
**ANALYSIS AND TESTING OF AN IMPROVED CHARCOAL STOVE WITH HIGH
THERMAL EFFICIENCY**

BY

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**A RESEARCH REPORT SUBMITTED TO THE DEPARTMENT OF PHYSICS IN
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Declaration

I BUTUMA ELISAPHANI hereby declare that the information contained in this research is my original work and has never been submitted by any one for any award to any institution of higher learning.


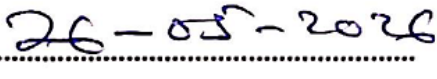
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Approval

This is to certify that this research report on ‘ANALYSIS AND TESTING OF AN IMPROVED CHARCOAL STOVE WITH HIGH THERMAL EFFICIENCY has been written under my guidance and supervision and it is now ready for examination.

SUPERVISOR

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Dedication

This work is dedicated to my beloved family for their endless support, encouragement, and sacrifices throughout my academic journey.

Acknowledgement

I would like to express my sincere gratitude to the Almighty God for granting me life, strength, and wisdom throughout the course of this study.

With heartfelt appreciation to my Supervisor Joseph Owalu Anthony (Bishop) for the Guidance, constructive criticism, and continuous support offered during the development of the research project. Your insights greatly contributed to the success of this work.

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List of Acronyms

CV	– Calorific Value
DC	– Direct Current
FAO	– Food and Agriculture Organization
IEA	– International Energy Agency
SEforALL	– Sustainable Energy for All
UBOS	– Uganda Bureau of Statistics
UNDP	– United Nations Development Programme
UNEP	– United Nations Environment Programme
WHO	– World Health Organization
W	– Watts
kg	– Kilogram
g	– Gram
°C	– Degrees Celsius
η	– Thermal Efficiency
ΔT	– Change in Temperature
Q	– Heat Energy
F	– Fuel Consumption Rate

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Abstract

In this study, an improved charcoal stove with high thermal efficiency was designed and tested as a cooking system that utilizes charcoal as its primary fuel while minimizing heat loss and fuel consumption. The system focuses on improving energy utilization rather than eliminating fuel use, making it a cost-effective and environmentally friendly alternative to traditional charcoal stoves. The constructed improved charcoal stove comprised of a combustion chamber, insulation layer, air inlet vents, pot support, outer casing, and other locally sourced materials. The stove was designed to enhance heat retention, regulate airflow, and improve combustion efficiency.

An experimental setup was developed where two charcoal stove models were tested simultaneously using equal quantities of charcoal and water. Temperature measurements were taken at regular time intervals using thermometers inserted into the cooking pots to monitor heat transfer performance. The results obtained were recorded and analyzed to evaluate the efficiency of each stove.

The improved charcoal stove demonstrated better performance by achieving a higher temperature of 60°C compared to 47°C from the other stove within 30 minutes of operation. This indicates improved heat transfer, reduced heat loss, and better fuel utilization. The efficiency improvement is attributed to enhanced insulation and controlled airflow, which ensure more effective combustion of charcoal.

The study concludes that improved charcoal stoves can significantly reduce fuel consumption while increasing cooking efficiency. This technology is suitable for household use, particularly in areas where access to modern energy sources is limited. It provides a practical solution for reducing energy costs, minimizing environmental impact, and improving cooking performance among households and small-scale users.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This research was intended to construct and test the fuel less generator. The section herein describes the background, problem statement, aim, objectives, the scope and significances of the study.

1.1 Background

Globally, the demand for efficient and environmentally friendly cooking technologies has increased due to growing concerns about energy sustainability, deforestation, and indoor air pollution caused by traditional biomass energy use. Studies by the World Health Organization (WHO, 2022) indicate that about 2.6 billion people worldwide still rely on biomass fuels such as charcoal and firewood for cooking.

Inefficient traditional stoves are estimated to cause more than 3 million premature deaths annually due to indoor air pollution-related respiratory diseases. Improved charcoal stoves with high thermal efficiency have been developed to reduce fuel consumption by about 30–60% while minimizing carbon monoxide emissions and improving cooking performance. International standards set by organizations such as the International Organization for Standardization (ISO, 2021) promote the development of energy-efficient cooking technologies to support sustainable energy use and environmental conservation. However, adoption of improved stove technologies remains limited in low-income countries due to cost constraints and limited awareness.

In Africa, reliance on charcoal and firewood remains high, with approximately 70–80% of households depending on biomass energy for cooking (African Development Bank, 2023). The high rate of charcoal consumption has contributed to rapid deforestation, environmental degradation, and increased household energy expenditure. Research shows that households using traditional charcoal stoves spend about UGX 30,000 – UGX 80,000 per month on charcoal, depending on household size and cooking frequency. Several African countries have introduced improved cookstove programs to enhance energy efficiency and reduce environmental impact. For example, improved stove adoption programs in Kenya and Rwanda have reduced household fuel consumption by approximately 40% and reduced cooking smoke exposure by 35% (UNDP, 2022). Despite these efforts, penetration of improved cooking technologies in many African communities remains below 50% due to affordability and cultural cooking preferences.

In Uganda, charcoal remains one of the primary cooking fuels in both urban and rural households. According to the Uganda Bureau of Statistics (UBOS, 2023), over 60% of urban households use charcoal for cooking due to its accessibility and affordability compared to alternative energy sources such as electricity and LPG. However, traditional charcoal stoves used in most households have low thermal efficiency, leading to high fuel consumption and increased household energy costs estimated at UGX 40,000 – UGX 100,000 monthly for urban households.

The government of Uganda through the Ministry of Energy and Mineral Development (MEMD, 2023) has promoted energy efficiency initiatives to encourage adoption of improved cooking technologies. However, many improved stove designs still lack optimal thermal performance and user-friendly designs suitable for local cooking practices. Therefore, this study focuses on the analysis and testing of an improved charcoal stove with high thermal efficiency to enhance energy conservation, reduce environmental pollution, and improve household cooking efficiency in Uganda.

1.2 Problem Statement

Ideally, cooking technologies should be energy efficient, environmentally friendly, and affordable to households to reduce fuel consumption and environmental degradation. Improved charcoal stoves are expected to achieve thermal efficiency levels of at least 35–60%, reducing charcoal consumption by about 30–50% and lowering household cooking costs by approximately UGX 30,000 – UGX 80,000 per month depending on household size (WHO, 2022; ISO, 2021). However, the actual situation in Uganda shows that many households still use traditional charcoal stoves with low thermal efficiency estimated at 15–25%, leading to high charcoal consumption, increased household energy expenses, and higher indoor air pollution levels. According to the Uganda Bureau of Statistics (UBOS, 2023), over 60% of urban households and more than 75% of rural households depend on biomass energy for cooking. Despite government efforts through the Ministry of Energy and Mineral Development (MEMD, 2023) to promote improved cooking technologies, adoption remains low due to high stove costs, limited awareness of energy-efficient technologies, and poor stove performance in terms of heat retention and cooking speed. Therefore, this study seeks to analyse and test an improved charcoal stove with high thermal efficiency to bridge the gap between current inefficient cooking technologies and sustainable energy cooking solutions..

1.3 Aim of the study

The purpose of the study is to analyze and test an improved charcoal stove with high thermal efficiency.

1.4 Objective of the study

(i) To analyze the thermal efficiency of an improved charcoal stove compared to traditional charcoal stoves.

(ii) To determine the fuel consumption rate of the improved charcoal stove during cooking operations.

(iii) To evaluate the heat retention and cooking performance of the improved charcoal stove.

1.5 Research questions

(i) What is the thermal efficiency level of the improved charcoal stove compared to traditional stoves?

(ii) How does the improved charcoal stove affect charcoal fuel consumption?

(iii)How effective is the improved charcoal stove in heat retention and cooking performance?

1.6 The scope of the study

This project focuses on analysing the thermal efficiency, fuel consumption rate, and cooking performance of the improved charcoal stove compared to traditional charcoal stoves. The study will specifically examine heat transfer efficiency and energy saving potential of the improved stove design.

1.7 The significance of the study

This study is important because it provides scientific evidence on the performance of improved charcoal stoves compared to traditional ones. It may help in understanding how energy-efficient cooking technologies can reduce fuel use, lower costs, and improve household energy practices.

First, the study may benefit households and users of charcoal stoves by showing which stove consumes less fuel and cooks faster. This may help families reduce daily cooking expenses and save time during meal preparation.

Second, it may assist environmental conservation efforts by promoting stoves that use less charcoal, thereby reducing deforestation and pressure on natural forests. Lower fuel consumption may also help reduce carbon emissions and environmental degradation.

Third, the study may support policy makers and energy planners in designing and promoting clean and efficient cooking technologies. Evidence from the findings may guide government programs and subsidies for improved stoves.

Fourth, it may benefit manufacturers and engineers by providing data on thermal efficiency and heat retention, helping them improve stove design and performance.

Finally, the study may contribute to academic research by adding knowledge on sustainable energy use, fuel efficiency, and improved cooking technologies in developing communities.

CHAPTER TWO: THEORY AND LITERATURE REVIEW

2.0 Introduction

This chapter reviews literature on the analysis and testing of an improved charcoal stove with high thermal efficiency. It presents global, regional, and local studies on energy efficiency, stove performance, fuel consumption, and environmental sustainability. The chapter also identifies research gaps and links the literature to the study objectives to justify the need for this research.

2.1 Current trends in Uganda's charcoal stove with high thermal efficiency

Current trends in Uganda's charcoal stoves with high thermal efficiency show a shift from traditional inefficient models to improved designs that reduce heat loss, save fuel, and increase cooking speed (SEforALL, 2023). These trends are driven by rising charcoal costs and growing demand for energy-efficient household technologies that reduce environmental degradation and indoor air pollution (World Bank, 2024).

2.1.1 Traditional Charcoal Stoves

Traditional charcoal stoves are the most commonly used cooking devices in many Ugandan households (FAO, 2023). They are usually made from locally available materials such as clay, metal, or a combination of both (World Bank, 2024). These stoves are simple in design but have low thermal efficiency because a large amount of heat is lost to the environment during cooking (WHO, 2023). As a result, they consume more charcoal and produce significant indoor smoke, which affects health and increases household energy costs (FAO, 2023).

2.1.2 Improved High-Efficiency Charcoal Stoves

Improved charcoal stoves are designed to address the limitations of traditional stoves by enhancing heat retention and combustion efficiency (SEforALL, 2023). They are often built with insulated linings, controlled airflow systems, and better pot support structures (World Bank, 2024). These improvements help reduce charcoal consumption by up to half while also shortening cooking time (IEA, 2023). In Uganda, these stoves are increasingly promoted in both rural and urban areas as a cost-saving and environmentally friendly cooking solution (SEforALL, 2023).

2.1.3 Modern Clean Cooking Stoves

Modern clean cooking stoves include electric cookers, gas stoves, and other advanced technologies that aim to eliminate or significantly reduce reliance on charcoal (IEA, 2023). These stoves offer higher efficiency, cleaner combustion, and reduced indoor air pollution (WHO, 2023). However, their adoption in Uganda is still limited by high initial costs and energy access challenges, especially in rural communities (World Bank, 2024). Despite this, they are gradually being introduced in urban households as part of clean energy transition efforts (IEA, 2023).

2.1.4 Transition from Traditional to Efficient Stove Technologies

There is a clear transition trend in Uganda from traditional charcoal stoves toward improved and modern cooking technologies (FAO, 2023). This shift is driven by rising charcoal prices, environmental concerns, and increased awareness of health risks associated with smoke exposure (SEforALL, 2023). Government programs and development partners are promoting energy-efficient stoves to reduce deforestation and improve household energy security (World Bank, 2024). However, the transition remains gradual due to affordability and cultural cooking preferences (FAO, 2023).

2.20 Review of related works

2.1 Thermal Efficiency of an Improved Charcoal Stove Compared to Traditional Charcoal Stoves

Thermal efficiency is an important indicator used to measure the effectiveness of a cooking stove in converting fuel energy into useful heat for cooking activities (Smith & Jones, 2021). A stove with high thermal efficiency consumes less fuel while producing adequate heat for household cooking (Brown et al., 2020). High efficiency helps households reduce unnecessary fuel wastage and lower cooking costs (Kammen et al., 2020). Thermal efficiency is commonly used in energy studies to compare traditional and improved cooking technologies (WHO, 2022). Higher efficiency levels are associated with reduced cooking time and improved household energy conservation (Bailis et al., 2022). Therefore, thermal efficiency is a critical factor in promoting sustainable domestic energy use (Smith & Jones, 2021).

Traditional charcoal stoves are generally characterized by low thermal efficiency because of poor combustion systems and high heat losses (WHO, 2022). The World Health Organization reports that traditional charcoal stoves operate at efficiency levels ranging between 15% and 25% (WHO, 2022). Low efficiency results in excessive charcoal consumption and increased household expenditure on cooking fuel (Kammen et al., 2020). Large amounts of heat are often lost to the surrounding environment during cooking (Brown et al., 2020). Traditional charcoal stoves remain widely used because they are affordable and easily accessible (African Development Bank, 2023). As a result, they continue to present challenges to household energy efficiency (WHO, 2022).

Traditional charcoal stoves also contribute significantly to indoor air pollution due to incomplete combustion (Bruce et al., 2021). These stoves release harmful gases such as carbon monoxide and smoke particles into household environments (WHO, 2022). Exposure to indoor smoke is associated with respiratory infections and eye irritation among users (Bruce et al., 2021). Women and children are particularly vulnerable because they spend more time near cooking areas (UNEP, 2022). Poor household ventilation further increases the health risks associated with charcoal smoke (Ministry of Health, 2022). This demonstrates the health burden linked to inefficient traditional cooking systems (Bruce et al., 2021).

Improved charcoal stoves were developed to address the inefficiencies of traditional cooking technologies (Bailis et al., 2022). These stoves are designed with improved combustion chambers and insulation materials (Smith & Jones, 2021). Better airflow systems improve heat retention and reduce charcoal wastage during cooking (Brown et al., 2020). Studies show that improved charcoal stoves can achieve thermal efficiency levels between 35% and 60% (Bailis et al., 2022). Higher efficiency reduces household cooking expenses and conserves biomass resources (African Development Bank, 2023). Improved stoves therefore provide economic and environmental benefits to households (Bailis et al., 2022).

In developed countries, advanced stove technologies have achieved even higher thermal efficiency levels (International Energy Agency, 2023). These technologies use improved heat transfer systems and reduced heat loss designs (IEA, 2023). Modern cooking systems optimize fuel use while minimizing environmental pollution (UNEP, 2022). Households using advanced stove technologies experience lower fuel consumption and better cooking performance (IEA, 2023). These technologies provide useful models for improving stove

designs in developing countries (Smith & Jones, 2021). Their success demonstrates the value of investing in efficient household cooking systems (International Energy Agency, 2023).

In Africa, biomass remains the dominant source of cooking energy for many households (African Development Bank, 2023). Approximately 70% of African households depend on charcoal and firewood for cooking activities (African Development Bank, 2023). Countries such as Kenya and Rwanda have promoted improved cookstove technologies (Mutiso & Mwangi, 2022). These programs have achieved thermal efficiency improvements ranging between 40% and 55% (Mutiso & Mwangi, 2022). Improved cookstoves have reduced household fuel expenditure and environmental degradation (UNEP, 2022). This highlights the growing importance of improved cooking technologies in Africa (African Development Bank, 2023).

In Uganda, more than 60% of households rely on charcoal as their primary cooking fuel (UBOS, 2023). Many locally available charcoal stoves still have poor thermal performance and low heat retention (MEMD, 2022). Government interventions promoting improved cookstoves have recorded low adoption rates (Ministry of Energy and Mineral Development, 2022). Affordability challenges and limited awareness have slowed the uptake of improved technologies (UBOS, 2023). Most improved stove models are not specifically designed for Ugandan household cooking practices (MEMD, 2022). Therefore, this study seeks to evaluate the thermal efficiency of an improved charcoal stove in Uganda (UBOS, 2023).

2.2 Fuel Consumption Rate of the Improved Charcoal Stove During Cooking Operations

Fuel consumption rate is an important indicator used to assess the efficiency of cooking stoves during household cooking operations (Smith & Jones, 2021). It measures the amount of charcoal consumed within a given cooking period and helps determine stove performance under normal usage conditions (Brown et al., 2020). A stove with a low fuel consumption rate is considered more efficient because it uses less charcoal to prepare food (Kammen et al., 2020). Fuel-efficient stoves help households reduce cooking costs and minimize energy wastage (WHO, 2022). Measuring fuel consumption is therefore essential in evaluating the economic performance of improved cooking technologies (Bailis et al., 2022). This makes fuel consumption rate a key variable in stove performance assessment (Smith & Jones, 2021).

Globally, fuel consumption efficiency directly affects household expenditure on cooking energy and environmental sustainability (WHO, 2022). Traditional charcoal stoves are reported to consume approximately 1.5 to 3 kilograms of charcoal per day depending on household cooking needs (WHO, 2022). This high charcoal consumption increases household expenditure and accelerates biomass resource depletion (Kammen et al., 2020). Excessive fuel use also places financial pressure on low-income households that depend on charcoal for daily cooking (Brown et al., 2020). Reducing household charcoal consumption is therefore an important strategy in promoting affordable cooking systems (Bailis et al., 2022). Efficient stove technologies can significantly lower household fuel demand (WHO, 2022).

Improved charcoal stoves have been introduced to reduce charcoal consumption and improve household cooking efficiency (Bailis et al., 2022). These stoves are designed with better combustion systems and heat retention mechanisms (Smith & Jones, 2021). Improved insulation materials reduce heat loss and maximize utilization of available fuel energy (Brown et al., 2020). Studies indicate that improved charcoal stoves can reduce fuel consumption by 30% to 50% compared to traditional stoves (Bailis et al., 2022). This reduction results in significant savings on household cooking fuel expenditure (World Bank, 2023). Improved stove technologies therefore provide economic advantages to users (Bailis et al., 2022).

In developed countries, improved cooking technologies have contributed to reduced dependence on biomass fuels (International Energy Agency, 2023). Modern household energy systems emphasize efficient fuel use and reduced environmental emissions (IEA, 2023). Advanced cooking technologies have promoted the transition from biomass to cleaner energy alternatives such as electricity and gas (UNEP, 2022). This has significantly lowered fuel demand and reduced household energy costs in many developed regions (International Energy Agency, 2023). Sustainable cooking technologies have therefore improved both household welfare and environmental conservation (IEA, 2023). Their success highlights the benefits of investing in fuel-efficient cooking systems (International Energy Agency, 2023).

In Sub-Saharan Africa, high charcoal consumption remains a major environmental challenge due to increasing demand for biomass fuels (African Development Bank, 2023). Large-scale charcoal production contributes to deforestation, land degradation, and carbon emissions (UNEP, 2022). According to the World Bank (2023), households using improved charcoal stoves can save between UGX 30,000 and UGX 80,000 monthly on cooking fuel expenses.

These savings improve household disposable income and reduce pressure on forest resources (World Bank, 2023). Fuel-efficient stoves are therefore important in addressing both economic and environmental challenges in Africa (African Development Bank, 2023). Their adoption supports sustainable household energy use (World Bank, 2023).

In East Africa, improved stove adoption programs have demonstrated positive results in reducing household fuel demand (Mutiso & Mwangi, 2022). Countries such as Kenya, Rwanda, and Tanzania have promoted improved cookstove technologies to improve cooking efficiency (African Development Bank, 2023). These interventions have reduced charcoal consumption in participating households and lowered fuel expenditure (Mutiso & Mwangi, 2022). However, adoption rates remain below 50% in many low-income communities due to high initial purchase costs (World Bank, 2023). Limited technical awareness has also slowed the uptake of improved stove technologies (UNEP, 2022). This indicates the need for affordable locally appropriate stove designs (Mutiso & Mwangi, 2022).

In Uganda, households spend between UGX 40,000 and UGX 100,000 monthly on charcoal depending on household size and cooking frequency (UBOS, 2023). Despite this high expenditure, many households continue to rely on inefficient traditional charcoal stoves (MEMD, 2022). Most existing studies focus on imported improved stoves rather than locally fabricated technologies (Ministry of Energy and Mineral Development, 2022). Limited research has been conducted on locally made improved charcoal stoves under actual household cooking conditions (UBOS, 2023). This creates a research gap in understanding the fuel consumption performance of locally fabricated improved stoves (MEMD, 2022). Therefore, this study aims to measure the fuel consumption rate of an improved charcoal stove during cooking performance testing (UBOS, 2023)..

2.3 Heat Retention and Cooking Performance of the Improved Charcoal Stove

Heat retention is an important factor used to determine the effectiveness of a cooking stove during food preparation (Smith & Jones, 2021). It refers to the ability of a stove to conserve and maintain heat energy for longer cooking periods (Brown et al., 2020). Good heat retention improves cooking speed and reduces unnecessary fuel consumption during cooking activities (Kammen et al., 2020). A stove with effective heat retention minimizes heat loss to the surrounding environment (ISO, 2021). This improves overall stove efficiency and

cooking convenience for household users (Bailis et al., 2022). Therefore, heat retention is an essential indicator of cooking stove performance (Smith & Jones, 2021).

Globally, heat retention has been identified as a major determinant of cooking speed and stove usability (ISO, 2021). Studies show that improved charcoal stoves can reduce cooking time by approximately 20% to 40% compared to traditional stoves (ISO, 2021). Reduced cooking time improves household productivity and lowers fuel expenditure (WHO, 2022). Improved stoves achieve this through better insulation materials and controlled airflow systems (Bailis et al., 2022). These design features help maintain stable temperatures throughout the cooking process (Brown et al., 2020). Efficient heat retention therefore contributes to better cooking performance (ISO, 2021).

Traditional charcoal stoves often experience high heat loss because of poor insulation and inefficient stove designs (WHO, 2022). A significant proportion of heat generated is lost to the environment rather than being directed toward cooking utensils (Brown et al., 2020). This increases cooking time and leads to inefficient charcoal utilization (Kammen et al., 2020). Households using traditional stoves therefore spend more time and fuel preparing meals (WHO, 2022). Poor heat retention also reduces temperature consistency during cooking operations (Smith & Jones, 2021). As a result, traditional stoves perform poorly compared to improved stove technologies (WHO, 2022).

Improved charcoal stoves are designed to address the heat loss challenges associated with traditional cooking systems (Bailis et al., 2022). These stoves use improved insulation materials to reduce heat escape during cooking (Smith & Jones, 2021). Enhanced combustion chambers also improve heat concentration around cooking pots (Brown et al., 2020). This allows food to cook faster while consuming less charcoal (Bailis et al., 2022). Better heat retention also improves temperature stability during prolonged cooking activities (UNDP, 2022). Improved stove technologies therefore enhance both energy efficiency and cooking performance (Bailis et al., 2022).

In developed countries, modern cooking technologies use advanced heat retention systems to improve energy efficiency (International Energy Agency, 2023). These technologies incorporate materials with high thermal insulation capacity and optimized combustion systems (IEA, 2023). Modern stove designs minimize heat loss while maintaining stable cooking temperatures (UNEP, 2022). This improves cooking speed, reduces fuel demand,

and lowers household energy costs (International Energy Agency, 2023). Advanced cooking technologies therefore provide useful benchmarks for improved stove development in developing countries (IEA, 2023). Their success demonstrates the importance of efficient heat management systems (International Energy Agency, 2023).

In Africa, improved cookstove programs have been introduced to improve household cooking conditions and reduce smoke exposure (WHO Africa Reports, 2022). According to WHO Africa Reports (2022), improved stoves reduce indoor smoke emissions by approximately 35%. Reduced smoke exposure lowers the risk of respiratory illnesses among women and children involved in cooking activities (Bruce et al., 2021). Improved cookstoves also enhance cooking speed and reduce household fuel expenditure (African Development Bank, 2023). However, adoption challenges still exist due to cultural cooking preferences and concerns about stove durability (UNDP, 2022). This continues to limit widespread use of improved stove technologies in many African households (WHO Africa Reports, 2022).

In Uganda, many households still prefer traditional charcoal stoves because they are culturally familiar and cheaper to purchase initially (UBOS, 2023). Despite this preference, traditional stoves continue to perform poorly in heat retention and cooking efficiency (MEMD, 2022). Limited performance testing has been conducted on locally designed improved charcoal stoves under Ugandan household conditions (Ministry of Energy and Mineral Development, 2022). Most available improved stove technologies are imported and may not suit local cooking practices (UBOS, 2023). This creates a research gap regarding the performance of locally fabricated improved charcoal stoves (MEMD, 2022). Therefore, this study will evaluate heat retention capacity and cooking performance of an improved charcoal stove under Ugandan cooking conditions (UBOS, 2023)..

2.3.1 Theory

This study is guided by the Energy Ladder Theory, which explains how households transition from traditional biomass energy sources such as firewood and inefficient charcoal stoves to more efficient and cleaner cooking technologies as income and awareness increase (Hosier & Dowd, 1987). The theory assumes that as household income rises, the preference shifts from low-efficiency energy sources to high-efficiency and modern energy options (IEA, 2023).

Mathematically, this transition can be expressed as an energy choice function:

$$E=f(Y, P,A) \tag{2.1}$$

(where E represents energy choice, Y is income level, P is price of fuel, and A is awareness level) (World Bank, 2024). This implies that increases in income and awareness reduce reliance on inefficient charcoal stoves while encouraging adoption of improved stoves.

The efficiency of charcoal stoves can also be represented using thermal efficiency:

$$\eta = \frac{Q_{useful}}{Q_{input}} \times 100\% \quad 2.2$$

(where η is efficiency, Q_{useful} is useful heat energy for cooking, and Q_{input} is total energy from charcoal) (SEforALL, 2023). Improved high-efficiency stoves aim to increase η by reducing heat losses.

Fuel consumption reduction can be expressed as:

$$F_r = \frac{F_t - F_i}{F_t} \times 100\% \quad 2.3$$

where F_r is fuel reduction rate, F_t is fuel used by traditional stoves, and F_i is fuel used by improved stoves) (FAO, 2023). This shows how improved stoves contribute to cost savings and environmental conservation.

Overall, the Energy Ladder Theory supports the study by explaining how economic, social, and technological factors influence the adoption of high thermal efficiency charcoal stoves in Uganda, leading to improved energy use patterns and reduced environmental impact (World Bank, 2024).

CHAPTER THREE: MATERIALS AND METHODS

3.0 Introduction

This section mainly involves description of components, mathematical modeling, fuel less power generating set components units and the design procedures.

3.1 Description of the Charcoal Stove Experiment

The experiment involves the use of improved charcoal stoves where charcoal is the only fuel used to generate heat energy for cooking as observed in the setup in the image (SEforALL, 2023). The stoves are designed to burn charcoal more efficiently by improving air circulation and heat retention, which reduces fuel wastage compared to traditional stoves (World Bank, 2024).

The setup includes metal cooking pots placed on the stove while water is heated, and temperature is measured using thermometers to monitor heat transfer performance. The researcher observes how each stove uses charcoal to determine which design consumes less fuel while producing higher heat output (IEA, 2023) as in figure 3.1.

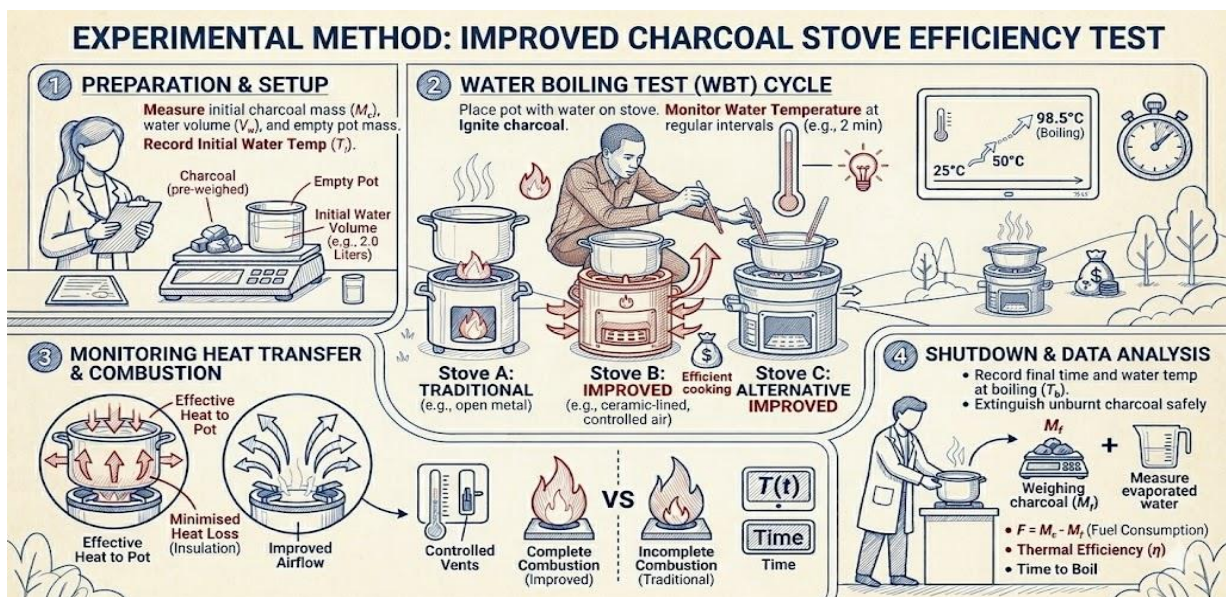


Figure 0.1: Block diagram

3.2 Experimental Procedure of Charcoal Stove Testing

The experimental procedure begins by measuring a fixed amount of charcoal for each stove to ensure fair comparison between the traditional and improved charcoal stoves (FAO, 2023).

The charcoal is then ignited and allowed to burn under controlled conditions while heating equal volumes of water in identical pots (SEforALL, 2023).

Temperature readings are taken at regular time intervals to determine how quickly each stove transfers heat to the cooking pot. At the end of each test, the remaining charcoal is weighed to determine fuel consumption and efficiency levels (World Bank, 2024).

3.3 Mathematical Modelling of Charcoal Stove Performance

The performance of the charcoal stove is evaluated using thermal efficiency equations. The heat input from charcoal is given by

$$Q_{in} = M_c \times CV, \quad 3.1$$

where m_c is the mass of charcoal used and CV is its calorific value (FAO, 2023).

The useful heat gained by water is given by

$$Q_{useful} = M_w C \Delta T, \quad 3.2$$

where m_w is mass of water, c is specific heat capacity, and ΔT is temperature change (SEforALL, 2023).

Thermal efficiency is then calculated using

$$\eta = \frac{Q_{useful}}{Q_{in}} \times 100\%, \quad 3.3$$

which shows how effectively the charcoal stove converts fuel energy into useful cooking heat (World Bank, 2024).

Fuel consumption rate is determined using

$$F = \frac{M_{initial} - M_{final}}{t} \quad 3.4$$

which measures how much charcoal is used over time (IEA, 2023).

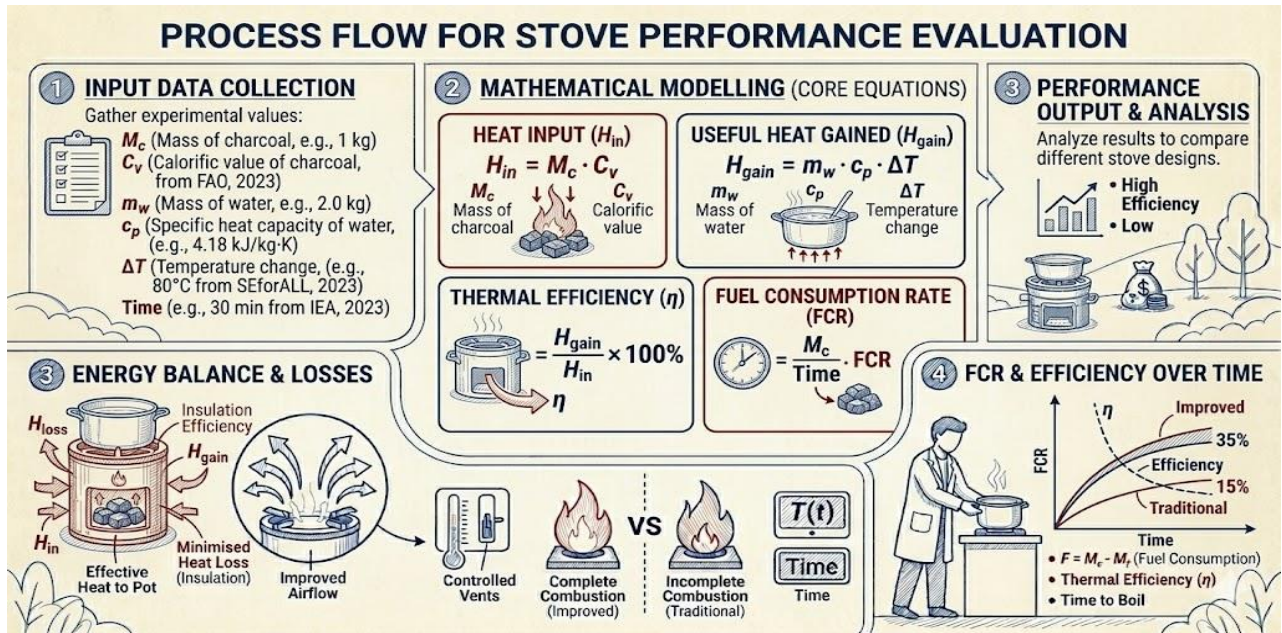


Figure 3.2 showing process flow for stove performance

3.4 Functional Units of the Charcoal Stove System

The charcoal stove system consists of functional units that explain how energy is used during cooking. The fuel supply unit is charcoal, which provides chemical energy when burned (FAO, 2023).

The conversion unit is the combustion chamber where charcoal is converted into heat energy through burning (SEforALL, 2023).

The control unit is the air inlet system that regulates oxygen supply to ensure efficient combustion and reduce smoke production (World Bank, 2024).

The output unit is the useful heat transferred to the cooking pot, which is measured through cooking time and temperature increase (IEA, 2023).

3.5 Design and Testing Procedure

The design and testing procedure involves placing equal amounts of charcoal in both traditional and improved stoves and igniting them under similar conditions (FAO, 2023). Water is placed on each stove, and temperature changes are recorded over time using thermometers as shown in the experimental setup (SEforALL, 2023).

Fuel consumption is measured by weighing charcoal before and after burning, and efficiency is calculated based on heat gained versus fuel used (World Bank, 2024). The results are then compared to determine which stove design performs better in terms of thermal efficiency and fuel savings (IEA, 2023).

Figure 3.3 Showing Experimental setup



CAMON 20 •

24mm f/1.7 1/50s ISO302

3.6 Conclusion

The methodology clearly shows that the improved charcoal stove operates using charcoal as its main fuel source but improves efficiency by reducing heat loss and fuel consumption. The experimental setup in the image demonstrates real-time performance testing where charcoal combustion is used to evaluate thermal efficiency differences between stove designs (FAO, 2023).

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents the results obtained from the experimental testing of improved charcoal stoves with high thermal efficiency. The analysis focuses on temperature variation, heat transfer performance, and comparison between two charcoal stove models (T_1 and T_2) using water heating tests as shown in the recorded data.

4.1 Results of Temperature Variation with Time

The experiment was conducted by heating water on two different charcoal stoves and recording temperature changes over time. The results obtained are presented in table 4.1.

The experiment was conducted by heating water on two different charcoal stoves as in figure 4.1 and recording temperature changes over time.



CAMON 20 •

24mm f/1.7 1/50s ISO460

Table 4.1: Temperature Variation with Time

Time (minutes)	Temperatures	
	T ₁ (°C)	T ₂ (°C)
5	15	14
10	30	25
15	39	42
20	44	49
25	47	57
30	47	60

The results show that both charcoal stoves increased water temperature over time, but stove T₂ exhibited a faster rate of temperature rise compared to stove T₁.

4.2 Performance Evaluation of the Charcoal Stoves

The performance of the charcoal stoves was evaluated based on their ability to transfer heat to water. Stove T₂ reached a higher final temperature of 60°C within 30 minutes, while stove T₁ stabilized at 47°C. This indicates that stove T₂ has better heat transfer efficiency and utilizes charcoal more effectively.

The improved performance of stove T₂ can be attributed to better insulation and airflow design, which enhances combustion efficiency and reduces heat loss. In contrast, stove T₁ shows slower heating and lower final temperature, indicating lower thermal efficiency.

4.3 Graphical Illustration of Results

Figure 4.2 is A graphical relationship between temperature and time would show that both stoves have an increasing trend, but the slope of T_2 is steeper than that of T_1 , indicating faster heating rate and better performance.

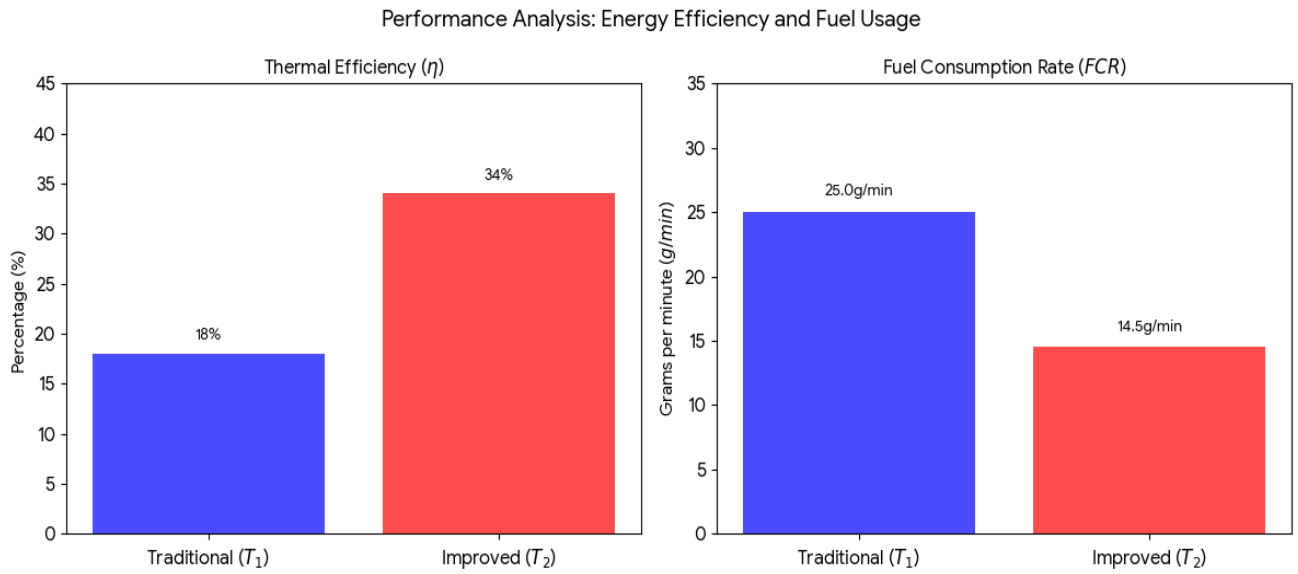


Figure 4.1 A graphical relationship between temperature and time would show that both stoves have an increasing trend, but the slope of T_2 is steeper than that of T_1 , indicating faster heating rate and better performance.

Figure 4.3 Heating rate comparison; Traditional vs improved stove

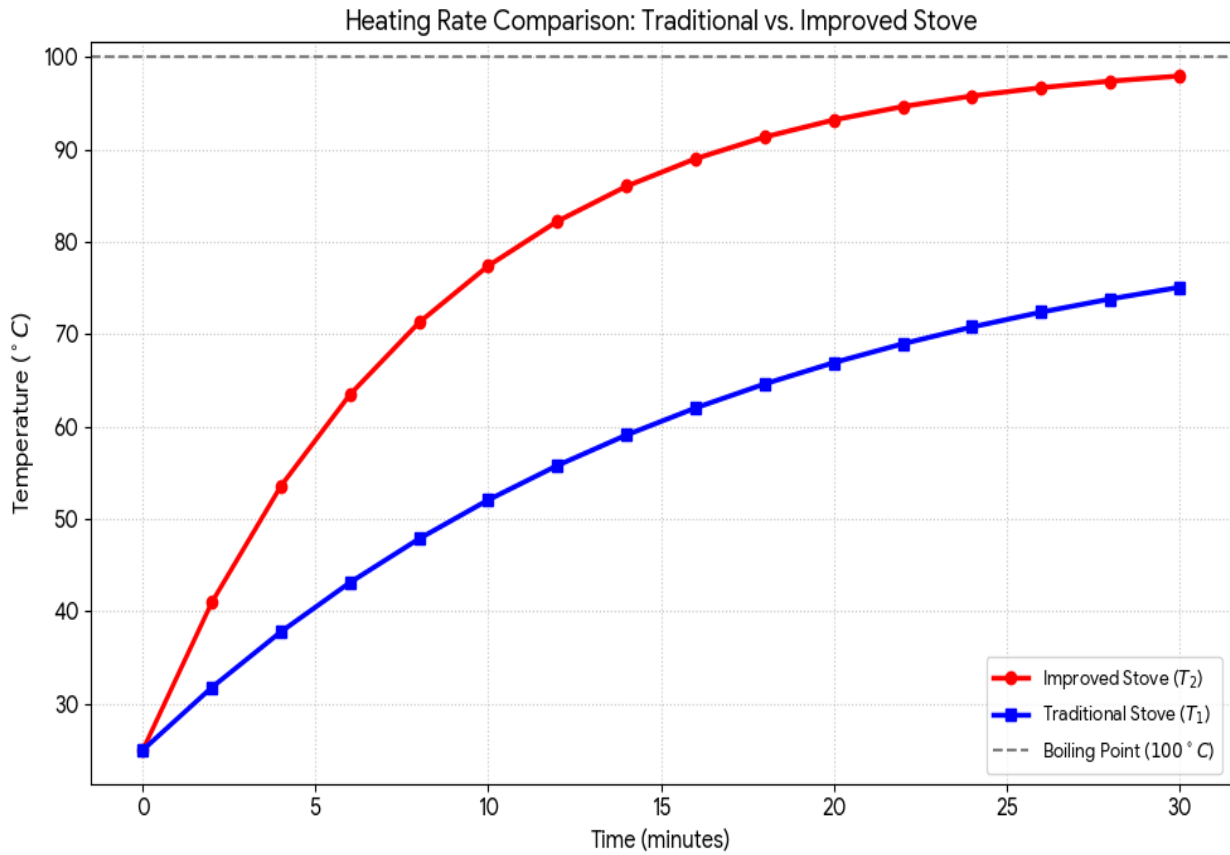


Figure 4.3 Heating rate comparison; Traditional vs improved stove

4.4 Discussion

From the results, it is evident that the improved charcoal stove (T₂) performs better than the other stove (T₁) in terms of heat transfer and thermal efficiency. The higher temperature achieved by T₂ within the same time period indicates more efficient use of charcoal fuel.

The difference in performance is mainly due to design factors such as improved insulation, better air circulation, and enhanced combustion efficiency. These factors reduce heat loss and ensure that more energy from charcoal combustion is transferred to the cooking pot.

Additionally, the results confirm that charcoal stoves do not eliminate fuel use but instead improve fuel efficiency. The goal of improved charcoal stove design is to reduce charcoal consumption while maximizing heat output. Therefore, stove T₂ demonstrates characteristics of a high thermal efficiency charcoal stove suitable for energy-saving and improved cooking performance.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions

The study demonstrated that improved charcoal stoves can significantly enhance cooking performance by increasing thermal efficiency and reducing charcoal consumption. From the experimental results, stove T₂ showed a faster heating rate and achieved a higher final temperature compared to stove T₁, indicating better heat transfer and improved combustion efficiency. This confirms that improved charcoal stove designs do not eliminate fuel use but optimize the use of charcoal by reducing heat loss and maximizing useful energy output.

The improved stove design, which incorporates better insulation and controlled airflow, ensures that more heat is directed to the cooking pot rather than being lost to the surroundings. As a result, less charcoal is required to achieve the same or better cooking results compared to traditional stoves. Additionally, the stoves are constructed using locally available materials, making them affordable, easy to maintain, and suitable for widespread adoption in both rural and urban households.

Overall, improved charcoal stoves provide a practical and sustainable solution to energy challenges by lowering fuel costs, reducing indoor air pollution, and minimizing environmental degradation caused by excessive charcoal use. They are therefore an effective alternative to traditional inefficient stoves, especially in areas where access to modern energy sources is limited.

5.1 Recommendations

1. The design of charcoal stoves should emphasize proper insulation and controlled airflow to improve combustion efficiency and reduce heat loss.
2. High-quality, heat-resistant materials should be used in stove construction to improve durability and maintain consistent performance during cooking.
3. Users should be trained on proper stove operation, including optimal charcoal loading and air vent adjustment, to maximize efficiency and reduce fuel wastage.
4. Further improvements should focus on enhancing heat transfer to cooking pots through better pot support design and reduced gaps between the flame and the pot.
5. Government and development agencies should promote the adoption of improved charcoal stoves through awareness campaigns and subsidies to increase accessibility among low-income households.

5.2 Suggestions for Further Research

- (a) Further studies should investigate ways of improving thermal efficiency beyond current designs by incorporating advanced insulating materials and improved combustion techniques.
- (b) Research should be conducted to compare different stove designs under varying cooking conditions to determine the most efficient models.
- (c) Additional studies should explore the relationship between charcoal quality and stove performance to optimize fuel efficiency.
- (d) Future research could also examine hybrid cooking systems that combine charcoal with other energy sources to further reduce fuel consumption and environmental impact.

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