

Fabrication of a Sustainable Charcoal-Fired Crucible Furnace for Recycling Aluminum Waste Cans

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Abstrak

Kata Kunci:

Tungku Crucible, Daur Ulang Aluminium, Tungku Pembakaran Arang, Manufaktur Berkelanjutan, Kaleng Limbah Aluminium

Daur ulang aluminium adalah proses penting dalam meminimalkan degradasi lingkungan dan menghemat energi. Makalah ini menyajikan desain, fabrikasi, dan evaluasi kinerja tungku wadah berbahan bakar arang daur ulang berbiaya rendah yang dibuat khusus untuk melelehkan kaleng limbah aluminium. Proyek ini bertujuan untuk mempromosikan upaya daur ulang lokal dengan menawarkan solusi hemat biaya dan hemat energi menggunakan bahan yang tersedia secara lokal. Tungku dibangun menggunakan tabung gas bekas sedangkan campuran semen kaolin, dan pasir tajam sebagai bahan isolasi. Wadah itu terbuat dari baja ringan. Evaluasi kinerja menunjukkan bahwa suhu pengoperasian maksimum adalah 850°C, waktu leleh rata-rata per batch adalah 29 menit 51 detik, dan tingkat pemulihan rata-rata 25,69%. Desain ini menawarkan solusi yang berkelanjutan dan terukur untuk operasi daur ulang aluminium skala kecil hingga menengah, terutama di negara berkembang.

Abstract

Key Word:

Crucible Furnace, Aluminum Recycling, Charcoal-Fired Furnace, Sustainable Manufacturing, Aluminum Waste Cans

Aluminum recycling is a vital process in minimizing environmental degradation and conserving energy. This paper presents the design, fabrication, and performance evaluation of a low cost recycled charcoal-fired crucible furnace specifically constructed for melting aluminum waste cans. The project aims to promote local recycling efforts by offering a cost-effective and energy-efficient solution using locally available materials. The furnace was constructed using used gas cylinders while mixture of kaolin cement, and sharp sand as insulation materials. The crucible was made from mild steel. Performance evaluation showed that the maximum operating temperature is 850°C, average melting time per batch is 29 minutes 51 seconds, and an average recovery rate of 25.69%. This design offers a sustainable and scalable solution for small to medium scale aluminum recycling operations, particularly in developing countries.

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INTRODUCTION

The increasing generation of aluminum waste, especially from beverage cans, poses significant environmental challenges (Mokaizh et al., 2025). Recycling aluminum saves up to 95% of the energy required for primary production and reduces greenhouse gas emissions (International Aluminum, 2024). In many developing regions like Nigeria, the lack of affordable and efficient recycling equipment hinders large-scale aluminum recovery. This present study focuses on developing a charcoal-fired crucible furnace as a low-cost and accessible alternative to electric and gas-fired units.

Aluminum is one of the most widely used non-ferrous metals in modern industries due to its lightweight, corrosion resistance, ductility, and excellent thermal and electrical conductivity (Zhu and Li, 2024). A significant portion of aluminum usage is in the production of beverage cans, packaging materials, automotive parts, and household appliances (Ashkenazi, 2019). However, the increasing consumption of aluminum products, especially single-use beverage cans, has contributed to the growing challenge of solid waste management and environmental degradation.

Recycling aluminum not only reduces the volume of waste in landfills but also offers considerable economic and environmental benefits (Raabe et al., 2022). One of the most compelling advantages of aluminum recycling is its energy efficiency recycling aluminum requires only about 5% of the energy needed to produce primary aluminum from bauxite ore (Sami et al., 2024). Additionally, recycling helps in conserving natural resources, reducing greenhouse gas emissions, and promoting sustainable manufacturing practices. Despite these advantages, aluminum recycling in many developing countries remains underutilized (Kumari

and Raghubanshi, 2023). This is primarily due to the high cost of standard industrial recycling equipment, lack of technical expertise, and inadequate infrastructure (Taiwo et al., 2023). Most existing furnaces for aluminum melting are powered by electricity or gas, which may not be readily available or affordable in rural or semi-urban areas Haruna et al., (2023). Consequently, there is a pressing need for low-cost, locally-fabricated solutions that can enable small-scale recycling and metal casting operations. This solutions lies in the use of furnaces, an important equipment in metallurgical and material science. It is useful in that it provides heat required for melting and heat treatment purposes. A furnace refers to a device through which chemical or electrical energy is converted into heat energy that is then used to raise the temperature of the material in it for heating or melting purposes. They are classified based on heating purpose, mode of heat transfer to the material, method of firing the furnace, size, working temperature, mode of material removal from the crucible and method of handling material through the furnace (Taiwo et al., 2023).

One of the fashionable ways in recent engineering designs and fabrications is using renewable energy to power engineering systems (Nwokediegwu et al., 2024). Therefore, charcoal, as a readily available and renewable source of fuel, presents an attractive alternative for powering small-scale furnaces. Its high calorific value, ease of use, and affordability make it suitable for localized recycling operations, especially in regions where electricity supply is unstable or prohibitively expensive (Ahmad et al. 2020). A charcoal-fired crucible furnace offers the potential to bridge the technological gap by providing an efficient and cost-effective platform for melting aluminum waste, particularly beverage cans. Furthermore, owing to the high cost and energy demands of commercial electric or gas-fired furnaces which often limit their accessibility to small-scale recyclers, as such, the development of alternative furnace designs using readily available, low-cost, and locally sourced materials has become essential. Hence, charcoal-fired furnaces provide a viable solution due to the affordability and availability of biomass fuel in rural settings (Haruna et al., 2022).

In this study, an innovative approach was taken by repurposing a discarded gas cylinder to fabricate the furnace body. The objective is to create an affordable, durable, and easy-to-operate furnace that utilizes locally sourced materials and tools. The furnace is intended to serve as a prototype for small-scale recyclers, technical training institutions, and community-based enterprises aiming to contribute to environmental sustainability through waste-to-wealth initiatives. The study evaluates key performance indicators such as melting time, fuel efficiency, and operational safety. By aligning with circular economy principles transforming waste (used gas cylinders and aluminum cans) into valuable resources this project contributes to sustainable development goals and local economic empowerment. Furthermore, it offers a scalable solution for environmentally conscious material processing in low-resource settings.

RESEARCH METHODS

Materials Used

The following materials were obtained for the construction of the crucible furnace; used 6kg gas cylinder, angle iron, iron rods, hollow pipes, charcoals, blower, kaolin, cement, mildsteel crucible, blower pipe, aluminum cans.

Design of Furnace

The furnace was designed using a computer aided design (CAD) software called SolidWorks. SolidWorks is a brand of software for solid modeling, computer-aided design and engineering. Front view, top and isometric views were all obtained using SolidWorks. Also the exploded and the interior view of the furnace are also designed using SolidWorks.

Fabrication Process

The fabrication process was carried out by cutting, welding and moulding.

Cutting: The cutting process was carried out on the gas cylinder using hacksaw. Hollow pipes with 64mm diameter was cut also to connect the blower to the cylinder. Angle iron was cut to sizes to serve as stand for the furnace.

Welding: Welding process was carried out to join parts such as hinges, stand and hollow pipe to the main frame which is the cylinder or the furnace body.

Moulding: The lining of the walls of the two furnaces where carried out by casting operation. Two different linings materials namely; Kaolin and POP was used on the two furnaces.

Preparation of Kaolin Lining; Kaolin was prepared by mixing kaolin sand with sharp sand, cement and water. The mixture was prepared by mixing, 3litres of water with 4.25Kg of kaolin with 0.5Kg of cement and

2kg of sharp sand. The presence of the sharp sand is to allow for gases to be trapped from inside the furnace while the cement serves as binder.

Casting Process: The fabricated charcoal fired crucible furnace was used in melting waste aluminum cans of beverages. To melt the waste aluminum cans, charcoal was weighed and charged into the furnace. Small quantity of diesel is then poured on the charcoal to aid in the burning after which the charcoal was ignited. The blower was turned on to aid distribution of burning of the charcoal. The charcoal was allowed to burn for some time to allow for enough heat to be generated and moisture to be reduced from the furnace. Cast metal from the melted cans are subsequently poured out and quenched in air.

Result

Design

The design of the charcoal fired crucible furnace using solid works is presented Figures 1 - 3.

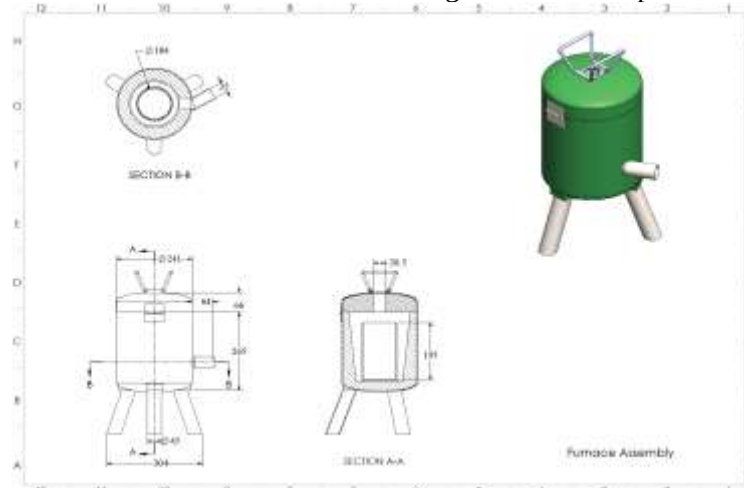


Figure 1: Dimensional Profile of the Charcoal Fired Crucible Furnace

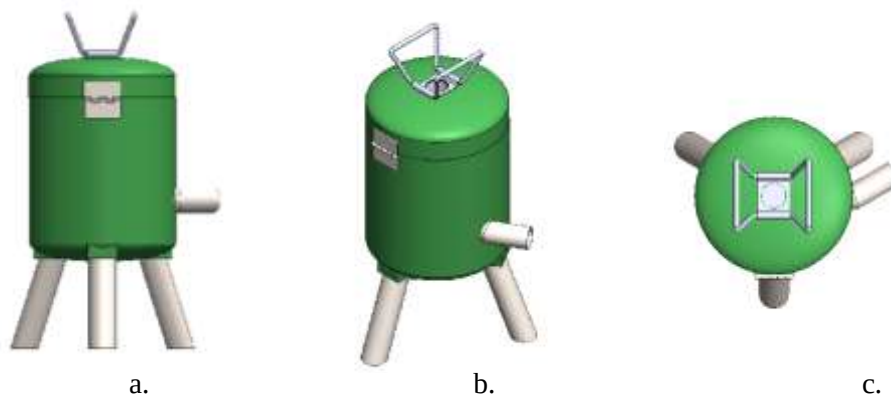


Figure 2: Views of the Designed Charcoal Fired Crucible Furnace a. side view b. isometric view c. top view.



a. b.
Figure 3: Exploded View of the Designed Charcoal Fired Crucible Furnace

RESULTS AND DISCUSSION

Fabrication.

Figure 4 and 5 below shows the fabricated charcoal fired crucible furnace before and after being assembled with the blower.



Figure 4: Different Views of the Modified Used Gas Cylinders

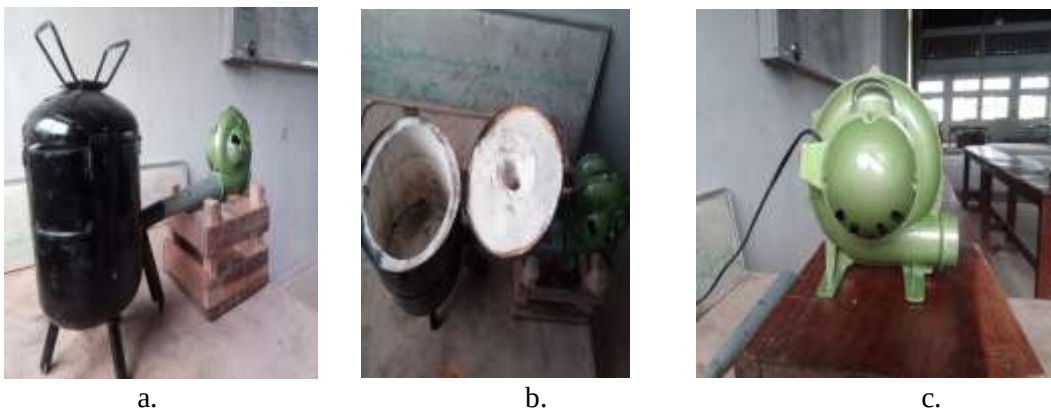


Figure 5: Fabricated Charcoal Fired Crucible Furnace a. assembled charcoal fired crucible furnace with blower b. top open view c. 0.295hp blower.

Performance Evaluation

The performance evaluation of the furnace was carried out by measuring some parameters during its melting operation. Figure 6 below shows the furnace in use during melting operation.

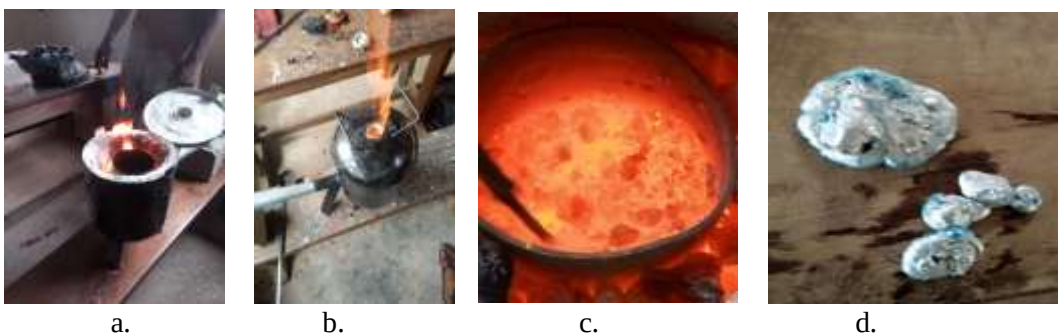


Figure 6: Melting Operation of the Fabricated Charcoal Fired Crucible Furnace a. opened furnace during melting operation b. closed furnace during melting operation c. aluminum melt. d. recovered aluminum casts.

Thermal Performance

Time to reach 750°C: 25 minutes

Maximum attainable temperature: 850°C

Fuel consumption rate: 261g of charcoal per melt

Average time to melt per batch (144 g of cans): ~29 minutes 51 seconds

Metal Recovery

Average aluminum recovery: 25.69%.

Observed losses were due to dross formation and oxide scale. Recycled aluminum can be poured into molds and cooled for further use

Economic Analysis

The total cost of materials and fabrication was estimated at \$150, significantly lower than commercial electric furnaces. Maintenance costs were minimal due to the robustness of the components.

Environmental Impact

Using recycled aluminum reduces carbon emissions by 95% compared to primary production (International Aluminum, 2024). The use of charcoal, while generating CO₂, is less carbon-intensive if sourced sustainably.

CONCLUSION

The charcoal-fired crucible furnace designed and fabricated in this study demonstrates an efficient and low-cost solution for aluminum recycling. It is suitable for cottage industries, small-scale foundries, and educational institutions. With minor modifications, the furnace can also be adapted for other non-ferrous metal recycling applications.

Recommendations

Adoption of waste-heat recovery systems to improve fuel efficiency. Use of temperature controllers for precise thermal management. Further studies on improving heat conservation, crucible lifespan and reducing slag formation.

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