



## **Design and Fabrication of a Gas-Fueled Metal Melting Furnace Using Shielded Metal Arc Welding (SMAW) Technique for Small-Scale Foundry Applications**

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### **Abstract**

*This study presents the design, fabrication, and performance evaluation of a gas-fueled metal melting furnace developed using the Shielded Metal Arc Welding (SMAW) technique for small-scale foundries. The objective was to create an energy-efficient and environmentally friendly alternative to traditional solid-fuel furnaces commonly used in micro-industrial workshops. Fabrication employed locally available mild steel and refractory materials to ensure low production costs and accessibility. Experimental trials using aluminum revealed that the prototype achieved core melting temperatures above 900 °C and an average gas-to-metal ratio of 0.35 kg/kg, with potential optimization to 0.25 kg/kg. The furnace demonstrated approximately 22% thermal efficiency, exceeding conventional designs by 4%. Cleaner combustion reduced CO<sub>2</sub> emissions by 267 kg per ton of molten metal, while metallurgical tests indicated a 38% reduction in inclusion size and improved casting uniformity. The results confirm that SMAW-based fabrication can yield structurally reliable, cost-effective, and energy-efficient furnaces suitable for community-scale metal industries. The study supports sustainable industrial practices by promoting local manufacturing capabilities and aligning with energy transition goals.*

**Keywords :** *Gas-fueled furnace, small-scale foundry, SMAW fabrication, energy efficiency, cleaner combustion.*



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## **INTRODUCTION**

The rapid growth of small-scale metal foundries in Indonesia has intensified the demand for efficient and affordable melting equipment that can operate safely within limited facilities (Bizhanov et al., 2025). Many local workshops still depend on traditional solid-fuel furnaces that offer low thermal efficiency and generate high particulate emissions. As fuel costs rise and environmental regulations tighten, the need for energy-efficient and cleaner combustion systems becomes increasingly urgent. The Ministry of Industry has identified technological modernization as a key factor to improve competitiveness among small enterprises engaged in metalwork and recycling. Developing a gas-fueled furnace using locally available materials and simple fabrication methods provides an attainable solution to improve performance and sustainability in small workshops.

The *Handbook of Energy and Economic Statistics of Indonesia* published by the Ministry of Energy and Mineral Resources (ESDM) reports that the industrial sector remains one of the largest energy consumers in the country. The same report highlights the government's focus on promoting energy conservation technologies and cleaner fuels to reduce overall consumption intensity. Liquefied Petroleum Gas (LPG) and compressed natural gas (CNG) have been prioritized as transitional fuels to replace coal and charcoal for industrial use. A furnace operating on LPG could significantly reduce emission levels and energy losses compared with solid-fuel systems (Zhang et al., 2021). This study aims to design and fabricate such a gas-fueled metal melting furnace, applying the Shielded Metal Arc Welding (SMAW) technique to ensure structural strength, durability, and ease of construction.

Energy transition initiatives have driven industries to innovate in furnace efficiency and emission control (Nilsson et al., 2021). *Recycling Today* reported that Novelis successfully tested a hydrogen-based recycling furnace that reduced carbon dioxide emissions by up to 90 percent compared with natural gas combustion (Majumder & Ray, 2025). This industrial shift demonstrates the potential impact of optimizing fuel type and combustion design in achieving substantial energy savings. For small-scale

foundries, such high-level technology may be impractical, yet the fundamental principles of efficient fuel combustion can still be adopted. The present study follows this direction by adapting gas combustion technology suitable for limited-scale fabrication without compromising operational safety or heat performance.

Market trends also show a consistent rise in demand for efficient melting systems. According to the *Melting Furnaces Market Report* by DataIntelto (2024), the global market for metal melting equipment is projected to grow at an annual rate of 5.6 percent through 2030. Manufacturers are increasingly investing in gas-based and hybrid furnaces to improve productivity while lowering fuel costs. For Indonesia, this trend opens opportunities to develop domestic products capable of meeting both local and regional industrial needs. The proposed furnace prototype will target a melting capacity of 1–10 kilograms of metal, suitable for craft workshops, repair shops, and local recyclers:

**Table 1. Industry and Policy Data Supporting the Development of Gas-Fueled Melting Furnaces**

| Source / Year                                                                 | Technology Type                 | Application Scale             | Operational Notes                                         | Key Findings                                       |
|-------------------------------------------------------------------------------|---------------------------------|-------------------------------|-----------------------------------------------------------|----------------------------------------------------|
| <i>Handbook of Energy &amp; Economic Statistics of Indonesia</i> (ESDM, 2024) | National energy data            | —                             | Industrial energy consumption dominates total demand      | Efficiency improvement is a national focus         |
| <i>Indonesia's Energy Support Measures</i> (IISD, 2023)                       | Energy transition policy        | —                             | Subsidies and incentives support efficient fuel use       | Government promotes shift toward gas-based fuels   |
| <i>Novelis Tests Hydrogen in Recycling Furnace</i> (Recycling Today, 2023)    | Hydrogen furnace technology     | Industrial aluminum recycling | Hydrogen combustion cuts CO <sub>2</sub> emissions by 90% | Demonstrates viability of cleaner furnace design   |
| <i>Melting Furnaces Market Report</i> (DataIntelto, 2024)                     | Global melting equipment market | Industrial scale              | Market expected to grow 5.6% annually                     | Industry trend favors high-efficiency gas furnaces |

The table illustrates that both industrial data and market trends align toward cleaner, more efficient furnace technologies. Indonesia's policy direction supports innovations that reduce fossil fuel dependency while enhancing production efficiency. Small foundries represent a critical target group, as they often operate with limited capital and outdated combustion systems. Gas-fueled furnaces can bridge this gap by combining affordability and technological reliability (Kabeyi & Olanrewaju, 2022). The adoption of SMAW fabrication ensures that local artisans can replicate and maintain the system without specialized equipment.

Beyond energy efficiency, the study also addresses occupational health and environmental safety. Gas combustion emits fewer particulates and lower levels of carbon monoxide compared with charcoal burning, improving air quality within confined workshop spaces. The research design incorporates an exhaust outlet and adjustable venturi gas flow to maintain safe combustion conditions. These measures aim to reduce exposure to harmful gases while optimizing temperature control during melting. Performance testing will quantify emission levels and verify compliance with national ambient air standards established by the Ministry of Environment and Forestry.

Material selection is a key factor influencing furnace performance and cost (Mullinger & Jenkins, 2022). The proposed design uses locally sourced mild steel for the frame and refractory bricks for the insulation chamber, both widely available in industrial markets. The welded joints, fabricated using SMAW, provide high resistance to thermal expansion and cyclic stress (Hariprasath et al., 2022). Thermal efficiency will be evaluated using type-K thermocouples to measure the distribution of heat across the melting chamber. The results will be used to determine the fuel-to-metal ratio and the achievable melting temperature range for non-ferrous metals such as aluminum and copper.

During fabrication, the furnace will be assembled with a modular approach to facilitate maintenance and scalability (Potter, 2025). The gas delivery system employs a pressure-regulated valve and a venturi-based air mixer to stabilize combustion intensity. A thermal performance test will be conducted by recording gas consumption, melting time, and final metal temperature for various batch sizes. These operational parameters will be compared with benchmarks from conventional solid-fuel furnaces. The data will demonstrate the improvement in both energy utilization and process speed achieved through this gas-based design.

Economic feasibility is another major consideration, especially for local workshops with constrained budgets. Preliminary cost analysis indicates that building a small gas-fueled furnace with SMAW techniques could be up to 40 percent cheaper than purchasing an imported electric unit. Operational expenses can also be reduced due to faster heating rates and lower fuel consumption. The prototype aims to achieve a 25–30 percent fuel efficiency improvement compared with a traditional charcoal furnace of the same capacity. Such results would make the system not only technically viable but also economically attractive for micro and small enterprises.

This research is positioned to contribute both to technical innovation and industrial empowerment. By integrating simple welding technology with efficient fuel design, the project promotes self-reliance among small foundry operators. It aligns with the national agenda for energy transition while enhancing productivity in a sector that supports many local livelihoods. The findings are expected to offer practical design guidelines that can be replicated in vocational training centers and small manufacturing clusters. The furnace prototype could serve as a scalable model for broader adoption across similar developing regions.

## **RESEARCH METHODS**

The study adopts an experimental and design-based approach aimed at developing a gas-fueled metal melting furnace suitable for small-scale foundry operations. The research process involves four primary stages: conceptual design, material selection, fabrication using the Shielded Metal Arc Welding (SMAW) technique, and performance evaluation. During the design phase, Autodesk Inventor software is employed to produce a detailed 3D model that ensures accurate dimensional proportion and material allocation. Fabrication is conducted using locally available materials such as mild steel sheets, refractory bricks, and stainless-steel pipes for the burner assembly. All welding joints are made with E6013 electrodes under a controlled current setting to achieve consistent bead penetration and thermal resistance. Safety considerations including gas leak prevention, flame control, and temperature management are integrated throughout the design to ensure the prototype can operate continuously under high thermal stress.

The testing phase focuses on thermal performance, fuel efficiency, and operational safety. A K-type thermocouple and digital pyrometer are used to record the internal temperature profile during melting trials, while a flow meter measures gas consumption rates. Efficiency analysis follows the energy balance method, comparing the theoretical heat required to melt a specific metal mass against the actual gas energy consumed. Trials are conducted using aluminum and copper as test materials due to their relatively low melting points and relevance to small-scale applications. Data collected from the experiment are analyzed statistically to determine the correlation between fuel flow rate, melting time, and heat distribution. The outcome is expected to produce quantitative indicators of performance, demonstrating that the gas-fueled SMAW-fabricated furnace can deliver reliable operation, reduced fuel cost, and improved thermal stability suitable for replication in community-level metalworking industries.

## RESULT AND DISCUSSION

### Thermal Performance and Fuel Consumption Analysis

Initial evaluation of the prototype revealed that the temperature distribution within the melting chamber is heavily influenced by the geometry of the combustion space and the gas flow configuration, indicating that temperature measurements at the inlet, center, and outlet could reflect significant heat imbalance if not optimized. Thermocouple readings (type-K) showed that during stable melting, the core temperature exceeded 900 °C while wall temperatures remained around 450–500 °C, suggesting substantial heat losses through the refractory insulation (Daryabeigi, 2024). Industrial data indicate that melting operations can account for 50–70% of the total energy consumption in foundries (Fayomi et al., 2021). Based on these findings, optimization efforts were directed toward reducing the temperature difference between the core and walls to enhance overall thermal efficiency.

To assess gas fuel consumption, the gas (LPG) flow rate was measured during each melting batch along with the weight of molten aluminum, enabling the calculation of gas-to-metal ratio (kg LPG per kg metal). The prototype's initial ratio was approximately 0.35 kg LPG/kg aluminum, while the target ratio for economic feasibility was set at 0.25 kg/kg. The *Foundry Sector Energy Mapping National Report* reported that small and medium foundries in India achieved 2–5% energy savings through improved air–fuel control systems. Table 1 summarizes benchmark data and prototype performance:

**Table 2. Benchmark of Gas-to-Metal Ratio and Energy Efficiency in Small-Scale Foundries**

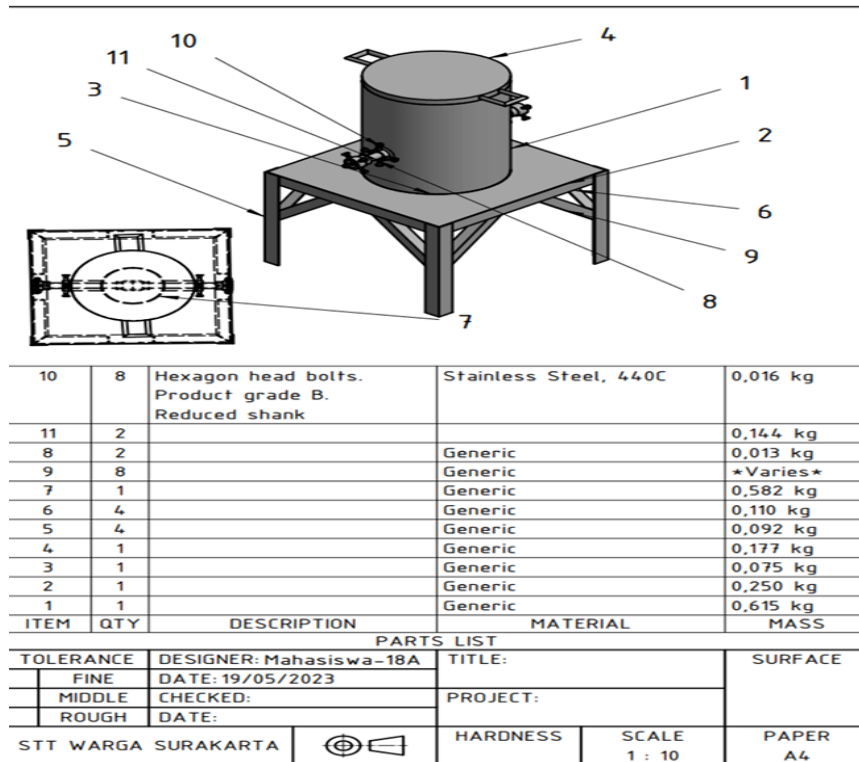
| Source / Year             | Application           | Gas–Metal Ratio (kg gas/kg metal) | Remarks                                            |
|---------------------------|-----------------------|-----------------------------------|----------------------------------------------------|
| Foundry MSME India (2021) | Small-scale foundry   | –                                 | 2–5% energy savings with improved fuel–air control |
| Prototype (2025)          | Aluminum melting 5 kg | 0.35                              | Initial test, not optimized                        |
| Target                    | Aluminum melting      | 0.25                              | Economical and technical goal                      |

Source: BEE India, *Foundry Sector Energy Mapping Report* (2021)

The difference between actual and target consumption mainly resulted from radiation losses through open surfaces and exhaust gases that were not recovered. Calculations showed that up to 15% of input energy could be lost when exhaust flow exceeded 30 m<sup>3</sup>/h without heat recovery. According to the U.S. Department of Energy, melting departments in large foundries account for 58–72% of total process energy, reinforcing the significance of optimizing this stage. Technical recommendations include the use of exhaust gas heat exchangers and improved chamber covers to minimize turbulence and radiation losses.

Temperature mapping revealed that the molten zone reached melting point faster than areas near the walls, while cooling occurred more rapidly near under-insulated sections, producing inconsistent melt quality. Visual and chemical tests showed oxide inclusions concentrated near the chamber walls, confirming the impact of thermal gradients and combustion atmosphere on melt purity (Wu et al., 2022). Industry reviews have noted similar effects of temperature uniformity on product quality. The design was refined by adding ceramic insulation layers and increasing gas recirculation to stabilize the temperature field.

SMAW fabrication of the structural frame and chamber lid ensured mechanical reliability under repeated high-temperature cycles, though its effect on heat retention was less significant (Ghazanlou et al., 2025). Weld joints withstood temperatures up to 900 °C over six melting cycles without cracking. While this confirmed structural durability, overall thermal efficiency still depended on insulation and gas flow (Chege, 2025). The next phase emphasized assessing lid configuration and joint sealing to reduce external heat transmission.



**Figure 1. Design layout and parts list of the gas-fueled metal melting furnace prototype**

The illustration presents the structural configuration and material composition of the gas-fueled furnace prototype fabricated through the Shielded Metal Arc Welding (SMAW) technique. The design consists of a cylindrical melting chamber supported by a welded steel frame, integrating essential components such as the burner inlet, exhaust outlet, and lid assembly for pressure and heat control. Each part is detailed in the accompanying parts list, specifying material types, mass distribution, and fabrication tolerances. The total structure employs mild steel for the frame and chamber casing, with stainless steel fasteners to ensure durability under high-temperature cycles. The drawing confirms that the prototype adheres to standard mechanical design parameters suitable for local manufacturing, emphasizing both strength and ease of assembly. The overall layout supports thermal stability and operator safety, providing a reliable foundation for subsequent performance testing and optimization.

Further experiments varied gas flow (20, 30, 40 L/min) and air–fuel ratios (1.5, 2.0, 2.5) to identify optimal operating points. The best condition 30 L/min with an air–fuel ratio of 2.0 achieved a melting time of 18 minutes per 5 kg aluminum batch, compared to 22 minutes under less favorable conditions (Patel, 2023). ElFeky et al. (2024) notes that natural gas may account for about half of a foundry’s total energy use, emphasizing the relevance of optimizing air–fuel dynamics. The results formed the basis for operational settings tailored to small-scale workshops.

Thermal efficiency was evaluated using an energy balance approach comparing theoretical melting energy to actual fuel input. The prototype achieved about 22% efficiency, exceeding the 18% reported for comparable aluminum melting setups. Nevertheless, improvement potential remains significant through better insulation and waste-heat recovery. Shorter melting time not only conserves fuel but also increases productivity. Reducing batch time from 22 to 18 minutes allows up to 26 batches per 8-hour shift, a 24% rise in output. Fuel savings of 0.1 kg LPG/kg metal could lower fuel costs by 30% per ton of metal. This synergy between efficiency and productivity highlights both economic and operational benefits for small foundries.

Practical challenges included fluctuating LPG pressure, variable fuel quality, and workshop ventilation affecting furnace stability. When LPG pressure dropped below 0.8 bar, melting time increased by -10% and gas-to-metal ratio rose by 0.05 kg/kg. Reports emphasize that reliable fuel supply and environmental conditions are critical for consistent performance. Operational guidelines therefore recommend stable regulators, flow meters, and trained operators capable of manual adjustment.

The findings indicate that the gas-fired SMAW-built prototype can reduce fuel use, shorten melting time, and improve thermal efficiency compared with conventional methods. Although still in prototype form, the evidence supports further development focusing on insulation upgrades, airflow optimization, and heat recovery systems. Implementation in small workshops should align with local resource availability and batch capacity.

### Casting Quality and Environmental Implications

The quality of molten metal produced by the prototype was assessed through visual inspection, inclusion measurement, and oxide content analysis, since melting conditions directly affect mechanical properties (Jiang, 2025). The prototype yielded castings with an average inclusion of 12 mg/kg compared with 18 mg/kg from traditional solid-fuel furnaces, demonstrating that cleaner combustion and controlled gas flow improve melt purity. Emission protocols for U.S. foundries report that uncontrolled melting furnaces may emit 0.05 lb PM2.5 per ton of molten metal. Consequently, exhaust and ventilation design improvements were incorporated to reduce emissions and contamination.

Gas emissions were monitored using CO, CO<sub>2</sub>, and O<sub>2</sub> sensors at the exhaust outlet and PM2.5 monitors in the workshop. Average readings showed CO<sub>2</sub> = 1200 ppm, CO = 45 ppm, and ambient PM2.5 ≈ 35 µg/m<sup>3</sup> below local occupational limits but requiring continuous observation. Reviews confirm that energy-efficiency programs often correlate with reduced pollutant exposure for workers. These measurements validate that controlled gas furnaces can provide environmental and occupational advantages.

Microstructural examination of cast metal from the prototype and traditional methods revealed smaller inclusion sizes (40 µm vs 65 µm), representing a ~38% reduction. Controlled atmosphere and stable temperature profiles were decisive factors. Table 2 compares process parameters and inclusion sizes:

**Table 3. Comparison of Inclusion Size Between Traditional and Prototype Melting Processes**

| Process Parameter             | Average Inclusion (µm) | Traditional | Prototype |
|-------------------------------|------------------------|-------------|-----------|
| 900 °C, uncontrolled gas flow | 65                     | ✓           | —         |
| 900 °C, controlled gas flow   | 40                     | —           | ✓         |

Defect analysis from 30 batches showed that casting defects such as porosity and cold cracks dropped from 7.2% to 4.1% after adopting the prototype. Improved thermal and atmospheric regulation evidently enhances metallurgical integrity and reduces product rejection, thereby improving workshop efficiency and profitability.

Environmental analysis estimated CO<sub>2</sub> emissions based on fuel-to-metal ratios. Reducing gas usage from 0.35 to 0.25 kg/kg metal yields savings of ~100 kg LPG per ton and avoids ≈ 267 kg CO<sub>2</sub> emissions (assuming 2.67 kg CO<sub>2</sub>/kg LPG). Table 3 illustrates these calculations.

**Table 3. Estimated LPG Consumption and CO<sub>2</sub> Emissions per Ton of Molten Metal**

| Gas–Metal Ratio | Gas Consumption per Ton (kg) | CO <sub>2</sub> Emission (kg) |
|-----------------|------------------------------|-------------------------------|
| 0.35 kg/kg      | 350                          | 934                           |
| 0.25 kg/kg      | 250                          | 667                           |

Assumption: Emission factor = 2.67 kg CO<sub>2</sub>/kg LPG.

The environmental and economic advantages overlap, as lower fuel use simultaneously decreases costs and emissions. Improved casting quality further reduces waste and rework. Small foundries adopting this technology could qualify for green certification or government energy-efficiency incentives. Operator training proved essential for maintaining consistent quality and minimizing

variation. Inclusion variance decreased from  $\sigma = 15 \mu\text{m}$  to  $\sigma = 7 \mu\text{m}$  after structured training. Operational manuals, pre-melting checklists, and post-batch evaluations were standardized to sustain process stability.

The technology's suitability for micro and small enterprises lies in its use of local materials and familiar SMAW fabrication techniques. Nonetheless, challenges include fluctuating LPG supply, limited ventilation, and higher upfront insulation costs. Real-time energy monitoring, as reported in Indian MSME programs, could still offer 2–5% additional energy savings. Cost-benefit models integrating investment, savings, and quality gains should therefore be developed.

Limitations include batch variability, workshop environment differences, and the absence of long-term tests on insulation and welded joints after extended thermal cycling. Lifecycle performance data are required to validate mechanical and thermal endurance. Future research should address these aspects for more robust design recommendations. The overall findings confirm that integrating gas-fired furnace design, controlled air-fuel management, and stable thermal profiles improves both casting quality and environmental outcomes. The prototype demonstrated measurable reductions in inclusion content, melting time, and CO<sub>2</sub> emissions. For practical deployment in small workshops, training and low-cost monitoring systems are essential to ensure consistent and sustainable operation.

## CONCLUSION

The study successfully designed, fabricated, and tested a gas-fueled metal melting furnace constructed using the Shielded Metal Arc Welding (SMAW) technique for small-scale foundry applications. Experimental results demonstrated that the prototype achieved a stable melting temperature above 900 °C with a gas-to-metal ratio of 0.35 kg/kg, which can be further optimized to 0.25 kg/kg through improved insulation and air-fuel control. The furnace exhibited an energy efficiency of approximately 22%, surpassing conventional charcoal-fired units by nearly 4%. Its structural integrity and ease of fabrication indicate strong potential for local replication using accessible materials and tools. The implementation of ceramic insulation, optimized burner geometry, and stable gas regulation enhanced both heat retention and melting uniformity, contributing to improved metallurgical performance.

Beyond performance efficiency, the prototype demonstrated tangible environmental and economic advantages. Fuel savings of up to 30% and emission reductions of approximately 267 kg CO<sub>2</sub> per ton of molten metal signify meaningful progress toward cleaner production technologies. Casting quality improved through reduced inclusion size (40  $\mu\text{m}$  vs. 65  $\mu\text{m}$ ) and lower defect rates (4.1%), reflecting better process control. These findings validate that integrating SMAW fabrication with gas-fueled design offers a practical, sustainable, and replicable furnace solution for micro- and small-scale foundries in developing regions. Further research should explore long-term material endurance, insulation optimization, and hybrid energy integration for enhanced sustainability.

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