BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF SCIENCES AND ENGINEERING

DEPARTMENT OF PHYSICS AND ENGINEERING

A PROJECT IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE BSc IN AGRICULTURAL ENGINEERING

DESIGN AND FABRICATION OF A ROCKET STOVE FOR RURAL AREAS IN ZIMBABWE

By:

CHAKANDINAKIRA VIMBAI L

SUPERVISOR

PROFESSOR ISNEL RODRIGUEZ

JUNE, 2024

DECLARATION

I, Chakandinakira Vimbai L, B192013A, I declare that, with the exception of what is noted in the acknowledgement and references, all of the research and work for this study was done by me. According to my knowledge NO other university has received this project, in whole or in parts.

Student's Signature: Date: 05/06/2024

Academic Supervisor's Name: Professor I. Rodriguez   Signature: ____________

Date: 05/06/2024

Project Coordinator's Name: Professor I. Rodriguez   Signature: ____________

Date: 05/06/2024

DEDICATION

As well as everything that I do, I would be honoured to dedicate this compilation to my mother. The people who gave me tools and values to be where I am standing. I will never finish to thank my mother and my sisters, Mrs Madumbu and Faith Chakandinakira for their support, prayers and encouragement. I am truly grateful to have such overwhelming support.

ACKNOWLEDGEMENT

First and foremost, I would like to thank the almighty God for the revelation, knowledge and understanding in the compilation of my project. I would also want to thank him for the helpers he sent my way to assist me financially and emotionally. I would like to express my gratitude to my academic supervisor, Professor Isnel. His support and supervision that gave me truly helps during the period of conducting my project. His never-ending supply of valuable advice and guidance has enlightened me and deeply engraved in mind.

I extend my profound gratitude to my family especially mom, my sisters, Faith and Mrs Madumbu and my daughter Tafadzwa for their unwavering support. I would also wish to extend my heartfelt gratitude to my teammates Clive Tsatsa and Farai Manza for their dedication in completing this project successfully. I am also happy to present my grateful acknowledgement to BUSE workshop technicians who has been so warmth and kind to provide sincere assistant and good cooperation during the manufacturing process. Their cooperation is much indeed appreciated. I would like to convey thanks to my Agricultural engineering lecturers Mr Zingwari, Mr Zendera and Professor Isnel for their unmatched support which brought this project to a triumphant conclusion. Not only did they abandon their duties to answer to my questions and assist me, but they encouraged and cheered me to give it my best. I am also indebted to the participants who willingly volunteered their time and provide valuable insights that served as the foundation for this project.

Lastly, I would like to state my appreciation to the Faculty of Science and engineering staff, my friend and colleagues for supporting me. Once again thank you all.

ABSTRACT

Firewood is the major source of energy for cooking and heating in rural areas of Zimbabwe. Many households are using traditional three stone stoves for cooking. However, due to incomplete combustion, these stoves consumes a lot of firewood and this results in higher firewood usage and leads to deforestation and environmental degradation. The purpose of this research was to manufacture a rocket stove which would be environmentally friendly and that can be adopted by rural households. The major goal was to reduce the rate of firewood demand in rural areas. Two stoves of different sizes were fabricated using different recycled materials from scrap yard, one was made of galvanic steel and the other one was made of steel. The stove consist of a heat riser, pot rest, the two feed tubes that is the air feed tube and the firewood fed tube. Performance tests of the manufactured prototypes and three stone stove as a control experiment was done using water boiling test. Same amount of water which was 2l with initial temperature of 22℃ and 3kg of wood was used for all the three experiments. The power output for the galvanic steel rocket stove and steel rocket stove was found to be 0.31KW and 0.27KW respectively. Thermal efficiency for galvanic steel rocket stove was found to be 39.2% and 30.6% for steel rocket stove. Results obtained shows that the taken to boil 2l of water to 98℃ was 12minutes for the galvanic steel rocket stove, 14minutes for the steel rocket stove and 25minutes for the traditional three stone stove. Complete combustion in rocket stoves was observed by comparing the amount of fuel burned and the amount of ashes produced. The results obtained shows that the stoves can reduce the amount of fuel needed for cooking. The results from the performance test shows that the system can be used by rural households and reduce the amount of firewood needed to prepare certain meals.

Keyword: rocket stove, firewood, environment, thermal efficient.

TABLE OF CONTENTS

Table of Contents

LIST OF TABLES

LIST OF APPENDICES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATION

$PM_{2.5}$	Particulate matter
CM	Chitetezo Mbaula
BUSE	Bindura University Science Education
RS	Rocket stove
TCS	Traditional cooking stove
TSS	Three stone stove

CHAPTER 1: INTRODUCTION

1.1. Background

Energy is an essential commodity in sustaining people's livelihoods (Clancy, *et.al,* 2002). Energy provides essential services and has an implication on economic productivity and development of any country (Loftness, 1978; Colombo, 1996).Energy consumption is a common phenomenon for today's world, but access to modern energy has become a fundamental issue for development and poverty reduction for developing countries (Chowdhury, *et.al*, 2021). Variations in household energy use exist between rural and urban populations, between high- and low-income groups within a country, among countries (Pachauri, 2004). Many African developing countries depend on wood for cooking energy. About 81% of Sub Saharan African household use firewood for cooking. The heavy reliance on firewood has contributed to environment degradation due to deforestation. This is stocking concern about the links between firewood access conservation and rural livelihoods. In Zimbabwe, firewood provides 61% of the total energy supply required and it is estimated that six million tonnes of firewood are consumed every year. Demand for firewood and charcoal is a driving factor to forest degradation hence leading to firewood to be seen as a scarce resource that needs to be regulated. Marylin Smith who was an independent conservationist based in Zimbabwe and a former staffer in the government of former President Mugabe once said "The rate at which deforestation is occurring here convert Zimbabwe into an outright desert in just 35 years if pragmatic solutions are not proffered urgently and also if people keep razing down trees for firewood without regulation" (Joshi, 2015).

In Zimbabwe, many rural areas depend on traditional open fire stoves like balancing the pot on three rocks to create what is known as mapfihwa or other conventional stoves for cooking. Traditional open fire stove is an efficient stove that is commonly used in a large variety of domestic level. Traditional energy usage and cooking on open fire furnace are contributing to unnecessary high level of biomass resource extraction and consumption (Konemund, 2002; Drunkerely, 1981).

Wood energy use can be reduced with efficient stoves. Wood saving stoves are essential in conserving natural resources because they are designed to burn firewood more efficiently, reducing the amount of firewood needed for cooking or heating. This helps to conserve precious wood resources especially in areas where deforestation and scarcity of firewood are pressing issues. Environmental impact reduction is also achieved by reducing the amount of firewood used. Wood saving stoves contribute to mitigating deforestation, soil erosion and greenhouse gas emission. This can help address climate change and protect local ecosystems.

Rocket stoves are intermittently burning wood stoves designed to burn fuels efficiently ad produce less smoke than conventional stoves and have reduced emissions. The most commonly used fuel is wood but can also run on leaves, card board and paper. They are designed for populations who depends on biomass for their cooking fuel. It was originally developed for cooking where a relatively small amount of continuous heat is applied to the bottom of a pot. It is great for developing countries where wood for fuel is scarce because they run on just a handful of twigs and the high heat generated can boil water much more quickly than open fire.

1.2. Statement of problem

The research gap addressed in this study was the lack of cost-effective wood saving stoves in rural areas of Zimbabwe. Many rural households rely on traditional stoves (mapfihwa) or open fires which often produces high levels of indoor pollution and poses a safety hazard in homes, particularly for children. Inefficient stoves necessitate the use of larger quantities of firewood, resulting in an increase on firewood demand for households that rely on wood as their primary fuel source and also excessive deforestation as more trees are cut down to the demand for fuel leading to environmental degradation, loss of biodiversity and disruption of ecosystem. Government and development agencies like the Environmental Management Authority (EMA) have focused on the physical availability of firewood in their approach to energy and conservation ad this approach, diagnoses of problems and the designs for solutions have been largely based on simple model of supply and demand. However, there is need to develop a wood saving stove that is accessible, affordable and easy to fabricate using locally available materials. This study aims to reduce firewood consumption by developing a wood saving stove that is far less wood consuming to produce comparable levels heat or light as less efficient forms of fires or stoves and produces less smoke to the air.

1.3. Main objective

The aim of this study is to fabricate a stove which is cost effective, efficient and adaptable to rural areas in Bindura, Zimbabwe, using wasted materials and reduce cutting down of trees.

1.3.1. The specific objective

1.3.1.1. To design a rocket stove in order to use in rural areas belonging to Bindura and Zimbabwe.

1.3.1.2. To fabricate a prototype cheap rocket stove for rural areas, using wasted and recycled materials.

1.3.1.3. To determine the efficiency of the designed Rocket stove in terms of wood saving and cooking time.

1.3.2 Hypotheses

Null hypothesis

1.3.2.1 There is no significant difference in wood saving between the rocket stove and other conventional stoves.

1.3.2.2 There is no significant difference in terms of cost between rocket stove and other conventional stoves.

1.3.2.3 There is no significance different in fuel efficiency and cooking time between the rocket stove and conventional stoves.

Alternative hypotheses

1.3.2.1 The design of a rocket stove will result in a cost effective and efficient wood saving solution for rural areas in Zimbabwe.

1.3.2.2 The use of available and recycle materials in fabrication of rocket stove will result in cheap ad sustainable solution for rural areas.

1.3.2.3 The construction of a rocket stove will result in increased wood fuel efficiency and reduced cooking time compared to open fire and other conventional stoves.

1.4. Justification

Firewood is the main source of fuel used for cooking in rural areas of Zimbabwe. However, many rural households rely on traditional stoves or open fire furnaces like mapfihwa which requires a lot of firewood to prepare a single meal or to boil a certain amount of water. This resulted in an increase in deforestation as more trees need to be cut down to meet the demands for firewood.

Traditional cooking methods also result in time consuming task. A lot of firewood would be required for cooking and valuable time and energy will be spent on firewood collection particularly by women and children. Open fires produce a high level of indoor air pollution as incomplete combustion releases harmful pollutant and prolonged exposure to these pollutants can cause respiratory diseases and eye irritation to people who spend more time around the cooking area. Open fires also pose a danger especially to children.

To mitigate the effects of environmental degradation due to firewood demand, it is necessary to fabricate a wood saving stove. Therefore, fabrication of a wood saving stove is essential. The researcher seeks to contribute to efficient use of firewood by fabricating a cheap wood saving stove.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

People living in areas with limited energy access and resource scarcity face difficulties in providing cooking energy. In rural areas, many households rely on firewood as a source of energy for cooking, boiling and heating water since a significant proportion of the population have no access to electricity and can-not afford advanced systems which provides energy for cooking. Wood is a renewable resource, unlike fossil fuels such as oil, coal and gas which are non-renewable. In fact, if firewood is harvested in a sustainable way, woodlots can provide an abundant source of fuel for years to come (Ostro, *et.al*. 1994). Traditional stoves are still the most prevalent way of cooking in developing countries regardless of their inefficiency and risk associated to human health and the environment (Arthur, *et.al*. 2010).The objective of this literature review section is to focus on publications and researches conducted before by other researchers in relation to designing and fabrication of a rocket stove. These researchers obtained different results maybe because of different locations and different altitudes.

2.2. Background and context

Access to electricity, rural (% of rural population) in Zimbabwe was 37.06 as of 2020. Its highest value over the past 28 years was 37.06 in 2020, while its lowest value was 3.06 in 1992 (World Bank, 2018). The overwhelming bulk of the region's electricity grid is concentrated in urban areas, while the vast majority of the population living without electricity is in rural and peri-urban areas and according to the Zimbabwe national energy policy report of 2012, 83% of urban households have access to electricity compared with 13% in rural areas (Chipango, 2020). Cooking is a major firewood demanding task in rural areas. There are many alternatives methods of providing energy for cooking for example liquid fuels like kerosene and paraffin, renewable gases like biogas and electrical energy like use of electricity but they are expensive for rural households. Due to high cost and lack of understanding and awareness of technology, access to these upgraded systems in rural areas is still limited (Puzzolo *et.al*. 2016). Lack of alternative- cheap and available sources of energy in rural areas of Zimbabwe leads to a higher demand in firewood as the source of energy. The lack of contemporary energy options for homes in Zimbabwe leads to the usage of biomass energy sources (Afshar, 2018). Many rural households are poor and cannot afford to adapt and use new cooking technology so they end up depending on firewood only. Many rural households have expressed a desire for alternative cleaner and more efficient cooking technologies such as gas stoves, bio gas digester and cook stoves with improved combustion systems (Kleinbaum, 2016). Due to lack of a national grid in many rural parts of Zimbabwe, households there must rely on alternative energy sources including paraffin, charcoal and firewood for heating and cooking (Prinsloo *et.al.* 2016). Paraffin is a liquid and it emits a lot of black soot which contains carbon monoxide which is harmful to human health. Use of charcoal results in a lot of deforestation for example in areas like Chiredzi, Mopane tree are cut down in large numbers in order to produce charcoal for sale. Use of firewood is also resulting in a massive deforestation of indigenous trees like Musasa, Mutondo and Muunze. Use of these energy sources can be hindered by various reasons like expensive, difficult to access and it might be tiresome and time consuming to acquire them. This can be a concern because obtaining these sources can be costly, time consuming, and harmful to the environment by causing deforestation and indoor air pollution (Kroon *et.al*.2013).

Many rural households in Bindura Zimbabwe mainly depends on traditional wood cooking stoves like three stone stoves and quite a few numbers are using metal grate stoves since they cannot afford modern cooking methods. These wood stoves consume a lot of firewood and emits a lot of gases which are hazardous to human health. Use of these inefficient wood stoves increase burden and pressure on women and children who plays a major role in firewood collection. Women still have a burden of workload to fulfil energy requirements of house showing adverse effect in their health and socialism (Adhikari and Jaishi, 2018). A lot of time is consumed on firewood gathering instead of other social and economic activities. Wood collection consumes considerable amount of time and distances covered over difficult terrain (Adhikari and Jaishi, 2018). Higher demand in firewood also results in environment degradation.

The construction of the rocket stove will have a huge positive impact on the livelihoods of Bindura rural families in Zimbabwe because of the following factors, accessibility and availability. Adoption process is also controlled by different extents by cooking tradition, resource availability (Subedee, *et.al*, 2017). The rocket stove will be constructed using recycled and wasted materials so it will be affordable and easy to access. People will often desire for an affordable improved cooking stove. According to a research study carried out in Nepal, the preference of local people living in Api-Nampa Conservation Area was on cheap, portable, small, affordable and low maintenance cost stove (Subedee, *et.al*,2017).Rocket stoves are cheap to use and run as compared to electricity and gas stoves. Rocket stoves use wood, plastics and sawdust as a source of energy and these things are easy to acquire in rural areas of Bindura.

Rocket stoves are also portable and this means that they can be easily moved. Bindura is characterised with high temperatures in summer and it will be too hot to prepare meals indoors. A rocket stove can be carried outdoor during periods of high temperatures and carried back indoors during rainy days.

The other important factor is fuel efficiency. Rocket stove has an average fuel efficiency of 25-30% (Subedee, *et.al*, 2017). According to a study carried out in Nepal, about 70% of the respondents responded that rocket stove consumed few firewood (Subedee, *et.al*,2017).Rocket stoves uses a few thin logs to prepare a certain meal as compared to traditional three stone stoves and other wood stoves used in rural areas. According to a study carried out in Nepal, the results suggested that RS has firewood saving capacity than TCS (Subedee, *et.al*, 2017. This will reduce the burden of firewood collection particularly on women and children who spent most of their time in firewood collection. It will also reduce firewood demand because a bunch of wood (svinga) collected by a single woman can be used to cook for a week and a few days. This will reduce deforestation in search of firewood contributing to a reduction in environment degradation. The use of more efficient stoves to reduce the demand for wood to sustainable level is usually more economically viable than planting new trees, at least initially (Barnes, *et.al*, 1994).

Rocket stoves are durable and they can last for five to ten years before they become obsolete and this reduces the replacement costs because one has to replace his or her stove after numerous numbers of years. Rocket stoves does not require academic knowledge to use. They can be operated by any person even the illiterate ones. They are also safe to use since they do not have a lot of emission because of complete combustion so they can be used indoor or outdoor depending on the choice of the user. A study conducted by Dhakal and Raut estimated that one improved cooking stove would reduce emission by 1.09t CO_2e per year compared to a traditional cooking stove (Dhakal and Raut, 2010).

Rocket stoves takes a few minutes to prepare a meal because heat is utilized and applied directly below the pot and the flame is not affected by wind. Three stone stoves and metal grate stoves are directly affected by wind since the flames can be easily blown away by wind causing less heat to be applied below the pot thus taking a lot of time to prepare a meal. Traditional three stone fires are fairly inefficient and for basic cooking about 2 tonne of biomass are needed each year per family (Kammen, *et.al*, 2002). According to a study carried out in Nepal, about 65% users of TCS users responded that high quantity of firewood consumption by these stoves was a major problem and 30% responded more time taken for cooking food (Subedee, *et.al*,2017) . Temperatures can be controlled easily on rocket stoves so it is suitable to prepare various meals. One can prepare meals which requires high temperatures and also meals which requires low temperatures.

The main aim of designing and fabricating a rocket stove is to reduce firewood demand in Bindura rural areas. A study carried out in Nepal shows that, the expected value of consumed by traditional cooking stoves (TCS) was found as 3.86 tonnes but the average value of wood consumption by the use of RS and TCS was 2.706 tonnes which was significantly decreased 0.974 tonnes per year per household, indicating that the consumption of TCS is greater than RS (Subedee, *et.al*, 2017).This will reduce the rate of deforestation and environment degradation. After identifying the need in cooking energy by various consumers in Bindura, there is need to construct a rocket stove so as to reduce stampede for firewood in rural areas and utilize the available firewood efficiently in order to reduce the rate of deforestation. Firewood collection is the main driver of deforestation and forest degradation in many South Asian countries (Subedee, *et.al*, 2017). The design and fabrication of rocket stove will reduce the burden of firewood collection on women and children since firewood will be used efficiently so the frequency of collection will be low. Efficient use of energy helps in enhancement of socio-economic status of financially weak people (Ekholm, *et.al,* 2010). Figure below shows the effects of deforestation in search of firewood for cooking.

(a) (b)

Figure 2.1: Logging in Mopani woodland (a) to create charcoal (b) in Chiredzi areas (source: Gotore, *et.al*, 2019).

2.3. Technical overview of wood fired stoves

Wood fired stoves have been used for centuries as an important supply of heat and cooking in countless homes worldwide. Today, they stay popular for their nostalgic charm, comfortable ambience and reasonable heating capabilities. This technical overview will delve into the quintessential elements of wood-fired stoves, imparting a comprehensive appreciation of their design, operation and environmental impact. I will discover the variety types of wood fired stoves available inspecting their unique points and applications. The anatomy of a normal wood stove will be analysed such as its combustion chamber and firebox.

By the stop of this technical overview, readers will attain a thorough perception of the design, operation, safety and environmental factors of wood fired stoves. This expertise will empower people to make informed decision concerning their use.

2.3.1. Rocket stoves

A rocket stove is an efficient hot burning stove which uses small amount of wood fuel. Even if wood is scarce where you are, rocket stoves only require a small amount of fuel anyway (Klaver,2022).A rocket stove is a wood saving stove that burns wood to produce a relatively small amount of continuous heat which is applied to the bottom of a pot. Rocket stoves can also run on leaves, card board, paper, saw dust but people often use wood fuel. Rocket stoves are mostly used in rural areas or places where there is a high stampede for firewood especially in developing countries where the majority of rural households have no access to the electrical grid because they run on just a small amount of twigs and generate high heat which can boil water much more quickly than an open fire. A study carried out in Ethiopia shows that the rocket stove has 29% thermal efficiency, 43% reduction in specific fuel consumption, 42% CO and 81% $PM_{2.5}$ emission reduction as compared to the traditional three stone stove (Mekonnen, 2020).

2.3.2. Working principles of a rocket stove

Principles of convection and radiation are used by the rocket stove to efficiently heat the cooking surface. The rocket stove consists of a small chamber with a small opening at the bottom. This combustion chamber contains a vertical insulated chimney which ensures complete combustion prior to the flames reaching the cooking surface. Fuel that is wood, biomass or other combustible material is placed into the combustion chamber and lighted.

Air enters through the bottom opening of the combustion chamber and mix with the fuel resulting in a fast burning reaction. Air entering the chamber will contains oxygen which will interact with wood resulting in the production of water, heat and carbon dioxide. The effectiveness of the combustion in the combustion chamber is determined by the amount of air drawn in. Air drawn into the chamber opening will force the combustion gases to rise and expand rapidly through the chimney creating a "rocket effect" which will increase the efficiency of the combustion process and reduce the amount of smoke produced.

Heat from the combustion is channelled to the cooking surface above by the process of conduction and radiation allowing for cooking efficiency. Conduction is a process whereby heat is transferred from a hot body to a cold body.

Gases produced will leave the chimney and are released into the atmosphere. These gases are cooler than those at the top of the combustion chamber, so they expand upon exit thus creating a slight vacuum that draws more air into the combustion chamber. This will result in the creation of a self-sustaining cycle that keeps the fire burning. The whole process depends on the process of convection which is the movement of particles through a substance, transporting heat energy from hot bodies to cool bodies.

2.4. Cooking technologies used in Zimbabwe rural areas

In the rural areas of Zimbabwe, cooking is a fundamental thing of a day by day life. Traditional cooking methods exceed down via generations and have played a quintessential function in sustaining communities. This part of the research will discover a range of cooking technologies commonly used in rural areas of Zimbabwe. Through a combination of qualitative and quantitative research methods, this study will bring light on the dynamics of cooking technologies mainly used in Zimbabwe rural areas. It will make a contribution to a higher understanding of how rural communities adapt to changes that technology is applying to shape their livelihoods.

2.4.1. Wood stoves

Zimbabwe is a developing country and many people in rural areas do not have access to the electricity grid. In Zimbabwe, alternatives to grid electricity are being sought in the light of limited electricity supply and under-performance of major electricity generation plants following the economic meltdown affecting the country since the mid-1990s, triggered by the Economic

Structural Adjustment Programme (ESAP), and more recently due to politically instability (Makonese, 2011). Most rural people are poor peasants who cannot afford other convenient cooking methods like the gas cooker but besides that, there are no gas filling stations in rural areas so it will be a challenge to refill the gas tank even if one owns it. This results in wood being the most commonly source of cooking energy in rural areas resulting in a massive deforestation within the country resulting in firewood being a scarce resource. Wood stoves are capable of burning wood, paper, sawdust and other compatible materials. Majority of rural households are using three stone fireplace, iron frame stoves and quite a few numbers is using tsotso stoves. These stoves consume a lot of wood leading to a high demand in firewood and they also have higher CO emission. The amount of CO emissions for the traditional wood stoves or fireplace were found to vary from 100 to 250g CO/kg dry wood fired (5.1-12.6g/MJ input) at an average wood consumption below 1kg/hr (Karlsvik,1993).

2.4.2. Review of available wood stove

Rocket stove is a wood saving stoves which is effective in providing high levels of heat prior to the amount of burned fuel. They differ in terms of shape, size and materials used for manufacturing the stove. Rocket stoves can be made from mud and bricks or from recycled materials.

According to the World Bank collection of development indicators, compiled from officially recognized resources, access to electricity, rural (% of population) in Zimbabwe was reported at 31,64% in 2021. This leads to a higher firewood demand because it will be the major source of energy for cooking. Improved cooking stoves projects in the developing world have the potential to reduce deforestation, improve health and slow climatic change. To meet the requirements, stoves must be carefully designed through testing and verification of performance (McCarty, *et.al,* 2010).

According to different studies carried out by different researchers in different countries, rocket stoves can use different sources of fuel like wood, recycled materials, papers, saw dust, card boards, tree barks, small branches or twigs. The best fuel for a rocket stove is dry, untreated wood, a couple of centimetres square and about 20cm to 30cm long. This can be split kindling, or sticks and small branches. Ideally you only need to have two or three pieces of wood in the stove at a time, as overfilling it will reduce the space for airflow. In a domestic biomass cook stove, the air supply plays a significant role in improving the combustion characteristics (Kaundal, A, *et.al.*2021).

Rocket stoves are effective in reducing wood consumption as compared to open fireplaces. A case study in Thermal engineering carried out by Bassazin Ayalew Mekonnen in Ethiopia concludes that the rocket stove reduces specific fuel consumption by 43% and reduce CO concentration by 42% as compared to 3 stone stoves (Mekonnen, B. A, 2022). A study conducted in India found that households using rocket stoves reduces wood consumption by 42%, cooking time by 24%, and fuel cost by 20% compared to traditional stoves (Balakrishnan *et.al* 2012). There are different factors which affect rocket stove effectiveness. These include size of a rocket stove, wood size, amount of air drawn into the combustion chamber and the designing and sizes of the Rocket stoves.

Rocket stoves are environmentally friendly because they eliminate the use of air polluting stoves like paraffin stoves which uses paraffin as a source fuel which in turn produces a lot of gases. Rocket stoves run on a handful of twigs, a couple of wood, paper or recycled materials and this will reduce the higher demand on firewood hence reducing deforestation. Complete combustion within the rocket stove reduces air pollution thus reducing air borne and respiratory diseases.

2.4.2.1. Three stone stoves

The traditional three fire (TFS) stove was invented around 12 000 years ago (Manoj *et.al.*2013). In Tanzania, a majority of rural residents are cooking using firewood based three stone fireplace stoves (Hafner, *et.al.*2018). This is a traditional method of cooking where three stones of almost the same size are used to balance the pot. Traditional three stone stoves consist of three stones around a fire and a pot is balance for cooking (Subedee, *et.al*, 2017). In some areas three bricks of the same size are used to balance the pot instead of stones. It is the cheapest method used in rural areas of Zimbabwe because it is easy to invent. Firewood is added between the stone and ignited to provide heat below the pot. Three stone stove is shown on the figure below.

Figure 2.2 : Three stone stove (Source: https://www.dsource.In/resource\kitchen products/stoves)

2.4.2.2. Metal grate stove

These four-legged stoves come with different in shapes and sizes. They are made up of metal and they can be used inside or outside the kitchen because they are movable. Some of these metal stoves consist of pot holes where pot is balanced during cooking and some will have metal bars which accommodates pots of different sizes. Firewood is added below the stoves and ignited to produce heat. These stoves are commonly used in rural areas where electricity and gas are expensive for the households. A figure below shows a metal grate stove.

Figure 2.3: Metal grate stove (Source: Fort with ma/gazine)

2.4.2.3. Tsotso (small sticks) stoves

Tsotso stoves are wood saving stoves which can run on a handful of twigs. Tsotso stoves are portable light weight stoves made from metal or mud. Rural residents are poor and they cannot afford to purchase sheet metals to construct tsotso stoves so they mainly use mud. The tsotso stove was originally developed by David Hancock at the Development Technology Centre based at the University of Zimbabwe (Mika and Tahwa, 2001; SCEE, 2001).

Figure 2. 4: Tsotso stove (Source: Global issue)

2.4.2.4. Chingwa stove

It was widely disseminated by the government through the department of energy and NGO's such as the Zimbabwe women's Bureau (Mika and Tahwa, 2001; SCEE, 2001). It is a high mass stove fitted with a metal grate, a pot hole and a hot plate and is made up of mud and bricks. This type of stove is built inside the kitchen so it requires a big kitchen so as to have enough space to accommodate it. The motive behind the construction of this stove was to reduce the consumption of firewood by half for instance, if a household was using to bunch of firewood per month, they will only need five bunch using the chingwa stove. The figure below shows a chingwa stove constructed in a kitchen.

Figure 2.5 : Chingwa stove (Source: http://www.bioenerglists.org)

2.4.2.5. "Yugen" mud stoves

It was introduced in the Plumtree district by AVOCA training centre. It was constructed outside the kitchen. It was difficult to build thus requiring experienced artisans. Importantly the stove was a failure because many households could not afford the wire mesh used to reinforce the mud (Mika and Tahwa, 2001).

2.5. Comparative analysis of wood stoves used in rural areas in Zimbabwe

Wood fired stoves are widely used in rural Zimbabwe as a primary means of cooking. However, the efficiency and protection of these stoves fluctuate greatly. This research aims at conducting a comparative analysis of different types of wood fired stoves used in rural areas of Zimbabwe and access their performance. The outcome of this study may help with providing an important insight on safety of these wood fired stoves. The results might aid to informed decision making on the selection and use of improved wood stove by various users.

2.5.1. Three stone stoves

This is the cheapest system of cooking which can be constructed by anyone. These types of stoves are highly used in developing countries because they utilise locally available materials, cheap and easy to build (Masera, *et.al*, 2000).This system provides light during the night and it also allows for space heating during the cold days. However, heat produce can escape into the air and also during windy days, flames will be blown away by the wind instead of being directed below the pot and this will result in an increase in amount of firewood required to prepare a specific meal. Three stone stoves also causes air pollution because it produces a lot of smoke. Traditional cook stove such as the three-stone fire are inefficient and polluting, leading to respiratory complications and other diseases (Panwar, 2010). It is also difficult to use because one is to hold the pot when cooking to prevent it from falling. Three stone stoves increase the burden of firewood collection to woman because they consume more firewood as compared to heat produced. Three stone fires are fairly inefficient and for basic cooking about 2 ton of biomass are needed each year per family (Kammen, *et.al*, 2002)

2.5.2. Metal grate stoves

These stoves may be less expensive depending on the type and sizes of the stove. They are easy to operate because one can simply add firewood on the grate and light it. The stove can be used for both heating and cooking. However, these stoves consume a lot of firewood because they require a constant supply of firewood. They can be difficult to clean and it may be difficult to balance small pots or big pots depending on the sizes of the grate.

2.5.3. Tsotso stoves

These are environmentally friendly stoves. They are cheap stoves which can be constructed using readily available materials. Materials used to construct Tsotso stoves include clay, cow dung and sand. These can be easily found in rural areas. Tsotso stoves are wood saving stoves which can run on a bunch of twigs called Tsotso. Positive characteristics of the tsotso stove are its efficiency, its ability to burn a wide range of fuels and the provision of a safe cooking environment (Kuhnhenn, 2003). The efficiency is higher than that of the traditional stove for three reasons, the Tsotso stove acts as a windshield, its walls are insulated and the shape of its results in a focusing of the heat on the pot (Scott, 2002). It also reduces the burden of firewood collection on women and children because only a few bunches of wood are needed to prepare a single meal. However, these stoves are fragile and they need to be replaced more frequently as compared to rocket stoves. They emit a lot of smoke which is harmful to human health due to their enclosed spaces. They are less durable so they need to be maintained carefully as compared to other wood stoves like rocket stoves.

2.5.4. Chingwa stoves

These stoves are cheap to construct. They use less wood compared to other wood stoves. They are easy to operate. These stoves also have the ability to prepare various foods at the same time. It produces less smoke which is good for human health. However, some of the houses in rural areas are too small to accommodate such stove. They also need to be carefully maintained so as to keep the in good working conditions.

2.5.5. Yugen mud stove

These stoves run on few woods as compared to three stone stoves. They are environmentally friendly because they produce less emission. They are durable stoves which can withstand heavy rains. However, this stove is expensive because an ordinary person cannot build it and this makes it difficult to access them. It was difficult to build thus requiring experienced artisans (Mika and Tahwa, 2001). These stoves require a wire mesh for mud reinforcement and because of poor lifestyles in rural areas, many households can-not afford to purchase this wire. Importantly, this stove was a failure because many households could not afford the wire mesh used to reinforce the mud (Mika and Tahwa, 2001). These stoves are not suitable for various climates throughout the country.

2.6. Improved wood fired stoves

Improved wood stoves are likely to provide better cooking facilities and improve livelihoods of human in developing countries especially in rural areas where households depend on wood as the main source of cooking energy. Traditional stoves used in rural areas produces a lot of smoke which causes respiratory problems. In rural India, 52% of the women participating in cooking store study in Khairatpur village reported experiencing health problems due to cooking with traditional cooking stoves (Singh *et al*., 2015). Improved wood stoves are mainly designed in such a way that they will burn wood or fuel efficiently and to have complete combustion so as to reduce the quantity of smoke and hazards produced. Improve wood stoves run on a few numbers of logs and this is because of their high wood burning efficient and also utilization of heat produced. This will reduce health problems caused by smoke produced from traditional stoves. A study carried out in Nicaragua shows that there was a large reduction in indoor pollutions and personal carbon monoxide among participants who adopted the improved stove compared to participants who reported continued open fire use (Yoder, *et.al*, 2014).

Improved wood stoves also aid in reducing environmental degradation. These stoves produce less pollutants and smoke which is an aided advantage to human health improvement especially to women who are main cooks. A study carried out in Malawi comparing three stone stove, locally used clay stove called Chitetezo Mbaula (CM) and Philips gasifying stoves shows that the CM uses 53% of fuel used by three stone fire stove, produces 59% carbon monoxide and 50% of particulate matter (PM2.5) of the three stone stove whilst the Phillips stoves uses 31% of the fuel and produces 38% of carbon monoxide and 22% of $PM_{2.5}$ of the three stone fire stove (Jagger, *et.al.*2017).

Excessive smoke produced by three stone stoves lead to diseases like blood pressure and some respiratory diseases. People with Asthma may find it difficult to breathe when exposed to areas with high smoke. Improved wood stoves reduce smoke production and also lowers the rate of diseases caused by smoke. A case study carried out in Guatemala shows a reduction in the incidence of acute lower respiratory infections by 50% with the use of improved wood cook stoves (Tomczyk,*et.al*,2019).

The adoption and use of improved wood stove depend on the willingness of the user and method of approach used to deliver information. User acceptance depends on various factors like availability, affordability, simplicity of use, saving family labour and time and also the durability of stoves. Some households might be willing to use improved wood stoves but lack of funds to acquire the stove might be a hindrance. A study carried out in Ethiopia shows low levels of adoption of improved cooking stoves and the study shows that this has been triggered by socio-economic, institutional, financial and resource endowments (Kare, *et.al.*, 2022). The approach used to deliver information to households can affect the adoption of clean cooking technologies. A study carried out in Central Mozambique on how to increase cook stove adoption shows that training approach plays a significant role in promoting clean cooking technologies.

In view of the above account, adoption of improved wood stoves depends on affordability, simplicity of use and user's acceptance. There is need to design and manufacture locally available and affordable wood stoves to meet the needs of various users.

2.6.1. Classification of improved wood fired stoves

Improved wood fired stoves are designed to enhance upon the usual traditional burning stoves in terms of reduced emission, fuel consumption and enhanced safety. They have been broadly promoted in growing nations as a skill to mitigate the poor influences of standard stoves. They can be classified into a range of sorts primarily based on their design features, firewood loading mechanisms and thermal efficiency or they may be classified according to the design features.

2.6.1.1. Gasifier stove

Gasifier stoves reduces wood consumption by 70% compared to traditional stoves. They work by burning wood in an oxygen restricted environment resulting in the breakdown of wood incombustible gases which will be burned to produce heat (Smith *et.al*, 2013). The gasifier has three parts that is the combustion chamber on top, fuel canister in the middle and air entrance at the bottom. When ignited at top, primary air enters at the bottom and moves up through packed bed of fuel. Secondary air enters from below into the top section, where it mixes with the gases for combustion (Njenga, et.al, 2016). According to a study carried out in Kenya, the gasifier stove constitutes a cleaner cooking system that saves fuel, produces charcoal for further cooking, cooks relatively faster and reduces indoor air pollution from cooking with biomass fuel.

2.6.1.2. Rocket stove

A rocket stove is a portable stove which burns at a very high temperature and is also extremely efficient. It uses small diameter wood fuel which is simply put into a combustion chamber (Hately, 2016).A case study carried out in Ethiopia shows an improved thermal efficiency of 32% compared to 14% of three stone stoves. Reduced carbon monoxide concentration by 42% and $PM_{2,5}$ concentration by 99.5% over three stone stove and 43% reduction in specific fuel consumption (roughly 652 kg fuel saving/year/device) (Mekonnen, 2022). In rural Kenya, a comparison of traditional three-stone stove and rocket mud stove (RMS) showed that RMS use resulted in a 33% reduction of carbon monoxide production in the kitchen and a 42% reduction in “personal” carbon monoxide production, which was measured with data loggers placed on clothing (Ochieng*,* *et.al*.2013).

2.6.1.3. Institutional stoves

These stoves are larger than household stoves and they accommodate large pots and pans. They can use wood and several biomasses as fuel. They are mainly designed for large scale cooking operations such as schools, hospitals, prisons and orphanages. A case study in Uganda with St Paul’s seminary shows that a school using an improved wood cook stove reduces wood consumption by 65% and carbon monoxide emission by 97% compared to traditional stoves (Adem *et.al*.2015).

2.6.2. Comparative analysis of improved wood fired stoves

Rapid rise in energy cost and environmental degradation due to firewood fetching are driving factors on fabrication of improved wood stoves. These improved wood stoves assure a promising solution in providing efficient and sustainable heating. This comparative analysis focuses on performance evaluation of chosen improve wood stoves in terms of key parameters like emissions, fuel consumption, usability and thermal efficiency. The analysis might lead to informed decision-making and increase adoption of improved wood fired stoves.

2.6.2.1. Rocket stoves

Rocket stoves need far less wood as compared to other wood stoves. Rocket stove is portable and use small chunks of wood (Subedee, *et.al*, 2017). They are environmentally friendly because they produce less smoke or emission into the air due to complete combustion which is good for human health. Rocket stove requires less cooking time as compared to other wood stoves. Rocket stoves are portable stoves which can be carried indoor or outdoor depending on the user's wish. However, rocket stoves are not as quick or convenient as a gas stove. Rocket stove showed various advantages over traditional stove like low emission, shorter cooking time, low maintenance and affordable (Subedee, *et.al*, 2017).

2.6.2.2. Gasifier stove

Gasifier stoves uses a variety of small size biomass residues and there is no need for wood pieces or charcoal. Saw dust briquettes showed very good results in terms of smokeless combustion after start-up (Bhattacharya, *et.al*, 2001). These stoves are more efficient and have reduced smoke production due to complete combustion. Maximum efficiency of the gasifier stove was found to be 15.76% (Bhattacharya, *et.al*, 2001). They enhance a clean burning of solid biomass resulting in a considerable reduction of soot, black carbon and indoor or outdoor pollution. Charcoal produced by gasifier stoves can be used for other purposes. However, these stoves require more time to ignite, at least an hour or more to start the process. Bulky raw material is needed and the frequent of fuelling is high to run the system continuously. Handling residues like ash, tarry condensate is a time consuming and dirty activity.

2.6.2.3. Institutional stove

This stove reduce wood consumption thus reducing environmental degradation. A better burning rate was obtained was also obtained in an institutional stove thereby producing less charcoal thereby conserving more fuel (Akuma and Emma, 2017). They are used to prepare bulk food thus reducing cooking time and saving cooking energy since food is prepared at the same time in one pot. It is environmentally friendly since they reduce emission of carbon monoxide into the atmosphere. According to a study carried out at Opoku Ware Senior High School in Ghana, the stove prevented heat, smoke and provided safety and security to the cooks who were mainly women (Commeh, 2022).However, they are specifically designed for large scale cooking so it will be a difficult task to prepare meals for a single family using these stoves.

Safety and environmental issues

Wood fired stoves are mainly used for cooking in developing countries especially in rural areas where the standards of living are poor. In some of the developing countries, wood stoves are used in urban areas because some of the household have no access to the electrical grid. However, these wood stoves may pose a danger to human beings and the environment. Environmental issues to be considered include inefficient energy use. Use of inefficient wood stoves like three stone stove result in excessive consumption of wood which will lead to a higher demand in firewood. This will contribute to environmental degradation due to excessive deforestation in search of firewood. Deforestation is also another environment issue associated with the use of wood fired stoves. Regular use of wood fired stoves requires a continuous supply of firewood leading to deforestation which will result in loss of wildlife habitat, natural beauty of a place and also a driving factor to soil erosion. Air pollution is also a major concern. Burning wood releases fine particulate matter and other pollutants which may cause respiratory problems to human beings and continuous release of pollutants may result in climate change and global warming. Safety issues include carbon monoxide poisoning. Improper combustion inside a wood stove may lead to the production of carbon monoxide. High concentration of carbon monoxide in a poor ventilated house may lead to suffocation and death of human beings. The other safety factor to be considered is fire hazard. Stoves can produce sparks which may ignite nearby flammable things. Most of the houses in rural areas of Zimbabwe has a roof of thatch grass which can easily ignite if there is any spark on in. inhalation of smoke produced by wood stoves nay trigger respiratory diseases and worsen diseases like asthma. Wood stoves for example the metal grate stove becomes very hot due to heat conduction during their period of use. Contacting the parts of a hot stove has resulted in a lot of injuries especially to toddlers and children.

2.7. Conclusion

In a nutshell, the design and fabrication of a rocket stove for rural household is essential. Many researches have been done in an attempt to come out with a suitable and sustainable idea on how to improve cooking efficiency and to reduce environmental degradation in developing countries where many households depend on firewood as a source of energy for cooking. Reviewed studies show that rocket stoves can effectively reduce wood consumption and reduce carbon monoxide and other emissions.

CHAPTER 3: DESIGN NALYSIS AND CALCULATIONS

3.1. Introduction

Having an efficient and reliable access to suitable method of cooking is the most desirable thing in developing countries where many households depends on firewood as the main source of cooking energy. Cooking is a day to day activity which requires constant energy supply. Use of firewood as a source of cooking energy is mainly dominant in rural areas. It is important to pay close attention on designing, analysing and fabrication of a rocket stove. The efficiency of a rocket stove directly depends on its design. A well-designed stove will ensure maximum heat transfer and this will result in firewood utilization and this will result in utilization of firewood since there will be less fuel usage. Emission of harmful gases can be reduced with a proper design and this will aid in environmental conservation through reduction of carbon monoxide in the atmosphere. There is a guaranteed safety to the user through thoughtful design and analysis. A poorly designed rocket stove can have a number of impacts to human environment. Poorly designed rocket stoves may not achieve complete combustion of fuel or wood which may result in high fuel consumption and the user will be required to replenish fuel more frequently. Smoke emission may increase and this can be due to incomplete combustion and prolonged exposure to this smoke may result in respiratory problems. A poorly designed rocket stove poses a safety hazard to the environment. The exterior of the stove may be too hot and this can be a danger to toddlers and children. A poorly designed stove may be susceptible to tipping which might cause ignition of nearby things.

The objective of this chapter is to provide an overview of the components of the rocket stove and the design considerations and calculations of the rocket stove. The detailed design of the rocket stove will be covered in this chapter. This design and analysis chapter will help to guarantee that the system is efficient, effective and capable of providing reliable and efficient cooking energy to rural households.

3.2. Key components of a rocket stove

The design of a suitable rocket stove involves accurately designing of key components. This will aid in reducing the chances of reworking and wastage of materials and also improves efficiency of a rocket stove. The key components are the feed tube, the combustion chamber, the heat riser or chimney and the cooking top or pot rest.

3.2.1. Feed tube

The rocket stove consist of two feed tubes that is the firewood feed tube and the air feed tube. The firewood feed tube is where firewood is placed. The air feed tube is responsible for drawing air into the combustion chamber. The diameter of the air feed tube must be designed to allow for proper air flow. It must be designed in such a way that it allows the required quantity of air to enter into the combustion chamber. The accurately designed feed tube must not draw too much or too little air into the stove. The feed tube must be designed in such a way that it allows for the person's more control.

3.2.2. Combustion chamber

The combustion chamber is the heart of the wood fired stoves because this is where wood or fuel is burned in order to generate heat. The combustion chamber must be designed in such a way that it ensures complete burning of fuel and proper transfer of thermal mass. The combustion chamber must be insulated so as to prevent heat loss. The design o the combustion chamber must fulfil the various heat output required prior to the type of wood fuel used. The chamber must be designed to withstand high heat and pressure generated within the rocket stove.

3.2.3. Heat riser or chimney

The heat riser accumulates and utilize heat produced during combustion so as to increase the stove's efficiency by reducing fuel consumption. It is also responsible for creating a draft which pills air into the combustion chamber. The heat riser preheats the incoming air which aids in an efficient and complete burning. It also reduces the risk of accidental burns by providing a safe way to direct hot gases and flumes away from cooking top.

3.2.4. Cooking top

This component is found at the top of the stove and it is specifically meant to accommodate pans and pots. The top can be flat or equipped with a series of rings so that it will accommodate different sizes of pots. It should be well insulated so as to prevent heat loss. Heat is channelled form the combustion chamber to the cooking top.

In addition to the key components, the overall of the rocket stove must be considered during designing so that it will have maximum effectiveness and efficiency rate. The height, shape and diameter must be considered during design consideration. The height of the chimney must be properly calculated to ensure successful drawing up of smoke and end products without creating any backdraft. The diameter of the combustion chamber and feed tube must be designed in such a way that it allows for proper airflow and combustion. Shape of the stove must be able to reduce heat loss. Materials must be considered. Use of highly insulating materials can help to improve the efficiency of a rocket stove.

Construction of a rocket stove is not a complicated task. The major skills required are cutting and welding.

3.3. Material selection for the rocket stove

Selection of materials for a rocket stove depends on various factors. Poor selection of fabrication materials can affect the efficiency and effectiveness of the rocket stove. Selection of materials depends on the following factors:

3.3.1. Heat resistance

Rocket stoves are characterised with high heat production therefore materials used to fabricate a rocket stove should be able to withstand high temperature and pressure without cracking, melting and breaking in order to prevent fire outbreaks.

3.3.2. Thermal conductivity

Heat utilization is a desired characteristic on rocket stoves. Materials with high thermal conductivity are suitable to adequately transfer heat generated from the combustion chamber to the cooking top without heat loss.

3.3.3. Strength and Durability

Rocket stoves must be constructed using strong and durable material. Strong material will not collapse due to the weight of the pot. Materials must be durable in order to have long life span and to withstand regular use and meet various outdoor conditions like rainfall, wind and harsh weather conditions.

3.3.4. Availability

Materials must be readily available for construction. Materials must be easy to find just in case of breaking, one can be able to repair the rocket stove without any hardship. Locally available materials are the most desirable.

3.3.4. Cost

Cost of rocket stove is directly proportional to the cost of the rocket stove. Expensive materials increase the cost of a rocket stove. Material for rocket stove fabrication must be affordable so that the rocket stove will also be affordable since most households are yearning for an affordable alternative way of cooking.

3.3.5. Environmentally friendly

The chosen material must be nonreactive. Some materials react with wood and produce toxic gases which are hazardous to human health. There are some materials which also reacts with cook ware passing an off taste to the cooked food.

3.3.6. Weight

Lightweight materials are desired mostly because they make portable rocket stoves which can be moved from one place to another easily.

3.4. Materials used to construct rocket stoves

Various materials can be used to manufacture a rocket stove. Selection of these materials mainly depends on affordability, availability and durability. Different materials for rocket stoves are listed below:

3.4.1. Steel

Steel is strong and can withstand high heat without any deformity which is the most desirable characteristic on rocket stoves. It is readily available and can be easily found. Steel is versatile, it can be moulded into different shapes and sizes according to the user’s choice, demand and desire. However, steel can succumb to rust if it is not properly maintained. It holds and retain heat for longer periods of time which might pose a potential burn hazard.

Refractory materials can withstand high temperatures. They have long lifespans which can resist wear and tear that damages other stoves. They have higher efficiency since they are good absorbers of heat. However, they might take a long time to heat. They are available in certain shapes and sizes making it difficult to mould them into desired shape. In addition, they are heavy making it difficult to move the rocket stove from one place to another.

3.4.6. Galvanic steel

Galvanised material is durable, it can resist corrosion, making it a right preference for outdoor purposes such as rocket stoves. The zinc coating protects the metal from rust and different forms of degradation, extending its lifespan. Galvanised steel is also sturdy and durable thus enabling it to withstand high temperatures and stipulation associated with rocket range operation. Lightweight is also a favourable characteristic of galvanised steel and this makes it handy to transport and to work with. The zinc coating on galvanized metal has a reflective surface which can assist to direct heat inward and improve effectiveness of rocket stove. Galvanised material is also cheap making it a low-price option for constructing rocket stoves. However, galvanised materials have a low thermal conductivity compared to other materials like stainless steel, and this capability may take longer time to warm the rocket stove so that heat may be channelled upwards. The zinc coating on galvanised steel may be hazardous to the environment. When heated, these steels can launch fumes containing zinc and different chemicals and this can be dangerous to health especially in enclosed spaces.

3.5. Design synthesis

3.5.1. Description of flow process in wood fired stoves

The generation of heat on rocket stoves from wood burning begins when the wood or biomass is loaded in the combustion chamber. As the timber burns, it exceptionally creates heat and smoke, which is a mix of gasoline and particulates unburned, releasing the viable power saved in the wood. The central principle behind a rocket stove's operation is complete combustion, which improves efficiency and reduces hazardous emissions. This is carried out through a vertical combustion chamber's design plan where the fire burns at the bottom and the hot gases upward shove through the chimney.

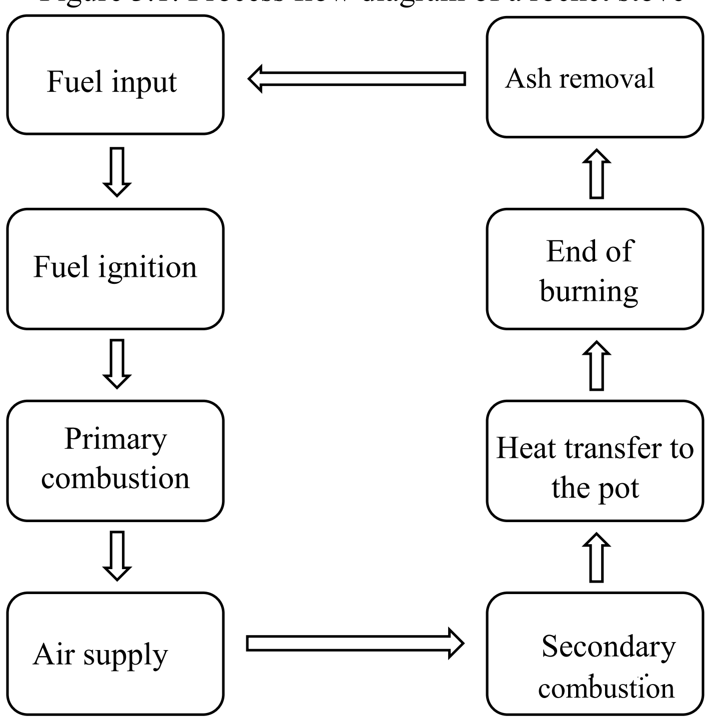
The stove draws in a constant grant of clean air, supplying the fire with the imperative oxygen for smooth burning. The vertical graph offers the heated air and gases with a course to go, developing a drawing 'chimney effect', accelerating the hot gases upwards. This movement pulls extra air into the combustion chamber, feeding the fire, and keeping it hot and burning rapidly, which is why it is referred as 'rocket'.

The stove channels heat generated in combustion at once to the cooking pot. The heat switch efficiency is maximised by insulating the combustion, which prevents heat loss and keeps the temperatures high for complete combustion.

After the burning process, the last warmness in the flue gases is expelled through a vertical chimney or is utilised in addition for secondary heating purpose. In more superior versions, a secondary burn device is added at the top of the combustion chamber, where additional air is introduced to burn any ultimate gases or particulates, further improving the stove's effectiveness and lowering smoke.

In summary, a rocket stove burns wood effectively at excessive temperatures maximising heat switch to the cooking pot whilst minimizing detrimental emissions. By utilizing standards of complete combustion chamber, rocket stoves can deliver excessive degrees of heat output using highly small quantities of wood. A flow chart below shows a summary of heat generation beginning from fuel loading to ash and remaining foreign substance removal.

Figure 3.1: Process flow diagram of a rocket stove



3.6. Design calculations

<u>Sizing the combustion chamber according to the pot size</u>

Assuming that the dimension of a pot suitable for a family of four are:

Diameter of the pot (D) = 26 cm

Height of the pot (H) = 14cm

3.6.1. Determining the volume and circumference of the pot

According to the rocket stove design guide,

$$V = \pi r^2 H$$

V is the volume of pot, H is the height of pot, D is the diameter of pot and R is the radius of pot

$$R = \frac{D}{2}$$

$$= \frac{26cm}{2}$$

$$= 13\text{cm}$$

$$V = \pi \times (13cm)^2 \times 14cm$$

$$= 7\,433.008 \text{ cm}^3$$

Since 1 litre $= 1\,000\text{cm}^3$

$$= \frac{7\,433.008cm^3}{1\,000cm^3/l}$$

Volume of the pot $= 7.433$litres

Since we do not have 7.433litres pots, the size of the pot will be 7.5 litres

Pot Circumference(C) $= \pi D$

$$= \pi \times 26cm$$

$$= 81.68cm$$

Relationship between pot size and combustion chamber entrance according to the rocket stove design guide is shown on the table below

Table 3.1: Relationship between pot size and combustion chamber diameter (source http://stove.bioenergylist.org)

Pot size (litres)	Entrance to combustion chamber
1-15litres	11cm by 11cm Cylindrical 12.5cm
15-50litres	15cm by 15cm
50-100l	16.5cm by 16.5cm
110litres	18cm by 81cm
100-200litres	20cm by 20cm
200+	22cm by 22cm

Since the size of my pot is 7.5 litres, it falls within the size range of 1-15litres, hence the size of the entrance to the combustion chamber will be as follows

Rectangular rocket stove = 11cm by 11cm

Cylindrical rocket stove = 12.5cm diameter

3.6.2. Sizing the combustion chamber of a rectangular stove according to pot size

Entrance to the combustion chamber (L) = 11cm

Cross sectional area of the entrance $= L \times L$

$$= 11cm \times 11cm$$

$$= 121cm^2$$

Calculating inner perimeter of the combustion chamber (P_{inner})

$$(P_{inner}) = 4 \times L$$

$$= 4 \times 11cm$$

$$= 44cm$$

Gap between the pot and inner perimeter of the combustion chamber (Gap^A)

$$\text{Gap}^A = \frac{Area}{Inner\ perimeter\ of\ combustion\ chamber}$$

$$= \frac{121\text{cm}^2}{44\text{cm}}$$

$$= 2.75\text{cm}$$

Gap between the pot and outer edges of the combustion chamber (Gap^B)

$$\text{Gap}^B = \frac{Area}{Outer\ Circumference\ of\ combustion\ chamber}$$

Circumference = $[(\text{L}+ 7-10\text{cm})\times\ \pi]$

Therefore Gap^B $= \dfrac{121cm^2}{[11cm+7-10cm)\times\pi]}$

$$= 4.8\text{cm}$$

Gap under the pot and the outer edge of the combustion chamber

$$\text{Gap}^C = \frac{Area}{Circumference\ of\ pot}$$

$$= \frac{121cm^2}{81.68cm}$$

$$= 1.48\text{cm}$$

Gap between the sides of pot and the stove body

$$\text{Gap}^D = \text{Gap}^C \times 0.75$$

$$= 1.48\text{cm} \times 0.75$$

$$= 1.11\text{cm}$$

<u>Determining the height of the combustion chamber use</u>

Assuming that the height of stove entrance (H_{1}) is 11cm

Height of combustion chamber above stove entrance (H)

$$H = 1.5 \times \text{height of stove entrance}$$

$$= 1.5 \times 11\text{cm}$$

$$= 16.5\text{cm}$$

Calculating total height of the combustion chamber TH

$$T_{H} = H1 + H$$

$$= 11\text{cm} + 16.5\text{cm}$$

$$=27.5\text{cm}$$

<u>Determining the volume of the combustion chamber</u>

Assuming that

- Energy required to prepare a meal = $0.694 KWh/day$
- Stove efficiency = 50%
- Number of main meals prepared per day= 3
- Expected average cooking time= $3\frac{1}{2}$ hours
- Wood energy densities= $4\ 770 kcal/kg$
- Capacity of combustion chamber= $8 kg\ of\ wood$
- Air to firewood ratio 15:1

<u>Calculating volume of combustion chamber</u>

$$V_{cc} = \frac{FED \times MFRF \times SE}{AFR(MJ) \times HOR(Watts)}$$

V_{cc} - volume of the combustion chamber

HOR – heat output rate

AFR- air fuel ratio

SE- stove efficiency

FED- fuel energy density

MFRF- mass flow rate of fuel

Calculating mass flow rate of fuel

$$= \frac{\text{wood capacity of combustion chamber}}{\text{air/fuel ratio}}$$

$$= \frac{\text{8kg of wood}}{\text{15air/fuel ratio}}$$

$$= 0.53$$

Calculating heat output rate

$$= \frac{\text{Daily energy demand(kwh)}}{\text{Number of hours used} \times \text{stove efficiency}}$$

$$= \frac{1.041kwh}{3\ 1/2hrs \times 0.5}$$

$$= 0.595kwh \times 1000watts$$

$$= 595 \text{ watts}$$

Converting 4 770kcal/kg to MJ $= 4\ 770kcal/kg \quad \times 0.004187$

$$= 19.97MJ$$

Therefore, $V_{CC} = \frac{0.53kg/s \times 19.97MJ/kg \times 0.5}{15/1 \times 595Watts}$

$$= 0.00059 \ \times 1\ 000$$

$$= 0.59m^3$$

Calculating daily energy demand

Daily energy demand $= Energy\ per\ meal\ \times number\ of\ meals \times stove\ efficiency$

$$= 0.694kwh\ \times 3meals \times 0.5$$

$$= 1.041kwh$$

$$1\text{kwh} = 3\ 600KJ$$

Converting to KJ$= 1.041 \times 3600$

$$= 3\ 747.6KJ \text{ Approximately } 3\ 750KJ$$

3.6.3. Sizing the combustion chamber of a cylindrical rocket stove according to pot size

Entrance to the combustion chamber diameter (D) = 12.5cm

Calculating cross sectional area

$$A = \pi r^2$$

$$= \pi \times (6.25cm)^2$$

$$= 122.7cm^2$$

Circumference of the circle$= \pi D$

$$= \pi \times 12.5\text{cm}$$

$$= 39.3cm$$

Gap between the pot and inner perimeter of the combustion chamber (Gap^{A})

$$\text{Gap}^{A} = \frac{Area}{Inner\ perimeter\ of\ combustion\ chamber}$$

$$= \frac{122.7\text{cm}^2}{39.3\text{cm}}$$

$$= 3.12\text{cm}$$

Gap between the pot and outer edges of the combustion chamber (Gap^{B})

$$\text{Gap}^{B} = \frac{\text{Area}}{\text{Outer circumference of the combustion chamber}}$$

$$= \frac{122.7\text{cm}^2}{87.9\text{cm}}$$

$$= 1.4\text{cm}$$

Gap under the pot and the outer edge of the combustion chamber

$$\text{Gap}^{C} = \frac{Area}{Circumference\ of\ pot}$$

$$= \frac{122.7cm^2}{81.68cm}$$

$$= 1.5\text{cm}$$

Gap between the sides of pot and the stove body

$$\text{Gap}^{D} = \text{Gap}^{C} \times 0.75$$

$$= 1.5\text{cm} \times 0.75$$

$$= 1.13\text{cm}$$

<u>Determining the height of the combustion chamber use</u>

Assuming that the height of stove entrance (H_{1}) is 12.5cm

Height of combustion chamber above stove entrance (H)

$$H = 1.5 \times \text{height of stove entrance}$$

$$= 1.5 \times 12.5\text{cm}$$

$$= 18.75\text{cm}$$

Total height of the combustion chamber (T_H)

$$T_H = H_1 + H$$

$$= 12.5\text{cm} + 18.75\text{cm}$$

$= 31.25\text{cm}$

<u>Determining the volume of the combustion chamber</u>

Assuming that:

Radius of the firebox $= 6.25\text{cm}$

Height of the firebox $=31.25\text{cm}$

Area of base (A_{base})$= \pi r^2$

$= \pi \times (6.5cm)^2$

$= 132.7cm^2$

$V_{CC}=A_{base} \times \text{Height}$

$= 132.7cm^2 \times 31.25\text{cm}$

$= 4\,146.9cm^3$

Fuel bed volume (V_{fuel}) $= \frac{1}{2} \times A_{base} \times \text{Height}$

$= \frac{1}{2} \times 4\,146.9\text{cm}^3$

$= 2\,073.5cm^3$

Effective combustion chamber volume = $V - V_{fuel}$

$= 4\,146.9cm^3 - 2\,073.5\text{cm}^3$

$= 2\,073.4cm^3$

$= 0.0021m^3$

Therefore, the combustion chamber of a wood stove must be sized at approximate dimensions so as to ensure complete combustion to improve fuel efficiency. Size of the combustion chamber of fabricated stoves will depend on the availability of materials.

3.7. Drawing of the whole assembly

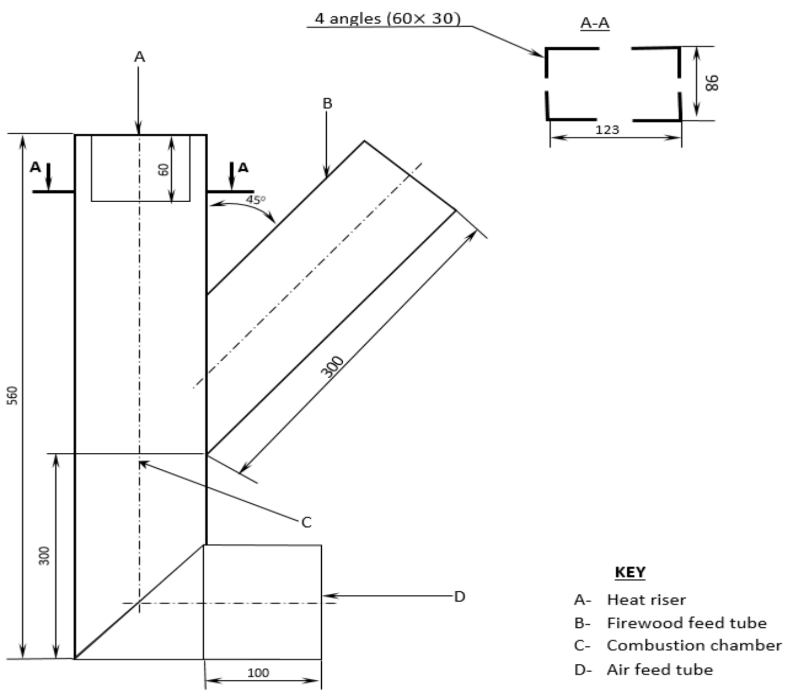


Figure 3.2 : Sketch of rectangular rocket stove prototype 1

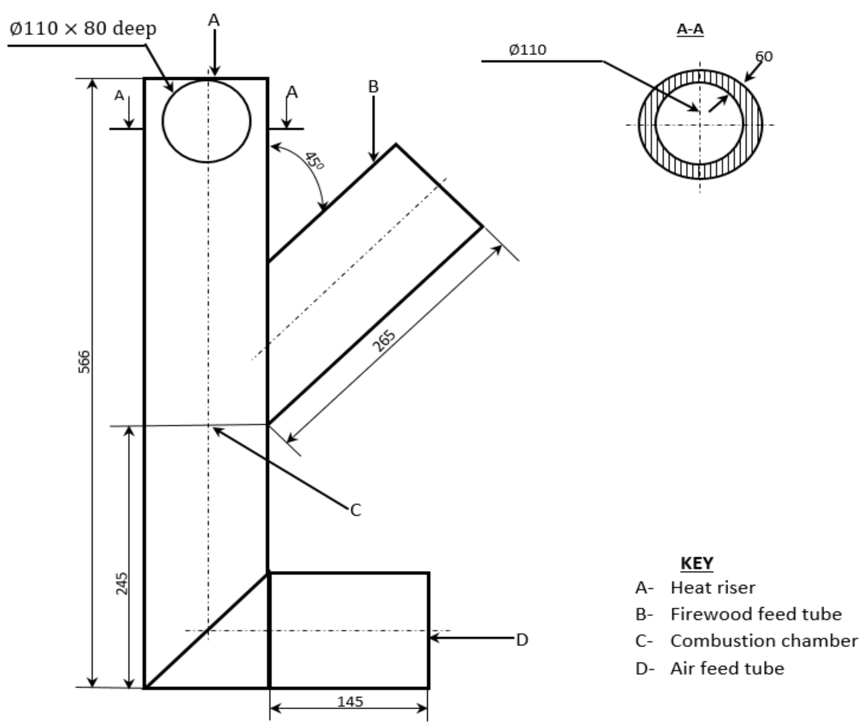


Figure 3.3 : Sketch of cylindrical rocket stove, prototype 2

3.8. Fabrication of the rocket stove

Step 1: Material collection and marking

- Materials collected from the scrap yard of BUSE construction site were transported into the workshop and cleaned to remove dirty like md and any soil particles.
- Materials were galvanised steel and steel of two different shapes, the other one was rectangular and the other one cylindrical in shape respectively.
- Materials were separated into three desired parts and sizes that is the two feed tubes, one for air and the other one for firewood and the heat riser and this process was done for all the three prototypes.
- An angle of 45° was marked on the air feed tube and the same angle was also marked at the bottom of the heat riser.
- An angle of 60° was marked on the middle of the heat riser.
- Marking the angles was done using a marker and measuring the dimension was achieved using a tape measure.

Step 2: Cutting the materials

- Materials required at this stage includes a metal cutting disc to cut the marked angles, a bench vice to balance the steels during cutting and eye protecting glasses.
- Metals with marked angles were clamped on the bench vice so as to prevent movement of steel during the cutting process.
- All angles were cut according to the dimensions measured and marked at stage 1.
- It is essential to follow safety procedures while handling the cutting disc and also to wear protective clothing like safety shoes and work suit to protect yourself from sparks produced during the cutting process.

Step 3: Welding process

- The firewood feed tube was joined with the heat riser by the process of welding. After successfully joining the firewood feed tube and the heat riser, the air tube was welded to the heat riser using the welding machine and welding rods.
- The cooking top was also welded on top of the pot.

- After completion of the welding stage, the stove was checked to see if it was completely closed to prevent air entrance so as to prevent entrance of excess air which might interfere with the combustion process.
- Workshop precaution measures were observed throughout the whole process.

3.9. Testing the prototype

The prototypes are going to be tested using water boiling test

<u>Procedure</u>

- Measure the weight of firewood on a scale and record the weight of firewood.
- Load the measured firewood in the rocket stove, ignite the fuel and allow the stove to reach the operating temperature that is around 260℃ to 351℃.
- Fill the pot with a known volume of clean water, measure the initial temperature of water using a thermometer and record it and place the pot on the stove without closing the pot.
- Start the stop watch as soon as you place the pot on the stove.
- Temperature of water must be checked periodically for example after every 10 minutes using a thermometer.
- Stop the stop watch as soon as water reaches the boiling point that is 100℃ or less depending on the altitude.
- Weight of water left in the pot was recorded to determine the actual volume and compare it with the initial volume.
- Repeat the process with different amounts of water and observe the consistency and accuracy of results.

CHAPTER 4: RESULTS ANALYSIS

This chapter contains the actual specifications of the manufactured prototypes. It contains pictorial steps followed during the fabrication process. The results obtained during the process of prototype testing are provided in this chapter. Materials used for fabrication is also shown in this chapter.

Figure 4.1: Materials used to manufacture rocket stoves

4.1. Pictorial steps followed during fabrication of the prototype

All the fabrication processes were done at BUSE engineering workshop at the Engineering Complex with minimum supervision from workshop technicians.

Step1: Angle marking

The first step was to mark angles using an engineer's square and a marker to make line of cut visible. Angles of 60° and 45° were marked on the fuel feed tube and air feed tube respectively and also on the heat riser using a marker.

Figure 4.2: Marking angles on desired materials

Step 2: Cutting the marked angles

Marked angles were clamped on a bench vice to prevent movement during cutting and the cutting process was done using a cutting disk. Picture below shows the cutting process.

Figure 4.3 : Cutting marked angles on steels whilst clipping the steel on a bench vice

Step 3: welding process

Type of welding used was arch welding.

Figure 4.4 : Welding the prototypes using arch welding

4.2. Prototype specifications

Two different prototypes were fabricated. One prototype was made of is galvanic steel and the other one was manufactured from steel. Galvanic steel was obtained from the gutter which was used to drain water from the roof to the ground and stainless steel was obtained from the scrap yard of BUSE construction site.

<u>First prototype</u>

- ✓ Material used is galvanic steel
- ✓ Length of the heat riser is 56cm
- ✓ Length of firewood feed tube is 30cm
- ✓ Length of air feed tube is 10cm

- ✓ Height of pot rest from stove is 6cm

<u>Calculating the volume of the combustion chamber</u>

Distance from the front to the back of the chamber (length) = 12.3cm

Distance from left to the right side of the chamber (width) = 9.8cm

Distance from the bottom to the top of the chamber (height) = 30cm

Base area of the combustion chamber $= Length \times Width$

$= 12.3cm \times 9.8cm$

$= 120.54cm^2$

Volume of the combustion chamber $= Area \times Height$

$= 120.54cm^2 \times 30cm$

$= 3\,616.2cm^3$

Converting to cubic metres $= \dfrac{3\,616.2cm^3}{1\,000\,000}$

$= 0.0036m^3$

Figure 4.5 : Prototype 1 (Galvanised steel rocket stove)

<u>Second prototype</u>

- ✓ Material used is steel
- ✓ Length of the heat riser is 56.5cm
- ✓ Length of firewood feed tube is 26.5cm

- ✓ Length of air feed tube is 14.5cm
- ✓ Height of pot rest from stove is 6 cm

Calculating the volume of the combustion chamber

Diameter of the firebox = 11cm, therefore radius of the firebox = 5.5cm

Height of the firebox = 24.5cm

Area of the base (A-base) $= \pi r^2$

$= \pi \times (5.5cm)^2$

$= 95.03cm2$

Volume = A-base × Height

= 95.03cm2 × 24.5cm

= 2 328. 24cm^3

Converting to cubic metres $= \dfrac{2\ 328.24cm^3}{1\ 000\ 000}$

= 0.0023284 m^3

= 0.0023m^3

Figure 4.6 : Prototype 2 (Steel rocket stove)

4.3. Results

Fuel used during the test is indigenous firewood obtained from Mun'ando tree commonly found in Bindura. Three tests were conducted, one for three stone stove and two for the prototypes.

NB: All experiments were carried out at BUSE engineering complex using same amount of water, fuel and water with same temperature for all the three tests. Fire was allowed to burn for two minutes before starting the experiment.

Figure 4.7 : Firewood used during the testing process

Table 4.1: Apparatus for all the three experimental tests

Item description	Quantity
Water in the pot	$2l$
Initial temperature of water in the pot	22℃
Amount of firewood used	3kg
Amount of ashes available	0g

4.4.1. Experiment test 1 with three stone fire stove

The picture below shows the testing process with three stone fire stove.

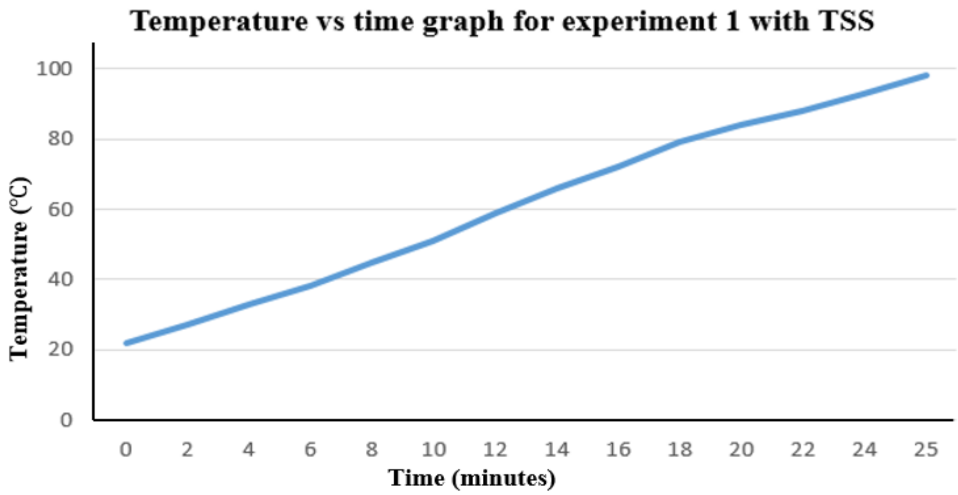
Figure 4.8 : Experimental test 1 process for three stone stove

Experiment 1 results

Time taken to boil water was 25minutes

Remaining water in the pot was found to be 1.53litres

Remaining firewood was found to be 2.11kg and ash produced was 0.35kg



Graph 4.1 : Graph for the results from experiment test 1

4.4.2. Experiment test 2 with rocket stove prototype 1

The testing process for experiment test 2 with galvanic steel rocket stove is shown below.

Figure 4.9: Experiment test 2 process

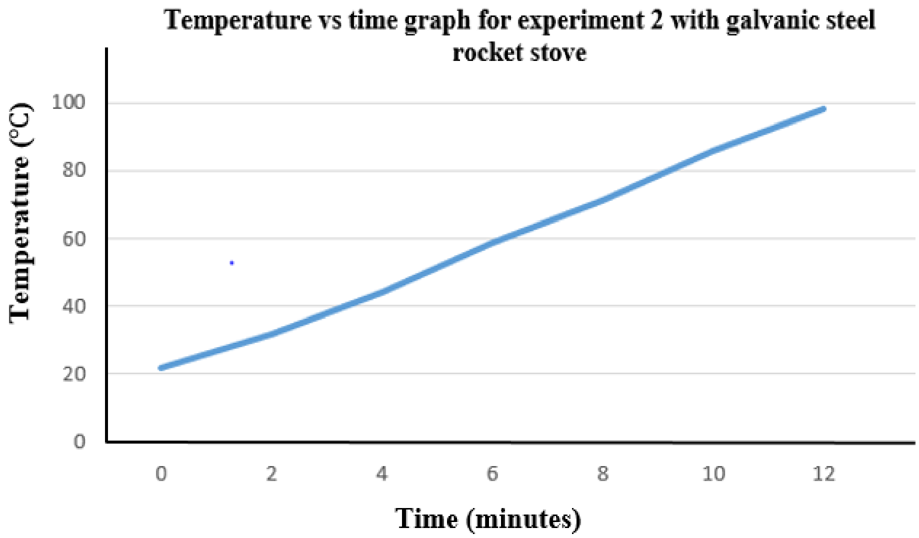
<u>Experiment test 2 results</u>

Time taken to boil water was 12minutes

Remaining firewood was found to be 2.55kg

Remaining water in the pot was found to be 1.084litres and ash produced was 0.1kg

Time and temperature changes during the experiment process were recorded and the results are represented by a line graph below.



Graph 4. 2: Result graph for experiment test 2

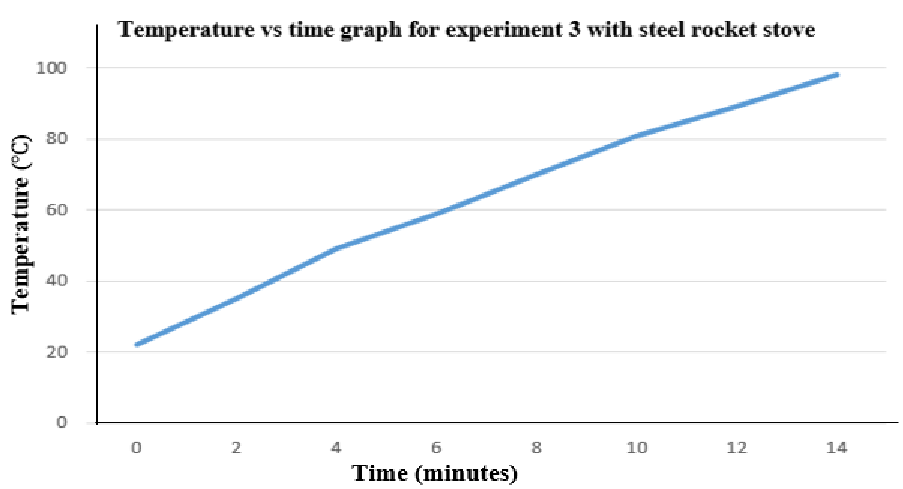
4.4.3. Experiment test 3 with rocket stove prototype 2

<u>Experiment test 3 results</u>

Time taken to boil water was 14minutes

Remaining water in the pot was found to be 1.222litres

Remaining firewood was found to be 2.49kg and ash produced was 0.17kg



Graph 4.3 : graph for results from experiment test 3

4.5. Results analysis

Result analysis for all the three experiments is done in this section.

NB: According to a study by the forestry commission of Zimbabwe, the calorific value of indigenous firewood ranges from 15MJ/kg to 22MJ/kg, so for all the three experiments my calorific value will be 15MJ/kg.

4.5.1. Result analysis for experiment number 1 with three stone stove

Values used of temperatures, mass of firewood and water volume are obtained from experiment test 1.

NB: to convert any amount of water in litres to mass in kg, one must convert amount of water in litres to volume in m^3 and multiply by the density of water which is $977 kg/m^3$.

Calculating efficiency of three stone stove

$$\eta\% = \frac{M_w \times C_{pw} \times (T_e - T_i) + M_{w.evap} H_l}{m_f \times H_f} \times 100 \ldots\ldots\ldots\ldots\ldots 1$$

M_w = Initial mass of water in the pot

C_{pw} = Specific heat of water, kJ/kg

T_e = Temperature of boiling water,℃

T_i = Initial temperature of water, ℃

$M_{w.evap}$ = Mass of water evaporated, kg

H_l = latent heat of evaporation at 100℃ and 10^5Pa, kJ/kg

m_f = mass of fuel burned

H_f = calorific value of fuel, kJ/kg

$$\eta\,\% = \frac{1.954kg \times 4.182kJ\ (98℃ - 22℃) + (0.459kg \times \frac{2260kJ}{kg})}{0.89kg \times 15\,000kJ}$$

$$= 0.124 \times 100\%$$

$$= 12.4\%$$

Calculating thermal efficiency of the galvanic steel rocket stove (prototype 1)

Using equation 1 to calculate efficiency

$$\eta\,\% = \frac{1.954kg \times 4.182kJ\ (98℃ - 22℃) + (0.895kg \times \frac{2260kJ}{kg})}{0.45kg \times 15\ 000kJ}$$

$$= 0.392 \times 100\%$$

$$= 39.2\%$$

Calculating power output of the stove

$$\text{Power output rating} = \frac{m_f \ x\ H_f\ x\ \eta}{860\ x\ 1000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

m_f = mass of fuel burned

H_f = calorific value of fuel used

η = thermal efficiency of the cooking stove as calculated above

$$= \frac{0.45kg \times 15\ 000kJ \times 39.2\%}{860 \times 1000}$$

$$= 0.308kw$$

$$= 0.31kw$$

Calculating efficiency of steel rocket stove (prototype 2)

Using equation 1 to calculate efficiency

$$\eta\,\% = \frac{1.954kg \times 4.182kJ\ (98℃ - 22℃) + (0.76kg \times \frac{2260kJ}{kg})}{0.51kg \times 15\ 000kJ}$$

$$= 0.306 \ \times 100\%$$

$$= 30.6\%$$

Calculating power output of the stove

Using equation 2

$$= \frac{0.51kg \times 15\ 000kJ \times 30.6\%}{860\ \times 1000}$$

$$= 0.272kw$$

$$= 0.27kw$$

CHAPTER 5: DISCUSSION OF RESULTS AND PROJECT EVALUATION

This chapter presents a discussion of results obtained from the project. It also includes a cost benefit analysis, considering the cost of labour, materials and others.

5.1. Discussion of results

5.1.1. Discussion of results objective 1: To design a rocket stove in order to use in rural areas belonging to Bindura and Zimbabwe.

The design of a rocket stove was successfully accomplished, meeting the objective of developing a useful stove for Bindura rural areas. All the three prototypes were successfully designed. The design of the rocket stove achieved the goal of creating a highly efficient and low fuel consuming stove. The objective of reducing fuel consumption was observed to be successful during the prototype testing process. It was discovered during the water boiling test that the wood fired rocket stove manages to heat water to the boiling point within a reasonable time. The stove was successfully tested in a field setting, using indigenous firewood mainly found in Bindura and it demonstrated a consistent performance under various conditions, highlighting its adaptability and usability. The stoves achieved a thermal efficiency of 39.2 and 30.6% for prototype 1 and 2 respectively, significantly higher than the 12.4 % of traditional stove. This was attributed to the stove's unique design, which allowed for complete combustion and minimal heat loss. As a result the stoves consumed 2.25kg and 2.28kg of fuel per hour, considerably less than conventional stoves. The stove proved to be user friendly and requires minimum maintenance. The design allowed tor easy fuel loading and igniting. Ashes and any remaining on the stove can be removed easily ensuring cleanliness and long life span of the stove. The design of the rocket stove achieved the objective of creating a highly efficient, low-fuel consuming and smoke reduction stove. The stove's successful field testing validated its effectiveness and suitability for diverse application. This project design demonstrated the feasibility of developing innovative and environmentally friendly cooking solution for improved livelihoods in Bindura rural areas.

5.1.2. Discussion of results objective 2: To fabricate a prototype cheap rocket stove for rural areas, using wasted and recycled materials.

The goal of constructing a cheap and affordable rocket stove for rural household was successfully accomplished. The goal of the project also included the fabrication of a simple design which is easy to operate. The fabricated rocket stove efficiently utilize recycled materials demonstrating the feasibility of sustainable manufacturing. The stove's simple design, using minimal components made it accessible for rural communities with limited resources. The use of recycled materials substantially reduce production costs, making the stove to be an affordable option for rural communities with economic hardships. The efficiency in fuel reduces operational expenses thus providing long term services. The stove was subjected to durability tests under real world conditions to demonstrate its robustness. The recycled materials shows resilient, thus ensuring a long life span and reliability eliminating replacement costs. The stove was tested using indigenous firewood commonly found in Bindura rural areas showcasing its flexibility and ability to available fuel sources. The wide fuel compatibility enhanced its practicality in diverse rural settings. The rocket stove exhibited exceptional fuel efficiency, with a significant reduction in fuel consumption compared to traditional cook stove. This also eliminates the urge to rely on non-renewable fuels like charcoal, paraffin and gas. The successful design and fabrication of the rocket stove sing recycled and wasted materials showcases its attainable as a cost effective and sustainable solution for rural areas. The stove's energy efficiency, fuel compatibility and durability make it a valuable tool to enhance livelihoods. The task contributes to the physique of knowledge on eco-friendly and low-priced cooking technologies, paving the way for further advancement in this field.

5.1.3. Discussion of results objective 3: To determine the efficiency of the designed Rocket stove in terms of wood saving and cooking time.

The efficiency of the stoves was evaluated by comparing the performance to that of a three stone stove. The rocket stoves consumed significantly less wood as compared to three stone stove. On average, the stoves uses 13.3 % and 11.2% less wood to boil the same amount of water and this shows that it can also take less time to cook food as compared to three stone stove. This reduction in wood consumption can have a significant impact on the environment by reducing deforestation and the associated carbon emissions. The efficiency of the rocket stoves was found to be 39.2% and 30.6%. The rocket stove's efficiency was significantly higher than that of the three stone stove. The design of the rocket stoves allowed for better air circulation and fuel mixing, resulting in a more complete burn. The improved efficiency of the rocket stove reduces wood consumption and thus having a significant environmental benefits like reduction of deforestation due to firewood demand. By reducing deforestation, the rocket stove helps to preserve forests and their biodiversity. The first rocket stove prototype burn 0.45 kg of firewood to produce power of 0.31KW to boil water to 98℃ within a period of 12minutes. The second rocket stove prototype burn 0.51 kg of firewood to produce power of 0.27KW to boil water to 98℃ within a period of 14minutes. This shows that a small amount of wood is burned relative to the amount of energy produced and this is a result of heat utilization within the stove. The successful design and fabrication of the rocket stove demonstrated its efficiency in terms of wood saving and cooking time. Compared to a traditional three fire stove, the rocket stove uses less fuel. The rocket stove's improved fuel efficiency and reduced smoke production reduces negative environmental impacts. These results shows that the rocket stove could be a viable alternative to traditional cooking methods used in rural areas, providing benefits to rural households and the environment.

5.2. Project evaluation

Project evaluation is a systematic and objective assessment of project's worthiness, viability and impact. It entails inspecting the project's workable advantages and costs as nicely as its organisational or societal goals. It is integral for decision making risk management and assignment improvement. Project evaluation includes cost benefit analysis, return on investment, net present value and payback period. Evaluating the success of a rocket stove project requires a comprehensive assessment of performance, impacts and feasibility. The evaluation of the rocket stoves manufactured include cost benefit analysis and overall benefits of the stoves.

5.2.1. Cost benefit analysis

A cost benefit evaluation of a rocket stove can supply valuable insights into its practicable advantages and costs. For a rockets stove, a cost 9benefit analysis should weigh cost of fabricating the rocket stove and its potential benefits.

Table 5.1 : Bill of quantity for fabrication of rocket stove for rural household

Item description	**Unit**	**Quantity**	**Total price (us$)**
Galvanised steel pipe 110mm	Metres	2m	25.00
Steel pipe 110mm	Metres	2m	38.00
Labour	Each	1	$20.00
Overall cost			$83.00

If one preferred to use galvanised pipe, the total will be $45.00 and $58.00 for steel pipe which is affordable.

Benefits

- Environmental sustainability

By decreasing deforestation and promoting smooth burning, rocket stoves make a contribution to environmental protection and mitigate local weather change due to excessive emission. Reduction in deforestation also reduces environment degradation and preserve endangered species.

- Clean burning

The format of the rocket stove ensures almost whole combustion, minimizing smoke emissions and enhancing indoor air quality. This is important in rural areas with constrained ventilation, decreasing respiratory fitness issues.

- Fuel efficient

Rocket stoves burn biomass, such as wood, charcoal, or agricultural waste, with excessive efficiency, permitting them to conserve fuel and decrease the rate of deforestation. Reduction in fuel demand reduces the burden of firewood collection on woman and children materials. This makes them a low-cost cooking solution for populations with low incomes.

- Cost effective

Building a rocket stove requires simply on hand and less expensive materials. This makes them a low-cost cooking solution for populations with low incomes.

CHAPTER 6: CONCLUSION AND RECOMMENTATIONS

6.1. Introduction

This chapter summarises the essential findings and conclusions of the project. It will also provide recommendations for further researches and improvements based totally on instructions discovered throughout the project's execution.

6.2. Summary

- All the fabrications processes were done at BUSE workshop.
- Materials used to fabricate both prototypes were obtained from the scrap yard of BUSE construction site.
- Two prototypes were fabricated, one using steel and the other was made of galvanic steel.
- The prototypes were tested using water boiling test at Engineering Complex of BUSE with the three stone stove as the control experiment.
- Type of fuel used was indigenous firewood from Mun'ando commonly found in Bindura.
- Amount of water in the pot was 2l, initial temperature of water was 22℃ and mass of fuel used was 3kg, for all the three experiments.
- The boiling point of water was observed to be 98℃ (208F) because of the altitude. Boiling point of water decreases with increasing altitude. This is because the atmospheric pressure decreases with altitude, and the boiling point of a liquid is the temperature at which vapour pressure equals the atmospheric pressure.
- Thermal efficiency of 39.2% was obtained from the galvanic steel rocket stove and 30.6% from the steel rocket stove.
- Amount of fuel burned by galvanic steel rocket stove was found to be 0.45kg and for steel rocket stove was 0.51kg.
- Power output for the galvanic steel rocket stove and steel rocket stove was found to be 0.31kw and 0.27kw respectively.
- Time taken to boil water to 98℃ for the galvanic steel rocket stove and steel rocket stove was 12minutes and 14minutes respectively.

6.3. Conclusion

The project successfully demonstrated the design and fabrication of a functional rocket stove that met the following objectives

- High Thermal Efficiency than that of three stone stove

The stoves achieved a thermal efficiency of 39.2% and 30.6% significantly reducing fuel consumption compared to three stone stove.

- Low emissions

The stove minimised harmful emission and pollutants by utilizing a controlled and complete combustion process.

- Cost effective

The stove utilised locally available and affordable materials making it accessible to communities with constrained resources.

Significance and impacts

The developed rocket stove has potential benefits for

- Economic empowerment

Local production and distribution of the stove can create employment opportunities and create employment.

- Environment sustainability

The stove consumes a few amount of firewood prior to energy produced and this will reduce the rate of deforestation thus protecting the environment.

6.4. Recommendation

- Appropriate adhesives, sealants and fittings must be used to ensure air tightness and durability.
- Rocket stoves can be used to provide heat and warm a room during winter days.
- The rocket stove must be properly maintained to maintain good performance and long life span.
- Improvements on the design of stoves must be done by insulating the combustion chamber using wood ash, pumice rock or baldosa tile which may help to maintain high temperature

within the combustion chamber by preventing heat from escaping the combustion chamber. Insulation also creates a more efficient burn, ensuring that fuel is finally combusted, reducing smoke soot and emissions.

- Incorporating features like spark arrestor or temperature gauge must be done to enhance safety and convenience.
- Local production and distribution of the rocket stoves must be promoted by establishing networks and partnerships with local artisans and businesses to enable the production and distribution of rocket stoves in a sustainable and cost effective way.
- Different types of fuel like charcoal, crop residues remaining, wood pellets, and twigs must be tested instead of wood logs only.
- Wet or green wood must be avoided as it can produce excessive smoke and reduce efficiency.
- Testing of the prototype must be done with different firewood and different amount of water so as to obtain accurate results.
- The next researcher must fabricate different sizes of rocket stoves with same shape and same material and then compare the results so as to evaluate the effects of height of the stove.
- Different types of firewood must be tested so that the researcher might be able to come out with the accurate efficiency of the stove.
- Stove made of same material, same shape but with different dimensions must be fabricated and tested or stoves with same shape, same dimension but different materials material to improve the accuracy or results.

References

1. Adem, A., & Shee, D.Y. (2015). Performance evaluation of the institutional improved cook stoves in Wakiso primary schools in Uganda. International Journal of Engineering Research and Technology, 4(2), 215-233.
2. Adhikari, P. and Jaishi, M. (2018). Workload Analysis in Firewood Collection Activities by Gender in Kailari Rural Municipality of Kailali District, Nepal. *International Journal of Scientific & Engineering Research (6), 1755-1766).*
3. Afshar, S., (2018). Energy Sources and Policy in Zimbabwe.
4. Balakrishnan, K., Sambandam, S., Ramaswamy, P., Mehta, S., Smith, K., R (2012). Exposure assessment for respirable particulates associated with household fuel use in rural district of Andhra Pradesh, India. Journal of Exposure Science and Environmental Epidemiology, 22(1), 65-72.
5. Bhattacharya, S.C., Siddique, A.H.M.R., Leon, M.A., Pham, H.L. and Mahandari, C.P., 2001. A study on improved institutional biomass stoves. *Asian Institute of Technology Journal,* pp.1-6.
6. Barnes, F.B., Openshaw, K., Smith, K.R. and van der Plas, R. (1994): World Bank Technical Paper Number 242, Energy Series, Washington, D.C.
7. Chipango, E., F (2020). How politics and poverty affect electricity provision in Zimbabwe (theconservation.com).
8. Chowdhury, S.A. and Mostafa, A.T., 2021. Sustainable Energy for rural Household Cooking in Developing Countries. *In Affordable and Clean Energy* (214-1222). Cham: Springer International Publishing.
9. Clancy, J., Skutsch, M.M. and Batchelor, S. (2002). The gender-energy-poverty nexus: Finding the energy to address gender concerns in development.
10. Colombo, B.1996.Resource and Development Natural, Institutional, and Demographic Dimensions of Development. CLARENDON PRESS, Oxford.
11. Commeh, M.K., 2022. Strategy for institutional cook stoves promotion in the context of a behavioural change- A case study of Opoku Ware School and ST. Paul's Seminary, Accra, as the control in the research in Ghana.
12. Dhakal, S. and Raut, A.K 2010. Potential and bottlenecks of the carbon market: The case of a developing country Nepal, *Energy policy, 38*, 3781-3789.

13. Drunkerely, J. 1981. Energy Strategies for Developing Nations. Johns Hopkins University press, London.
14. Ekholm, V., Krey, Pachauri, S. and Riahi, K. 2010. Determinants of household energy consumption in India. *Energy policy 38(10),* 5696-5707.
15. Fort with magazine
16. Global issue
17. Gotore, T., Muchawana, A., Merepa, R., Tembani, M., Mutete, P., Muchena, R., Makumbe, P., Mwase, R., Mureva, A. and Mujuru, L (2019). Drivers of deforestation and forest degradation in Zimbabwe.
18. Hafner, J., Uckert, F., Hoffmann, H., Kimaro, A.A., Sererya, O. and Sieber, S (2018). "A quantitative performance assessment of improved cooking stoves and traditional three-stone -fire stoves using a two-pot test design in Chamwino, Dodoma, Tanzania. *Environmental Research Letters*, 13(2), p.025002.
19. Hately, J. 2016, What is a rocket stove pdf.
20. *http://www.bioenerglists.org*
21. *https://www.dsource.In/resource\kitchen products/stoves*
22. Jagger, P., Pedit, J., Bittner, A., Hamrick, L., Phwandaphwanda T. and Jumbe, C., 2017. Fuel efficiency and air pollutant concentration of wood-burning improved cook stoves programme. *Energy for Sustainable Development, (41)*, pp.112-120.
23. Joshi, A.2015. Deforestation driven by economic hardship in Zimbabwe.
24. Kammen, D.M. (2002): *Technological innovations s and diffusion in developing countries,* Annual meeting of the international energy workshop, EMF/IEA/IIASA, Stanford University, USA.
25. Kare, S., Alemu, A., Mulugeta, M. and Ganewo, Z., 2022. Determinants of improved cook stove adoption and its benefit in Ethiopia.
26. Karlsvik, E., Hustad, J.E. and Sønju, O.K., 1993. Emissions from wood stoves and fireplaces. *Advances in thermochemical biomass conversion,* pp. 690-707.
27. Kaundal, A., Powar, S. and Dhar, A., 2021. Numerical investigation of the effect of air supply on cook stove performance. Inhalation Toxicology, pp.1-11.

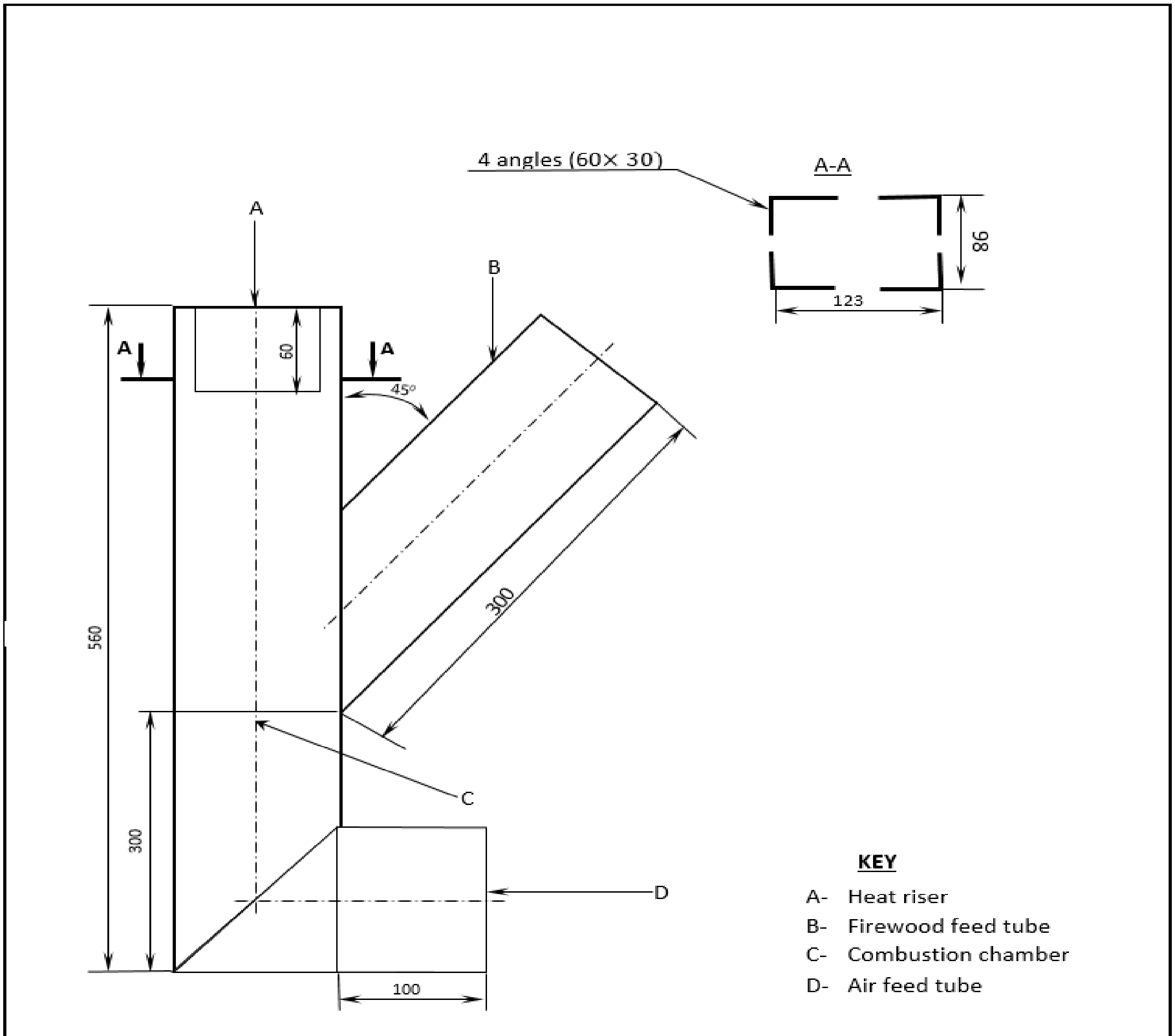
28. Kleinbaum, J. 2016. Zimbabwe Energy Situation, Report for Zimbabwe Alternative Energy Association. Retrieved from http://www.matrixdevcorp.com/wp-content/uploads/2016/09/Zimbabwe-Energy-Situation.pdf.
29. Konemund, T. 2002. The Household Energy Crisis in Ethiopia: A possible way out Desta et al (eds). *Energy in Ethiopia: Status, challenges, and Prospects. Proceedings of Energy Conference 2002*, Professional Associations Joint Secretariat, Addis Ababa, Ethiopia.
30. Van der Kroon, B., Brouwer,R. and Van Beukering, P.J.,2013. The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and sustainable energy reviews*, 20, pp.504-513.
31. Huhnhenn, K., 2003. Environmental and socio-economic impact of improved stoves-the case of the Tsotso stove in Northern Namibia. *Research thesis. Downloaded on from www.kuhnhen_kai.pdf.*
32. Loftness, R.1978. Energy Hand Book. Van Nostrand Reinhold Company, New York.
33. MacCarty, N., Still, D. and Ogle, D., 2010. Fuel use and emission performance of fifty cooking stoves in the laboratory and related benchmark performance. *Energy for sustainable development*, 14(3), pp.161-171.
34. Makonese, T., Chikowore, G. and Annegarn, H.J., 2011. The potential and prospects of improved cookstoves (ICS) in Zimbabwe.
35. Manoj, K., Sachin, K., Tyagi, S.K., 2013. Design, development and technological advancement in the biomass cook stove: a review. Renew, Sustain. Energy Rev.26, 265-285.
36. Masera, O.R., Saatkamp, B.D. and Kammen, D.M.2000. From linear fuel switching to multiple cooking strategies. *A critique and alternative to the energy ladder model 28(12),*pp 2083-103.
37. M.de F.S.R Arthur, Zahran, S. and Bucini, G. "on the adoption of electricity as a domestic source by Mozambican households,'. *Energy Policy, (38)*, no.11, pp. 7235-7249, 2010.
38. Mekonnen, B.A., 2020. Design and Performance Evaluation of Rocket Stove for Cleaner Cooking in Rural Ethiopia.
39. Mekonnen, B.A., 2022. Thermal efficiency improvement and emission reduction potential by adopting improved biomass cook stoves for sauce-cooking process in rural Ethiopia. Case Studies in Thermal Engineering, 38, p.102315.
40. Mika, L. and Tahwa, J. (2001) Wood burning stoves of Zimbabwe, ProBEC Special Focus on Zimbabwe Newsletter, February.

41. Njega, M., Liyama, M., Jamnadass, R., Helander, H., Larsson, L., De Leeuw, J., Neufeldt, H., De Nowina, K.R. and Sundberg, C., (2016). Gasifier as a cleaner cooking system in rural Kenya. *Journal of cleaner production, 121*, pp.207-217.
42. Ochieng, C.A., Vardoulakis, S., Tonne, C., (2013). 'Are rocket mud stoves associated with lower indoor carbon monoxide and personal exposure in rural Kenya? : Kitchen and personal CO from traditional and rocket stoves". *Indoor air* (23):14-24.
43. Ostro, Bart, D., Michael, J., Lipsett, Mann Jennifer, K., Wiener Matthew, B. and Selner, John. Indoor air pollution and asthma. Results from a panel study. *American journal of respiratory and critical care medicine*, 149 (6): 1400-1406, 1994.
44. Pachauri, S. (2004). An analysis of cross-sectional variations in Total Households Energy requirements in India using Micro Survey Data. Energy policy 32(15), 1723-1735.
45. Panwar, N.L. (2010). Performance evaluation of developed domestic cook stove with Jatropha shell. *Waste and Biomass Valorisation*. 1(3):309-314.
46. Prinsloo, G., Dobson, R. & Brent, A. 2016. Scoping exercise to determine load profile archetype reference shapes for solar co-generation models in isolated off-grid rural African villages. Journal of energy in Southern Africa, 279(3), 11-27.
47. Puzzolo, E., Pope, D., Stanistreet, D., Rehfuess, E.A., & Bruce, N.G. 2016. Clean fuels for resource poor settings: A systematic review of barriers and enablers to adoption and sustained use. Environmental research, 146,218-234.
48. SCEE, 2001. *Implementation of renewable energy technologies –Opportunities and barriers: Zimbabwe country study*, UNEP, Denmark.
49. Scott, S. (2002). Biomass energy study-final report.
50. Smith, K.R., Pillarisetti, A., Seto, E., Kalra, N., 2013. Cooking well: Improving health, household, and environment through improved biomass cookstove. Geneva: World Health Organization.
51. Subedee, B.R., Chaudhary, R.P., Shrestha, K.R. and Dorji, T., 2017. Use of Rocket stove for firewood savings and carbon emission reductions by the households involved in Allo (Girardinia divers folia) fiber processing at Khar VDC, Darchula District, Nepal. *International journal of Latest Engineering and Management Research,* 2, pp.28-35.
52. Tomczyk, S., McCracken, J.P., Contreras, C.L., Lopez, M.R., Bernart, C., Moir, J.C., Escobar, K., Reyes, L., Arvelo, W., Lindblade, K. and Peruski, L., 2019. Factors associated with fatal

cases of acute respiratory infection (ARI) among hospitalized patients in Guatemala. *BMC Public Health, 19,* pp.1-11.

53. World Bank, 2018. Access to electricity. Rural (% of population)
54. Yoder, S., Peel, J., Bachand, A. and Nelson-Ceschin, T.L., 2014. Impact of an improved stove intervention on exposure and health among Nicaraguan women.

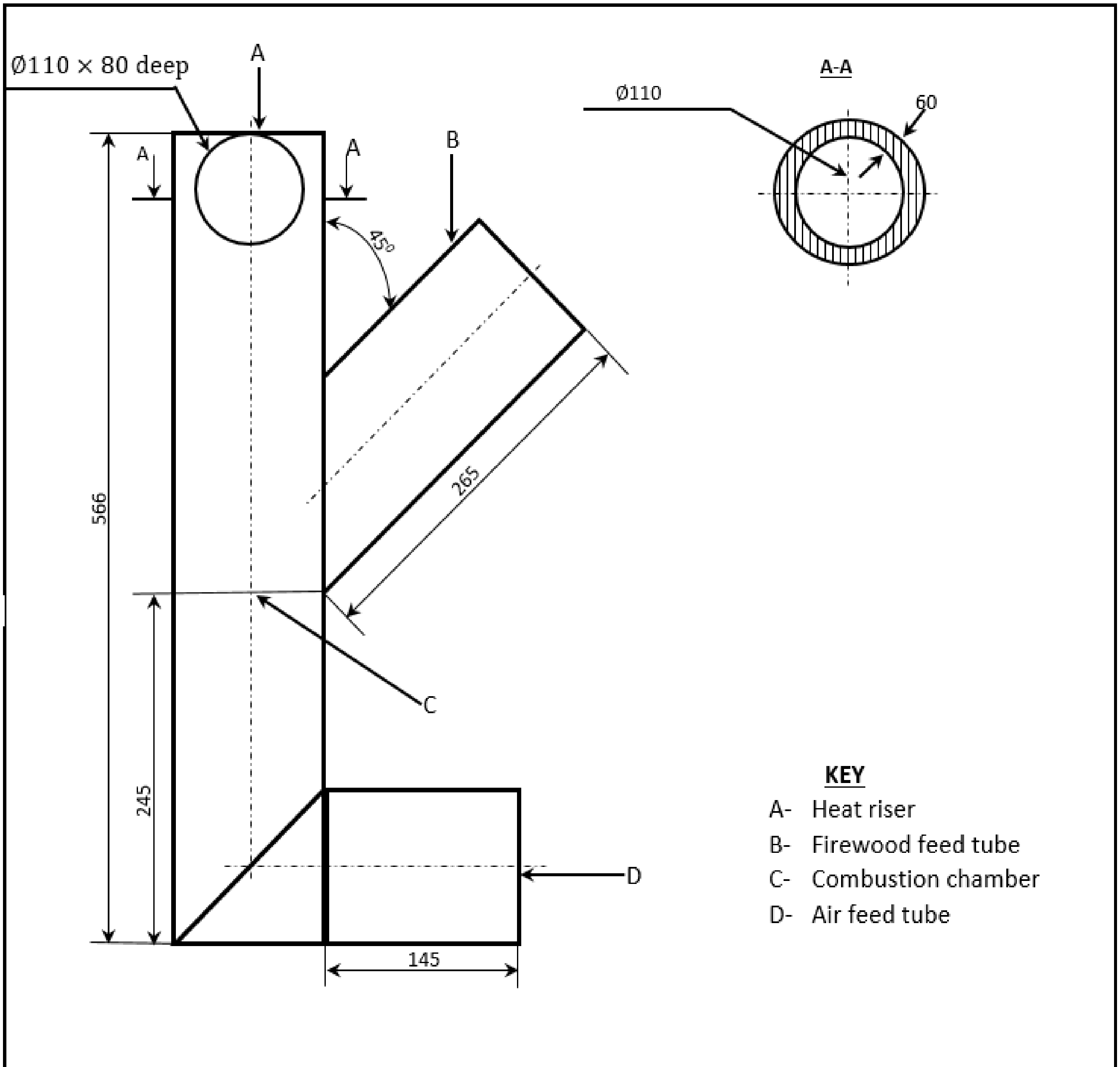
APPENDICES



	DATE	NAME	SIGNATURE	BINDURA UNIVERSITY OF SCIENCE EDUCATION
DRAWN BY	03/06/24	VIMBAI C		
CHECKED BY	05/06/24	I RODRIGUEZ		

SCALE 1:3	RECTANGULAR ROCKET STOVE	NUMBER: 01
		REPLACE TO:-
		REPLACED BY:-

Appendix 1 : Rectangular rocket stove sketch



	DATE	NAME	SIGNATURE	BINDURA UNIVERSITY OF SCIENCE EDUCATION
DRAWN BY		VIMBAI C		
CHECKED BY	05/06/24	06/06/24		
SCALE 1:3	CYLINDRICAL ROCKET STOVE PROTOTYPE 1			NUMBER: 02
				REPLACE TO:-
				REPLACED BY:-

Appendix 2: Cylindrical rocket stove sketch

Appendix 3 : Three stone stove testing

Appendix 4: Rectangular rocket stove testing