fuel sources, specifically waste oil. The specific objective of this research is to evaluate the furnace's performance in terms of temperature control, melting efficiency, fuel efficiency, and suitability for small-scale industrial applications. The use of alternative fuels, such as waste oil, has also been shown to offer significant economic and environmental benefits in small-scale metal melting processes (Nugroho & Saputro, 2019; Andayesh et al., 2023).

2. Methodology

The methodology used in this study is the Research and Development (R&D) approach. The primary focus of the research is the design, construction, and performance testing of a portable metal-melting

furnace that utilises used oil waste as its primary fuel source. This approach aims to produce a functional prototype while systematically evaluating its performance and efficiency.

The first stage of the research involves the design and fabrication process. In this stage, the furnace structure is designed to be portable, enabling easy relocation while maintaining structural strength and durability. Furnace specifications, such as wall thickness and refractory lining materials, are selected based on the melting point of the target metal. In addition, a fuel system is developed to ensure proper injection or atomization of used oil, enabling it to burn efficiently and generate the high temperatures required for metal melting.

The second stage is the experimental testing phase, where the furnace is operated to evaluate its performance. The melting process uses used oil as fuel to convert solid metal into liquid form. Several parameters are measured during this stage, including cost analysis and material efficiency. The cost analysis involves calculating the production cost of each component and fuel consumption, while material efficiency is assessed by measuring the ratio of metal mass before and after melting to determine the percentage of material loss (metallurgical loss).

The third stage consists of analysis and evaluation, focusing on improving the furnace's overall performance. Thermal efficiency is analysed to enhance heat transfer within the furnace and reduce melting time. Cost-optimisation strategies are also explored to minimise operational expenses without compromising the quality of the molten metal. In addition, energy conservation is evaluated by comparing the use of used oil with other fuel sources such as new oil, gas, or electricity (Nugroho & Saputro, 2019).

The final stage is report preparation and publication, which aims to communicate the research findings to the scientific community. This stage includes the discussion section, where the results are interpreted and compared with previous studies, as well as the conclusion and recommendations, which summarise the findings and provide guidance for future research. Results are disseminated through publication in scientific journals or presentation at seminars and conferences.

3. Result & Discussion

In this section, a comprehensive explanation of the results of the entire fabrication process for the metal melting furnace that uses used oil as its primary fuel source is provided. As shown in **Fig. 1**, the constructed furnace consists of a sturdy metal frame that supports the main combustion chamber, fuel delivery system, and auxiliary components. The furnace body appears to be cylindrical and enclosed, designed to withstand high temperatures during operation. The structural frame ensures stability and safety, especially during the melting process. In addition, the integration of a fuel supply line connected to the burner system demonstrates how used oil is delivered and atomised to produce a consistent, concentrated flame. This configuration highlights the furnace's practical, functional design, making it suitable for small-scale industrial applications.

Furthermore, each component of the furnace plays a critical role in ensuring efficient operation. The combustion system, located on one side of the frame, is designed to mix used oil with airflow, allowing complete combustion and optimal heat generation. The central chamber functions as the main melting area, where metal materials are placed and exposed to high temperatures. The arrangement of the components also reflects a systematic fabrication process, starting from frame construction, installation of the combustion chamber, integration of the fuel system, and final assembly. Overall, the design illustrated in **Fig. 1** demonstrates a simple yet effective approach to constructing a portable, low-cost metal-melting furnace that is easy to operate, maintain, and replicate by local artisans.



Fig. 1. Design and Construction of a Simple Metal Melting Furnace

Fig. 2 illustrates the operational stage of the simple metal-melting furnace after fabrication. The furnace, developed in the Mechanical Engineering Laboratory of Universitas Abulyatama, is specifically designed to use used oil as its primary fuel. Visually, the furnace is cylindrical, supported by a rigid metal frame that ensures stability during operation. The combustion chamber is equipped with a heat-resistant inner lining that protects the outer body from extreme temperatures and retains heat within the chamber. The presence of intense flames inside the furnace, as shown in the figure, indicates that the system is capable of generating the high thermal energy required to effectively melt metal materials.

The furnace's working principle is primarily supported by the combustion (burner) system, which plays a crucial role in producing a stable, high-temperature flame. In this system, used oil is not burned directly in liquid form; it is first atomised into fine droplets and mixed with airflow supplied by a blower. This process ensures more complete combustion, resulting in a larger, more focused flame and higher heat efficiency. As shown in Fig. 2, the flame is confined within the melting chamber, allowing the metal inside to heat evenly and melt efficiently. This design demonstrates that integrating a proper fuel delivery system and airflow mechanism significantly enhances furnace performance, making it suitable for small-scale metal melting applications.



Fig. 2. Combustion Process of Metal Melting in the Furnace

Fig. 3 illustrates the internal structure of the metal-melting furnace, highlighting the insulating wall (refractory lining) and the metal container (crucible). The inner wall of the furnace is constructed using a mixture of cement, sand, gravel, and bricks, which functions as a thermal insulating layer. This refractory lining plays a crucial role in preventing heat from escaping the combustion chamber, ensuring that the generated thermal energy remains concentrated within the melting zone. As a result, the furnace can achieve and maintain high temperatures more efficiently. In addition, this insulating layer enhances operational safety by reducing the temperature at the furnace's outer surface, thereby minimising the risk of burns to users operating nearby.

Furthermore, the furnace is equipped with a metal container, or crucible, that serves as the primary vessel for holding the metal to be melted. As shown in **Fig. 3**, the crucible is positioned at the centre of the furnace to ensure uniform heat distribution from all directions. This central placement exposes the metal to consistent thermal energy, promoting even melting and reducing the likelihood of incomplete fusion or localised overheating. The combination of an effective refractory lining and proper crucible placement demonstrates a well-integrated design that optimises heat utilisation, improves melting efficiency, and ensures the quality of the molten metal.

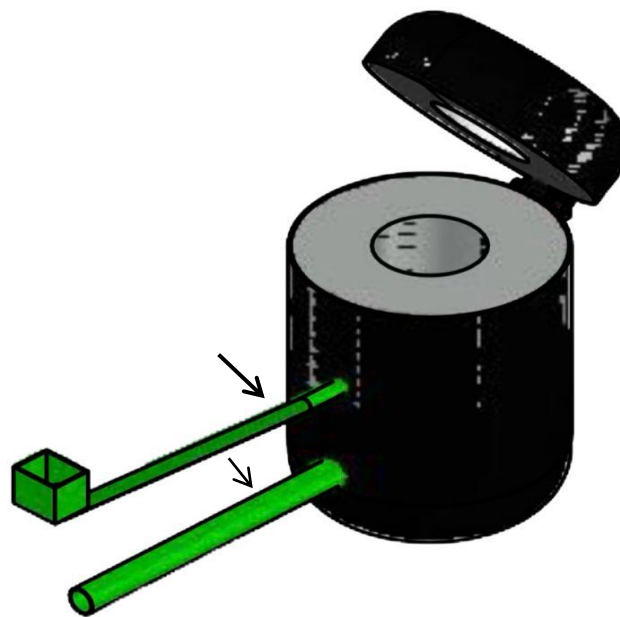


Fig. 3. Insulating Layer of the Metal Melting Furnace

Fig. 4 shows the use of a digital temperature-measuring device during the operation of the metal-melting furnace. The implementation of a digital temperature sensor is crucial for monitoring thermal conditions inside the furnace in real time. Instead of relying on visual estimation to determine whether the metal has reached its melting point, the operator can directly observe accurate temperature readings displayed on the device. As shown in the figure, the thermometer indicates a temperature of approximately 597.5°C, confirming that the furnace can reach the required melting temperature for aluminium. This level of precision enhances the reliability of the melting process and ensures that the furnace operates within the desired thermal range.

Furthermore, integrating a digital temperature measurement system significantly enhances process control and safety. By continuously monitoring temperature, operators can adjust the fuel supply or airflow to maintain optimal combustion conditions. This prevents overheating or insufficient heating, both of which can negatively affect the quality of the molten metal. In addition, accurate temperature data allows for better evaluation of furnace performance and efficiency. Overall, using a digital thermometer not only improves operational accuracy but also delivers consistent, high-quality results in small-scale metal melting applications.



Fig. 4. Thermocouple Temperature Sensor Used in the Furnace System

Table 1 presents a systematic workflow for fabricating the metal-melting furnace, beginning with the preparation stage. This initial stage is crucial as it ensures that all required materials and tools are available and in proper condition before the fabrication process begins. The use of commonly available materials such as steel plates, pipes, angle iron, cement, sand, gravel, and bricks highlights the practicality and cost-effectiveness of the design. Additionally, preparing essential tools such as grinders and drills ensures a smooth execution during subsequent stages, minimising delays and improving overall efficiency.

The second and third stages focus on the construction of the furnace body and the installation of the inner lining. Using a freon cylinder as the main body demonstrates an innovative approach to reusing available materials. Proper sterilisation of the cylinder is essential to ensure safety by eliminating any residual gas before cutting. The installation of the inner lining, a mixture of cement and sand, serves as a refractory layer that protects the furnace structure from direct exposure to high temperatures. The curing process is particularly important because it prevents cracking and ensures the furnace's durability during operation.

Table 1. Fabrication Process Flow of the Metal Melting Furnace

No	Work Stage	Description
1	Preparation of Materials & Tools	1. Materials: steel plates, pipes, and angle iron. 2. Casting materials: cement, sand, gravel, and bricks. 3. Tools: grinder and drill in ready-to-use condition.
2	Furnace Body Fabrication (From Freon Cylinder)	1. Sterilisation: Remove all remaining gas from the freon cylinder completely. 2. Cutting: Cut the top part of the cylinder for the lid and the side for air/oil inlet holes.
3	Installation of Inner	1. Mix cement and sand to form the inner wall lining. 2.

No	Work Stage	Description
	Lining (Casting)	Coat the inside of the cylinder evenly to protect the metal from direct flame. 3. Curing process: Allow the mixture to dry completely to prevent cracking when exposed to heat.
4	Installation of Fuel Supply System	1. Install the pipe for the used oil input. 2. Connect the pipe to the blower (air fan). 3. Position adjustment: Ensure the pipe is installed at an angle to create a swirling flame inside the furnace.
5	Installation of Frame & Insulation (Reinforcement Stage)	1. Install furnace legs using angle iron to ensure stability. 2. Add sound insulation on the outer part to reduce blower noise. 3. Ensure all additional components (e.g., handles) are securely welded.
6	Painting (Finishing)	1. Clean welding residues and rust using a grinder or a wire brush. 2. Apply heat-resistant paint (high-temperature paint) to prevent corrosion and improve durability.
7	Operational Testing	1. Fill with used oil and ignite the initial flame; turn on the blower and adjust oil flow. 2. Monitor for any leakage or obstruction in airflow and fuel supply.
8	Final Stage & Re-Inspection	1. After testing, check for cracks in the inner lining. 2. Ensure all bolts and pipe connections remain tight after exposure to heat. 3. The furnace is ready for routine operation.

The next stages involve installing the fuel supply system and reinforcing the furnace structure. The fuel delivery system, which uses used oil, is carefully designed to ensure efficient combustion by integrating a blower to supply airflow. The angled positioning of the fuel pipe creates a swirling flame inside the furnace, improving heat distribution and combustion efficiency. Meanwhile, installing the frame and insulation enhances structural stability and reduces operational noise. These stages demonstrate the integration of functional and mechanical considerations to optimise furnace performance.

Finally, the finishing, testing, and re-inspection stages ensure that the furnace is ready for safe and efficient operation. The application of heat-resistant paint improves durability and protects the furnace from corrosion due to high temperatures. Operational testing evaluates system performance, including fuel flow and airflow stability, and identifies potential issues such as leaks or obstructions. The final inspection ensures that all components remain secure and that the inner lining is intact after exposure to heat. Overall, the structured workflow outlined in Table 1 provides a comprehensive and practical approach to developing a reliable, efficient metal-melting furnace suitable for small-scale applications.

4. Discussion of Test Results

Based on the experimental data, the developed metal melting furnace demonstrates high efficiency in both processing time and temperature control. The furnace melted aluminium in just 8 minutes and 19 seconds, reaching 597°C. This rapid melting process indicates that the combination of airflow from the blower and the atomization of used oil within the burner system produces a highly concentrated, effective combustion flame. The achieved temperature is sufficient to convert solid aluminium from used beverage cans into a fully molten state, making it ready for casting.

In terms of fuel performance, the use of used oil as an alternative energy source proved to be highly effective and stable. Although commonly regarded as waste material, used oil can generate significant heat when properly atomised and mixed with air in the combustion chamber. The results show that the

thermal output from used oil combustion is comparable to that of conventional fuels such as gas. This finding highlights not only the technical feasibility of using waste oil but also its economic advantage, as it significantly reduces operational costs by utilising readily available workshop waste materials. Another important aspect observed during testing is the refractory lining's effectiveness in maintaining thermal stability within the furnace. The inner wall, composed of a mixture of cement, sand, gravel, and bricks, functions as an efficient thermal insulator. Throughout the heating process to 597°C, the furnace's outer surface remained relatively unaffected by excessive heat. This indicates that the insulation layer successfully minimises heat loss and retains thermal energy within the combustion chamber, thereby improving overall efficiency and ensuring operational safety. Furthermore, the quality of the molten aluminium produced by the furnace is considered satisfactory. The recycled aluminium cans melted uniformly with minimal formation of slag or solid residues. This uniform melting process simplifies the removal of impurities before pouring the molten metal into moulds. As a result, the furnace not only performs efficiently but also produces molten metal of adequate quality for further casting processes. These findings confirm that the developed furnace is suitable for small-scale industrial applications that require efficient, low-cost, and reliable metal melting solutions.

5. Conclusion

Based on the results of the design, fabrication, and testing of the metal melting furnace, several conclusions can be drawn:

- a) **Successful Development of the Furnace:** This study successfully designed and constructed a simple metal melting furnace that operates effectively using an alternative fuel source, namely used oil.
- b) **High Performance and Efficiency:** The furnace demonstrated the ability to melt aluminium (used beverage cans) to 597°C in 8 minutes and 19 seconds. This indicates that the combustion system developed is highly efficient.
- c) **Waste Utilisation:** The use of used oil as a fuel proved highly effective for generating the high temperatures required for metal melting. In addition, it provides a practical solution for utilising workshop waste that would otherwise be discarded.
- d) **Safety and Durability:** The furnace design, which features a lining of cement and other insulating materials, effectively retains heat in the combustion chamber. As a result, the furnace's outer body remains safe and resistant to damage from high temperatures.

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