JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

CIVIL AND ENVIRONMENTAL ENGINEERING FACULTY

ENVIRONMENTAL ENGINEERING CHAIR

# ALTERNATIVE ECO-FRIENDLY ENERGY RECOVERY FROM SOLID WASTE: CHARCOAL PRODUCTION FROM KHAT WASTE USING BANANA PEELS AS A BINDER TO BRIQUETTE

By: - Kebede Eticha Galato

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Environmental Engineering.

February, 2020

Jimma, Ethiopia

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Advisor: - Dr.-Ing. Fikadu Fufa

Co-Advisor:- Mr. Wagari Mosisa

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## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

I have cited all material in this thesis, which is not my own work through appropriate referencing and acknowledgement.

| | | |
|---|---|---|
| Kebede Eticha Galato | ____________________ | ____________________ |
| Candidate | Signature | Date |

This thesis has been submitted for examination with my approval as a university supervisor

| | | |
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| Advisor | Signature | Date |
| Mr. Wagari Mosisa | ____________________ | ____________________ |
| Co-Advisor | Signature | Date |

## ABSTRACT

*All human beings are use materials for their continuous life. However, they threw away after use rather than using as re-use, re-cycle or changing to energy without thinking of about environment or sustainability of the eco-system. By considering such problem this study done on alternative Eco-friendly energy production from khat waste using sample of khat waste to minimize environmental pollution caused by solid waste and charcoal production from forest trees. Therefore, the study conducted to recover energy potential from khat waste by producing briquette from its char using banana peel as a binder. In the study sample of khat waste, banana peels and water have used by using purposive sampling technique. The study achieved using primary and secondary data source that combination of experimental, quantitative and qualitative. To determine carbonization efficiency, temperature and time 9, 18 and 27 kg of sample was dried and carbonized in 200 L kiln that found in Jimma Agricultural Engineering and Mechanization Research Center. Then produced carbonized material mixed with binder of the ratios 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water to banana peel to carbonized khat waste material) and briquetted to determine proximate characteristics and calorific values with each ratio. For molding the mixed materials extruder machine, that found in Jimma Agricultural Engineering and Mechanization Research Center used. Then briquetted samples have taken to Geological Survey of Ethiopia for determination of proximate characteristics and energy potential. Therefore, from the results 51.89 ± 1.02, 56.55 ± 1.57 and 52.28 ± 0.46 % carbonize efficiency was gained at temperature of 200, 325 and 450 ℃ within 35, 50 and 70 minutes from 9, 18 and 27 kg khat waste samples respectively. From all mixing ratios used to bind the carbonized material from khat waste, 0.33:0.67:4 was best ratio due to the gained energy potential was 23.8 ± 0.03 KJ/g which greater than the other rest ratios of energy potential. The proximate characteristics gained from this mixing ratio were 16.24 ± 0.34, 57.33 ± 0.38, 18.32 ± 0.27 and 8.05 ± 0.22 % for AC, FC, VM and MC respectively and 0.61 ± 0.01 cc/g of BD and 0.06 ± 0.00 % of SC. Generally, the results gained from the laboratory in this research were in line with the standard of (FAO 1987 and 1999) with all mixing ratios. Therefore, the study result showed that charcoal briquetting from khat waste using banana peels as a binder is good option of minimizing solid waste rather than threw it to the street and fill to the land fill. In addition, it is the best alternative of energy source rather than producing charcoal from forest tree that cause increase of global warming.*



**Key words:** *alternative energy, carbonization, khat waste, proximate characteristics*

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## ACRONYMS

| | |
|---|---|
| AC | Ash Content |
| BD | Bulk Density |
| BBR | Biomass Binder Ratio |
| BP | Banana Peel |
| C | Carbon |
| Cc/g | Cubic Centimeter per gram |
| CE | Conversion Efficiency |
| CKWM | Carbonized *Khat* Waste Materials |
| C-S | Coal-sawdust |
| CT | Carbonize Temperature |
| Ct | Carbonize Time |
| CV | Calorific Value |
| ERA | Ethiopian Roads Authority |
| FC | Fixed Carbon Content |
| FAO | Food and Agriculture Organization of the United Nations |
| g | Gram |
| H | Hydrogen |
| HHV | Higher Heating Value |
| IRKW | Input Raw Khat Waste |
| JIT | Jimma Institute of Technology |
| Kg | Kilo gram |
| KJ | Kilo joule |
| KWS | Khat Waste Sample |
| LHV | Lower Heating Value |
| MC | Moisture Content |
| MDG | Millennium Development Goals |
| MLF | Municipal Land Fill |
| MSW | Municipal Solid Waste |
| MSWM | Municipal Solid Waste Management |
| N | Nitrogen |
| NA | Not Assigned |
| NL | Nederland |
| NOx | Nitrogen Oxide Gases |

| | |
|---|---|
| O | Oxygen |
| OCM | Output Carbonized Material |
| PS | Phytoplankton Scum |
| RB | Rice Bran Bran |
| RH | Rice husk |
| RKW | Raw Khat Waste |
| RKWS | Raw Khat Waste Sample |
| S | Sulfur |
| SC | Sulfur Content |
| SD | Standard Deviation |
| SOx | Sulfur Oxide Gases |
| SW | Solid Waste |
| SWM | Solid Waste Management |
| T | Temperature |
| t | Time |
| UNDP | United Nations Development Program |
| VM | Volatile Matter |
| WH | Water Hyacinth |
| WHO | World Health Organization |

# 1. INTRODUCTION

## 1.1. Background of the Study

All human beings are use materials for their continuous life and throw away after use rather than using as re use, recycle or changing to energy without thinking of about environment or sustainability of the eco-system. After thrown away the materials are become danger as polluting the environment whether in short period of time or after long period *(*Omran *et al., 2008,* Ahsan *et al.*, 2014, Onekon *et al.*, 2016, Abebaw *et al.*, 2005 and Meka, 2014).

Major usable material thrown away from all house hold or from people live on street, from commercial areas, from industrials, from construction places, from agricultures and from other sources are become in ones and may be cause of human health problem. It is not for human health but also pollute water that damage aquatic life and pollute air that cause for global warming (Mondol *et al., 2013).*

These thrown used materials are food wastes such as food remnants, fresh and decaying leaves, vegetation, garden wastes, plastics such as plastic bottles and packaging materials. Metals cans, bottle caps, ferrous metals, aluminum items, papers such as newspapers, magazines, office papers, junk mails, envelopes, glasses such as glass bottles, jars and textile such as clothes, belts, shoes and also miscellaneous wood, stones, pebbles, waste electrical and electronic equipment, batteries, ash, dust, sand are termed as solid waste (SW). Important problem of managing liquid waste of the cities and towns by shutting the drainage systems if it is simply threw after use everywhere (Tambea *et al., 2016*).

Municipal Solid Waste management (MSWM) has been always a topic much studied and discussed during the years from many points of views. All over the world from production, treatment, management and disposal faced with a growing interest when a country follows the pathway of the optimization of the environmental management (Sakai, 1996, Saskalopoulos, 1998, Oung 2001, Cleary, 2009, Rada, 2009 and Ionescu, 2013). In the last years the connection between MSW and energy has become very important for a sustainable development, as written in the Rio declaration in 1992 and up-dated in 2012 through the “Rio+20” Earth summit. In order to achieve this aim, society must reduce the use of the primary resource, specially the not renewable ones, and increase the use of the second resource or materials from recycling stages and residual wastes (Santibanez-Aguilar, 2013).

As well, manufacture of charcoal is one reason of deforestation and the increase of greenhouse effect that contribute in the global warming (Nederland's Ministry of economic agency, 2013, Chidumayo *et al.,* 2012). In addition, the major dangerous producing charcoal is it may affect to destroy the species of largest trees and the cause of migration and death for wild life while manufacturing within forest in traditional land kiln method.

As reported by (Nederland's Ministry of economic agency 2013), at least 80% of the African population depends on traditional biomass resources such as charcoal and firewood for household energy use. Most charcoal is produce in forests near urban areas, where most charcoal consumption takes place. Charcoal production is an important cause of deforestation, one of the most urgent environmental problems of Africa.

Emissions of greenhouse gases from charcoal production in tropical ecosystems in 2009 estimated as 71.2 million ton for carbon dioxide and 1.3 million ton for methane. The failure of past charcoal policies to address environmental impacts and achieve sustainability could attribute to erroneous assumptions and predictions by national and international organizations regarding wood-based fuels (Chidumayo *et al.,* 2012).

Possible ways of enhancing charcoal policies' legitimacy and therefore effective implementation are multi-stakeholder participation and demonstration of coherence with globally recognized principles, goals and relevant international regimes, such as the Millennium Development Goals (MDGs). In this way, charcoal production can significantly contribute to poverty reduction and environmental sustainability (Chidumayo *et al.,* 2012).

As published by (Tucho *et al.*, 2015) access to modern energy services remains an issue for poor people in developing countries. In Ethiopia about 83% of the population does not have access to electricity and 93% uses biomass-based energy for cooking, which surpasses 99% in rural areas Ethiopian Welfare Monitoring Survey Report of 2011 (Energy for All, 2011). Firewood is the main fuel followed by crop residues and cows dung collected from common resource pools or own resources. This situation is typical for many regions in Sub-Sahara Africa (UNDP, 2009).

Jimma is also one of the largest town that found in south western Ethiopia of Oromia regional state; with rapidly developing in building and growth of population that produce huge amount of municipal solid waste each day (Getahun *et al.,* 2011). These make challenge to manage for the town municipality since the produced solid waste is threw away simply on the street, into sewer drainage, into rivers like Awetu and Kito as it is observing in our daily life. In case of Jimma the problem of MSW was also reported as it is the most problem, when Jimma town Drainage Master Plan for management of liquid waste of the city by closing the drainage system of the city (Brave Consultants, 2014).

In all the solid waste that produced in Jimma town, the waste of Khat (scientific name: *Catha edulis Forsk*) (Alles, 1960) or locally its waste is called 'garba' and banana peels are contributed in the large amount. A productive portion of the Ethiopian population, especially of the youth, has taken up the habit of chewing *Khat (*Lemessa, 2001). Growing use of the stimulant is obviously generating a huge amount of waste making the already-bad situation of solid waste management in Jimma also worse.

(Wachirasiri *et al.*, 2008) reported for banana peel, as it is worse waste that deposited in municipal landfill (MLF) in Thailand, banana peel is one of the SW contributed in large amount to Jimma MSW. It is every ware of the city part as seen every day near side of the road. So many low incoming peoples are use as their daily income by buying from the village around Jimma and sell it into Jimma town. Many users of banana for eating purpose are buying from banana sellers and take to home, after eating banana then they threw away to the road its peels. Others use at sellers place and threw the peels into provided carton by the sellers in small extent. Unless and otherwise they also threw to the road simply as it observed from the road daily especially from like Merkato, Kochi, Ajipp, Bishishe and other parts of Jimma town.

Since all of these problems are fazed, alternative eco-friendly charcoal producing from *khat* waste is an important and the best alternative of energy recovery. It is environmentally sound process for the minimization of solid waste discharge to provide place, to street and sewer drainage by street boy chewers and others. In addition, to minimize deforestation that degraded duo to charcoal production, and save tree species and wild life. In the other hand, it is important doe to energy be gain simply from unusable waste. It is also, to be the work option for people who have no common work simply by collecting *khat* waste to provide for charcoal production.

## 1.2. Statement of the Problem

Use of the plant *khat* (scientific name: *Catha edulis Forsk*) in Ethiopia has long since become one of the hallmark of urban centers-old and new alike. A good portion of the population, especially among the youth, has taken up the habit of chewing it (despite the escalating price) so much so that trade in *khat* and delivery of associated services are growing fast and spreading everywhere (Yusuf, 2014 and Alles, 1960).

In case chewing *khat* is use as cultural stimulant beyond major peoples of Jimma and around. The ever-widening use of the stimulant is obviously generating a huge amount of waste making the already awful situation of solid waste management in Jimma worse. As observed, simply when walking on the road the *khat* waste is everywhere in Jimma town even if in the river like Awetu and Kitto which are passes in the center of the town is undesirable. In addition, charcoal production from large tree species and using woody fire in Ethiopia including Jimma and around is an observable and daily practice of the peoples.

The current problem in the management of *khat* waste is already posing a serious threat to the environment. With the expected increase in the consumption of both items, the problem will certainly grow correspondingly. That, this problem has to be addressed; somehow and addressed fast, before the damage on the environment gets irreversible. It would so be agreeable that recovering energy from these wastes is a very good way of managing them (Yusuf, 2014). In Ethiopia about 83 % of the population does not have access to electricity and 93 % uses biomass-based energy for cooking, which surpasses 99% in rural areas (Ethiopian Welfare Monitoring Survey Report of 2011, Energy for all, 2011). The present research aims at studying the possibility of recovering energy from *khat*, waste by using a pyrolysis process.

It also used banana peels as binder, which is best eco-friendly since it selected from MSW that also challenge for MSWM. In addition, it is locally available and best cementing material as (Mukhopadhyay *et al.,* 2017) use for bio plastic production due to it has high tensile strength and rich in starch like corn. Therefore, the study was done by using excess sample of *khat* waste carefully, without mixing with other MSW. The sample was taken from Jimma town and proceeds to charcoal briquette to give energy.

## 1.3. Objectives

### 1.3.1. General Objective

The main intention of the study was to investigate alternative eco-friendly energy recovery from *khat* waste by producing charcoal using banana peels as a binder to briquettes *khat's* char powder.

### 1.3.2. Specific Objectives

This study also had the following specific objectives:

1) Evaluate conversion efficiency, temperature and time of raw *khat* waste into carbonized material
2) Determine proximate characteristics of produced charcoal briquettes from *khat* waste with different mixing ratios with binder
3) Determine energy potential of produced charcoal briquettes from *khat* waste using different ratio with binder

## 1.4. Research Questions

1) What is the carbonize efficiency, temperature and time of raw *khat* waste while changed into carbonized material?
2) What are the proximate characteristics of charcoal briquettes that produced from *khat* waste?
3) How much energy gained from charcoal briquettes produced from *khat* waste?

## 1.5. Significance of the Study

Today the world is fail into dangerous global warming and the ecology is disturbed as we are experiencing from our daily life and read from different published study. Unmanageable MSW is one factor of environmental pollution that exceeds global warming. Deforestation and degradation of tree that mostly used for charcoal production as energy and income source especially for undeveloped countries is also another factor of the problem.

Therefore, the study was investigated the possibility of using waste *khat* for simple alternative eco-friendly energy recovery using banana peels briquetting binder, was contribute to make available an alternative way of handling the wastes. In another way, it also contributed for minimization of deforestation of tree diversity that deforested for charcoal production, also contributed to simply handling of air pollution by charcoal smoke released to atmosphere, save the wild life that are lived in the forest and generally contributed in sustaining ecosystem. Using banana peels rather than other binders such as corn powder, wheat powder, clay soil, molasses, gum Arabic and other costly source of starch was make the study significant with respect to eco-friendly and sustainability contribution. As it is also lead the way to identify the efficiency, energy potential and process *khat* waste for a purpose as such, the findings can used as a reference for future studies.

## 1.6. Scope of the Study

The aim of the study was conducted the alternative eco-friendly energy recovery by changing *khat* waste to charcoal using banana peels as a binder. This study was not characterized *khat* waste and banana peels but depending on pre-determined characteristics as in literature review, *khat* waste was carbonized and briquetted using banana peel as a binder. Through the process, carbonize efficiency was determined using the measurement of taken waste sample *khat* and dried carbonized of the sample. Next, produced charcoal characterized as the pre-determined on other different agricultural waste. In addition, its energy potential, sulfur content and bulk density were determined. The study was geographically limited to alternative eco-friendly energy recovery as produced charcoal from *khat* waste and banana peel binder using sample from Jimma town, Ethiopia, in Oromia regional state.

## 1.7. Limitations of the Study

The molding machine that was used to briquette charcoal, that found in Jimma Agricultural Engineering Research Center is old and has effect on compacting well.

# 2. LITERATURE REVIEW

## 2.1. Municipal Solid Waste Management

For the duration of the last few decades, the problems associated with MSWM have acquired an alarming dimension in the developing countries. High population growth rate and increase of economic activities in the urban areas of developing countries combined with the lack of training in the modern SWM practices complicate the efforts to improve the its services. In developing countries, the per capita generations of the SW in urban residential areas is much less compared with the developed countries; however, the capacity of the developing countries to collect, process, dispose, or reuse it in a cost effective manner is significantly limited compared with the developed countries (Tchobanoglous, 1993 and Omran, 2017).

The majority of inhabitants in most towns in the country often use unsafe solid waste disposal practices, such as open dumping, burning, burying and so on. For instance, according to (Birke, 1999) study of the municipal solid waste management practices of 15 regional cities of Ethiopia, a controlled solid waste disposal is practiced in only 2 of them. The study of Bonga town in southwestern Ethiopia (Temesgen *et al.*, 2005) also shows the widespread lack of proper municipal solid waste services and similarly like that in Jimma town (Degnet *et al.*, 2005). It also reported as it is the most problem, when Jimma town Drainage Master Plan for management of liquid waste of the city by closing the drainage system of the city (Brave Consultants, 2014).

Jimma town is one of the towns that fond in developing country Ethiopia with a rapid population growth and industrial activities pose many environmental challenges due to aspect of urban growth posing a threat on sustainable development is poor SWM, which results in environmental pollution. As investigated, 88,000 kg of the total waste is generating daily in Jimma town and the average per capita generation rate is 0.55 ± 0.17 kg/capita/day. Since 13 % produced by households, 87 % of the waste by institutions, and street sweepings generated a negligible fraction 0.1 % (Getahun et al., 2011).

Jimma town MSW is 54 % by weight with an average moisture content of 60 % that falls within the required limits for composting. In addition, non-biodegradable components constitute 46 % of which 30 % of it was non-recyclable material and 25 % of the community uses municipal containers for disposal at the selected landfill site, 51 % of the households disposed their waste in individually chosen spots, whereas 22 % burned their waste. Two % of households use private waste collectors. The study state that, the biodegradable waste is a major fraction having suitable properties for recycling and economic benefit can be obtained from this waste while avoiding the need for disposal (Getahun *et al.,* 2011).

Household SWM has remained a major challenge to the municipal government of Jimma town. One of the main constraints facing the local government in the provision of adequate solid waste collection and disposal services to its citizens is the shortage of enough financial and physical resources. Furthermore, private sector investment in solid waste services has been very little (if any) or non-existent at all. Experiences elsewhere demonstrate that local people's participation in planning, financing and monitoring of solid waste management services is one of the main mechanisms to address this gap. However, adequate information has not been available on how to initiate and apply such practices by various municipality governments of Ethiopia including that of Jimma (Degnet *et al.,* 2005).

## 2.2. Charcoal Manufacturing

At least 80% of the African population depends on traditional biomass resources such as charcoal and firewood for household energy use. Most charcoal produced in forests near urban areas, where most charcoal consumption takes place. Charcoal production is an important cause of deforestation, one of the most urgent environmental problems of Africa. To date experience with the use of wood charcoal alternatives, produced from feeds stocks such as charcoal dust, harvest residues, processing residues and invasive species, has been limited. Its production requires additional techniques, investments and an organization structure that needs to compete with the existing, usually informally organized charcoal sector (Nederland's Ministry of economic agency, 2013).

As reported by the (Netherlands Ministry of economic agency, 2013), Ethiopia is the most second country of charcoal manufacturer of Africans top twenty countries next to Nigeria which produce large amount of tones per day as shown on figure 2.1.

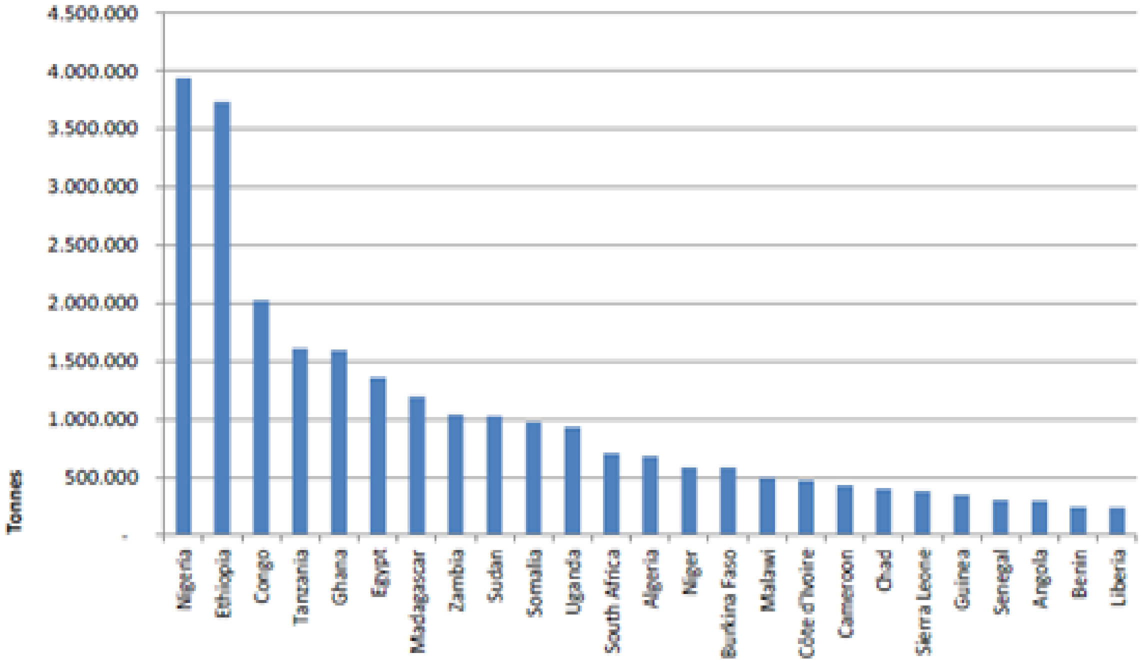

Figure 2.1 Top 25 wood charcoal producing countries in Africa (FAO, 2010)

## 2.3. Pyrolysis of Solid Waste

Pyrolysis of solid waste fuel are defined as a thermo-chemical decomposition of waste fuel at elevated temperatures, approximately between 500 and 800 ℃, in the absence of air and it converts MSW into gas (syngas), liquid (tar) and solid products (char). The main goal of pyrolysis is to increase thermal decomposition of solid waste to gases and condensed phases. The amount of useful products from pyrolysis process (CO, $H_2$, $CH_4$ and other hydrocarbons) and their proportion depends entirely on the pyrolysis temperature and the rate of heating (World Energy Council, 2016).

Depending on the residence time in the reactor pyrolysis is divided into two: slow (long residence time) and fast pyrolysis (short residence time). Under slow pyrolysis, a bio char yield between 25 - 35 % can be reproducibly produce depending on the nature of the feedstock, reactor type as well as the degree of operating conditions optimization. To obtain a high bio-oil yield, fast pyrolysis recommended. However, fast biomass pyrolysis needs to satisfy four conditions. The conditions are namely, medium temperature (450 - 600 ˚C), high heating rate (103 - 104 KJ/s), short vapor residence time (< 2 s) and fast condensation of vapors (Lee *et al.*, 2013). Under slow pyrolysis, a bio char yield between 25 - 35 % can produced depending on the nature of the feedstock, reactor type as well as the degree of operating conditions optimization (Ayllon *et al.*, 2006).

In Ethiopia, charcoal commonly produced using the traditional earth kiln method, earth mound kiln and earth pit kiln. Earth mound kiln were being the most frequent method with an efficiency of 10 – 15 %. It has to note those high amounts of gases and other unburned hydrocarbons released into the atmosphere. This traditional technology is inefficient and leads to deforestation since most of the people use woody biomass to produce charcoal in Ethiopia (Girmay *et al.,* 2014).

In order to reduce the environmental impact of charcoal using these traditional kilns, new alternatives can implemented to convert biomass into valuable products. Innovative slow pyrolysis technologies must adopt in developing countries to produce bio-char that is efficient and environmentally friendly. Thus, instead of using woody biomass as the only means to produce bio-char in Ethiopia, several biomasses can use like flower wastes, agricultural wastes, bamboo and others (Bogale, 2017).

Even though biochar has many advantages from energy and environmental perspective point of view, it is has not been used widely in Ethiopia. Most of the bio-char reactor that were used before has low conversion efficiency, very small scale and rarely found in rural areas even though 85 % of the population of Ethiopia lives in rural areas. Besides, approximately 90 % of the Ethiopian population used biomass for cooking purpose (Bogale, 2009). This will leads to indoor air pollution and creates healthy problems for the society (WHO, 2016). However, finding a long-term solution that will solve rural society problem efficiently, economically, and environmental friendly is a very challenging task (Bogale, 2017).

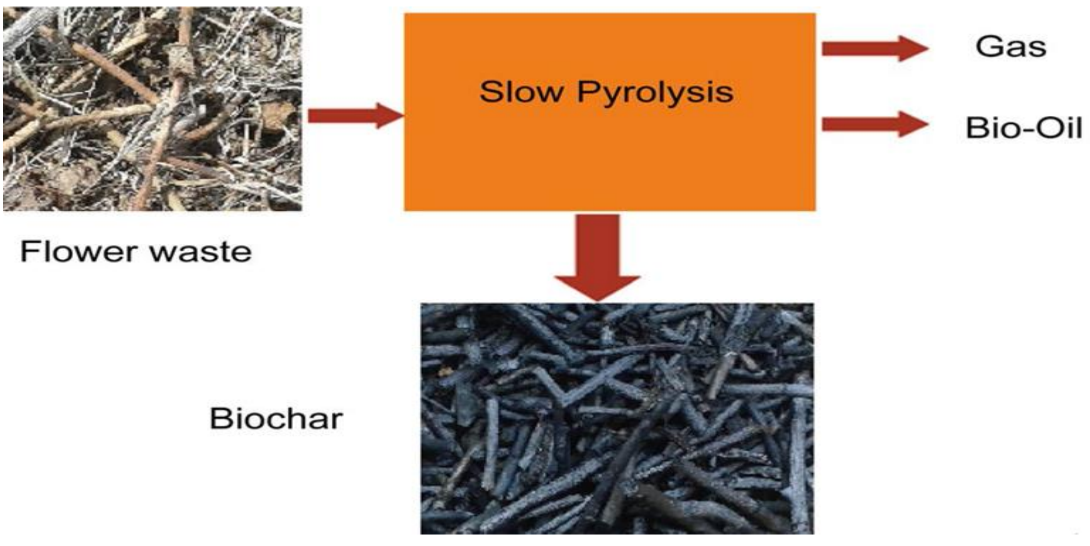


Figure 2.2 slow pyrolysis to produce biochar from flower (Bogale, 2017)

### 2.3.1. Application of Pyrolysis

Application of pyrolysis for proper management of solid waste and resource recovery from a wide variety of feedstock is its main allure. Solid waste materials that are otherwise difficult to safely dispose can thus use as feedstock for pyrolysis to end up as useable products for numerous applications. Tire wastes, coal and petroleum residues, used lubricating (or heavy) oils, sewage sludge, and contaminated soil are only some of the materials that can be carbonized (Yusuf, 2014). Tire recycling, energy recovery from sewage sludge, and soil cleaning can hence be achieved (Riediger *et al.,* 2010).

Pyrolysis of end-of-life tires gives high-energy gas, hydrocarbon oils, char, and steel. This can attributed to the presence of a lot of chemical bound energy. Efficiency of sludge pyrolysis very often discussed in many literatures. Pyrolysis of sludge is a very energy-efficient process and the dryer the sludge the more energy efficient the main process. A more energy efficient process can achieved through the usage of undigested sludge for nearly double the energy content found than that of digested sludge from the biogas plants. Soil that contaminated with oil, hydrocarbons, dioxins, furans, or mercury can purify by pyrolysis. For this application raised temperatures will reached by using either direct or indirect heated kilns. Heating converts the volatiles to vapor, which incinerated in a downstream combustion chamber (Yusuf, 2014, Bogale, 2017 and Merete *et al.*, 2014).

### 2.3.2. Pyrolysis Process

(Bogale, 2017) did the heat required for the pyrolysis reactor supplied by burning a portion of waste on flower waste. This heat is to be transfer to the reactor to convert waste flower into bio-char. The reactor is covered with a refractory coverage to avoid heat loses. Besides, the portion of the produced gas is re-circulated to increase the efficiency of the system. The reactor is a double barrel reactor where the inside one is the pyrolysis reactor and the external one is where combustion is occurring. Air is inserting at the bottom of the combustion chamber. Thus, the heat released from combustion is used for the inside pyrolysis reactor.

### 2.3.3. Pyrolysis Results

As (Bogale, 2009) did it, on agricultural solid waste it is with good result of bio-char as on the figure 2.3.

Figure 2.3 Produced bio-char, mixing, briquette and combustion (Bogale, 2009)

Also as (Yusuf, 2014), the amounts of solid (bio-char), liquid, and gas products obtained from each run given in the table while the solid method was considered for this study.

Table 2.1 Products from Pyrolysis Experiments (Yusuf, 2014)

| Run | Experimental factors | | | Mass of products (g) | | |
|---|---|---|---|---|---|---|
| | % kh | T (°C) | t (min) | Solid | Liquid | Gas1 |
| 1 | 100.00 | 750 | 60 | 23.6 | 13.00 | 13.40 |
| 2 | 30.00 | 650 | 30 | 11.9 | 2.20 | 35.90 |
| 3 | 100.00 | 750 | 30 | 35.1 | 11.50 | 3.40 |
| 4 | 30.00 | 550 | 60 | 15.9 | 12.50 | 21.60 |
| 5 | 30.00 | 750 | 30 | 10.6 | 1.50 | 37.90 |
| 6 | 30.00 | 650 | 60 | 4.5 | 2.80 | 42.70 |
| 7 | 100.00 | 650 | 30 | 26.4 | 11.10 | 12.50 |
| 8 | 70.00 | 750 | 60 | 13.1 | 9.10 | 27.80 |
| 9 | 70.00 | 550 | 60 | 12.5 | 6.70 | 30.80 |
| 10 | 100.00 | 550 | 30 | 17.1 | 9.70 | 23.20 |
| 11 | 100.00 | 650 | 60 | 25.6 | 12.00 | 12.40 |
| 12 | 70.00 | 750 | 30 | 11.79 | 9.00 | 29.21 |
| 13 | 30.00 | 750 | 60 | 10.6 | 1.50 | 37.90 |
| 14 | 30.00 | 550 | 30 | 16.8 | 10.90 | 22.30 |
| 15 | 70.00 | 650 | 30 | 12.5 | 5.00 | 32.50 |
| 16 | 70.00 | 650 | 60 | 12.5 | 5.00 | 32.50 |
| 17 | 100.00 | 550 | 60 | 16.61 | 10.40 | 22.99 |
| 18 | 70.00 | 550 | 30 | 13.3 | 6.20 | 30.50 |

The maximum liquid fuel produced (13.0 g) was when 100 % of *khat* waste was pyrolyzed at 750 $^oC$ for 60 minutes *(Run #1)*. Solid product was also maximum for the same temperature and *khat* percentage but when pyrolysis went on for 30 minutes *(Run #3)*. The highest amount of gas, on the other hand, was produced when 30 % *khat* was pyrolyzed at 650 $^oC$, for 60 minutes *(Run #6) (*Yusuf, 2014).

### 2.3.4. Effect of Processing Conditions on Product Distribution

As (Yusuf, 2014) determine, "Amount of *khat* in the feed composition and pyrolysis temperature significantly influenced the distribution of products both separately (main effects) and interacting (interaction effects). Pyrolysis time, however, had the minimal influence on the product spectra obtained. Very small variations were observed between the amounts of products obtained from respective pyrolysis experiments that run only for different times while the amount of *khat* and temperature remained the same".

## 2.4. Characterization of *Khat* Waste

As done by (Yusuf, 2014), a number of physical and chemical characteristics of *khat* waste were identified.

Table 2.2 Characteristics of *Khat* Proximate Analysis (Yusuf, 2014)

| Characteristics | (% wt) |
|---|---|
| Moisture (as discarded) | 76.3 |
| Ash | 5.31 |
| Chemical Components (% dry basis) | |
| Cellulose | 59.0 |
| Lignin | 31.7 |
| Physical Properties | |
| Bulk Density | 0.42 g/cm3 |
| Ultimate Analysis | |
| % C | 47.12 |
| % H | 6.0 |
| % N | 1.23 |
| % O (determined by difference) | 45.65 |
| HHV | 17.46 MJ/kg |
| LHV | 12.57 MJ/kg |

It shows that khat waste has very high moisture while its percentage ash content is to be around the average. Lower amount of organic liquid product can expected from pyrolysis of as discarded khat waste due to the very high moisture contained. The lower ash content whereas indicated more positive suitability of *khat* waste in thermo chemical conversion, due to the prevalent organic nature it affirmed (Yusuf, 2014).

As (Sadaka *et al.,* 2008, Sinha *et al.,* 2004, Atadana, 2010, Vigouroux, 2001), also the lignocellulosic composition values inferred that *khat* waste had relatively Cellulose 38–46 and 16–28 % lignin were found to be the average composition ranges for woody materials in general. These components are further responsible for the variety and complexity of products formed during the pyrolysis of biomass. Above 300 $^{o}$C, cellulose breaks down to give tarry products containing low sugar derivatives and little char while lignin is condensed to carbonaceous char and gives smaller amounts of pyrolyzate containing phenolic compounds (Sadaka *et al.,* 2008). These phenomena implied that less amount of liquid product may be expected from pyrolysis of *khat* at temperatures > 300 $^{o}$C. Gas and char products, correspondingly, become higher due to higher amounts of cellulose and lignin.

The elemental analysis results shows that respective compositions of C, H, O, and N are similar to most biomass wastes (Jenkins *et al.,* 1995). The absence of S along with the very small amount of N, moreover, indicated that using *khat* waste in a thermo chemical conversion process have insignificant production of NOx and SOx to pose any pollution threat.

## 2.5. Characterization of Banana Peels

Banana peels are good source of pectin and some food nutrients such as minerals, sugars and dietary fibers (Ragab *et al.,* 2016). According to William and Magharabi that compared and presented by (Ragab *et al.,* 2016) the characteristics of banana peels are present as in the table.  Banana peels has the characteristics of high plasticity rather than clay soil that is used as a binder for briquette of charcoal from coffee husk and coffee pulp done by (Merete *et al.,* 2014).

Table 2.3 The proximate chemical composition of banana peels (Ragab *et al.*, 2016)

| Components | Banana component varieties (%) | |
|---|---|---|
| | William | Maghrabi |
| Moisture content | 90.88 | 90.76 |
| Total solid | 9.12 | 9.24 |
| Crude protein | 5.21 | 6.68 |
| Ether | 5.52 | 6.96 |
| Ash | 13.84 | 12.44 |
| Lingo cellulose | 49.14 | 41.31 |
| Crude fibers | 36.37 | 41.31 |
| Pectin | 12.77 | 13.03 |
| Available carbohydrates | 26.29 | 19.56 |
| Total carbohydrates | 75.43 | 73.92 |

## 2.6. Briquetting

Briquetting technologies are available in a wide capacity range, from very small to very large and with varying degrees of mechanization and automation. Main categories identified are manual techniques, small-scale electrical techniques and medium-scale electrical techniques (Nederland's Ministry of Economic Agency, 2013). As it will assigned for this study, it will be to use extruder machine that found in Jimma Agricultural Mechanization Research Center like as (Merete *et al.*, 2014) on alternative potential energy from coffee husk and pulp.

The briquetting process can divided into the steps as Nederland's Ministry of Economic Agency, (2013). Those are screening (sieving) required to remove stones and other material from the dust, drying the dust needs to be perfectly dry, Sizing or crushing dust is convey to the hammer mill, which produces bits of uniform sizes. Next the charcoal dust is crushed and pressed through the perforated metal, mixing with binder Briquetting once binder and dust are properly blended the mixture is taken to the briquetting machine where the briquettes are produced. Packaging the dried briquettes is package in plastic bags and sealed. Neatly packaged, the charcoal briquettes can be selling as in different Africans countries such as Kenya and Tanzania (Nederland's Ministry of Economic Agency, 2013).

## 2.7. Binders

Nederland's Ministry of Economic Agency, 2013 report that as agglomeration is the main technology used for producing charcoal briquettes from cotton stalks, as they give high quality briquettes, require a relatively low investment, and are therefore suitable for small industrial applications. Since charcoal is a material totally, lacking plasticity, it needs addition of a sticking or agglomerating material to enable a briquette can form. The binder should preferably be combustible. As reported by Nederland's Ministry of Economic Agency, 2013, Clay is often used as binder in small-scale applications; starch, molasses and gum Arabic in semi-industrial applications.

Therefore, to form charcoal briquette from *Khat* waste the samples were carbonized and changed into charcoal powder in this study, the banana peels binder was selected. Since, it is locally available and low cost and one source of starch about 12.78 $\pm$ 0.9 g/100 g (Wacirasiri *et al.,* 2009) rather than clay, molasses and gum Arabic in semi-industrial applications as stated by Nederland's Ministry of Economic Agency, 2013 for charcoal from cotton stalks which are very costly, environmentally not eco-friendly and locally not available. Banana peel is the best cementing agent do to lignocelluloses 49.14, 41.31 %, pectin 12.77, 13.03 % is available in it (Ragab *et al.*, 2016). Also it is locally available as one of that challenge to manage MSW **(**Wacirasiri *et al.,* 2009) which means that is environmentally it is supported and eco- friend when it is used as binder for energy recovery.

It also examined by (Ugwu *et al.,* 2013) as briquettes produced from empty fruit bunches of oil palm plant using starch and asphalt separately as binders. The briquettes were comparing based on their physical and chemical properties. The briquettes made with starch binder from fruit had high calorific value, higher burning rate and higher heat output. It also produces less smoke and ignites within short time than the briquettes made with asphalt as binder. From the results, it is easier to choose the binders for briquettes making between asphalt and starch from fruit bunch, though other parameters may be considered.

To produce high quality charcoal briquettes selection of binder type and binder to charcoal dust ratio is the main thing. Because binder type and ratio is mainly, affect all proximate characteristics, bulk density and calorific values of the briquettes (Ranjit *et al,*. 2016 and Carnaje *et al.,* 2018).

Table 2.4 Comparison of FC, VM, moisture, and ash of water hyacinth-molasses briquette with briquettes produced from other sources of biomass and binder (Carnaje *et al*., 2018).

| Briquette type (biomass: binder) | BBR | FC (%) | VM (%) | MC (%) | AC (%) | HHV (MJ/kg) |
|---|---|---|---|---|---|---|
| Coal-sawdust(C-S) | 50:50 | 79.5 | 11.0 | 1.7 | 7.83 | 32.1 |
| Coal-sawdust (C-S) | 33:66 | 85.0 | 7.8 | 0.9 | 6.3 | 31.6 |
| Coal-sawdust(C-S) | 25:75 | 85.9 | 7.3 | 1.1 | 5.7 | 32.0 |
| Neem wood-starch | 1:3 | 85.2 | 10.5 | NA | 4.2 | 32.8 |
| Neem wood-starch | 5: 2 | 84.25 | 10.0 | NA | 5.7 | 32.3 |
| Wood sawdust-cow dung | 70:30 | 75.7 | 11.1 | NA | 14.9 | 28.6 |
| Rice husk(RH)-rice bran bran(RB)–water | 10 % RB | NA | NA | NA | NA | 16.0–16.4 |
| Bagasse-clay-molasses | 40:1:1 | 36.4 | 27.2 | 4.1 | 36.4 | 18.4 |
| WH-phytoplankton scum(PS) | 50:50 | NA | NA | NA | NA | 17.91 |
| WH-EFB-Cassava starch | 25: 75 | 80.3 | 15.97 | 9.3 | 15.97 | 17.17 |
| WH-molasses | 40:60 | 45.8±0.6 | 13.2±1.3 | 14.6±0.3 | 26.2±1.0 | 15.9±3.9 |
| WH-molasses | 30:70 | 47.4±1.5 | 15.0±1.2 | 18.1±0.1 | 19.5±2.6 | 16.6±2.1 |
| WH-molasses | 20:80 | 48.0±2.2 | 16.8±0.8 | 18.6±0.2 | 16.5±2.3 | 13.45±1.6 |

## 2.8. Manual Mechanical Molder

As Small-scale extrusion Char dust Ltd. (Kenya) and BRADES (Senegal) systems that reported by Nederland’s Ministry of Economic Agency, 2013, started their businesses using manual extruders, but have both moved on to using motorized systems with a view of increasing capacity and reducing production costs. For a study it is proposed to use the equipment that is avail in Jimma agricultural mechanization research center as the method that done before by (Weldemedhin *et al.*, 2014) done on potential alternative environmental friendly energy recovery from coffee husk and pulp.

Figure 2.4 Briquetting charcoal dust in Saint-Louis using the rotor press (Nederland's Ministry of Economic Agency, 2013)

## 2.9. Energy Potential of Charcoal from Waste Section

Rather than using open damp or using landfills for management of MSW, energy recovery from it is an interesting way of handling and minimization system of environmental pollution. In addition, energy can gain simply from waste section (Rada, 2017). According to Bogale, 2017 did, energy potential from flower waste is 26.5 KJ/g and (Merete *et al.,* 2014) did for coffee husk and pulp are 21.09 and 16.89 KJ/kg, respectively.

## 2.10. Summary

Generally, MSWM is the worse assignment for all cities and towns of the overall world, especially for developed countries as studied written as so many journals, books, articles, news peppers, conferences and different agencies. In addition, there are different management techniques of MSW were wrote. From such there was alternative energy recovery from MSW that used as multipurpose as MSW, energy recovery and pollution control that is environmentally sound to minimize global warming and to sustain ecosystem for future generation. In case of this study, there also be identified the related literatures that was used for supporting the title as references. There were different investigations on charcoal production from SW by the process of pyrolysis, crush or grinding, mixing with binder and lastly sample was briquetted and tasted for energy potential in calorie using bomb calorimeter. This thesis also by referring such materials and picking *khat* waste from MSW that produced largely in Jimma town per day as SW. The characteristics of *khat* waste also identified as predetermined in different studies and were used for reference of this study.

# 3. MATERIALS AND METHODS

This chapter deals with the materials and methods used for the study. Details of the approaches employed in different parts of the research where sample collected and analyzed are also included in this chapter.

## 3.1. Materials

Materials used for feedstock in pyrolysis experiments of this study were *khat* waste (garaba), banana peel and water for binding the carbonized material from *Khat* waste as briquettes. The sample *khat* waste collected from the garbage of one chewing house called Aba Jifar located at Kebele Amist of Jimma town around Jimma Agricultural Engineering Research Center where many customers regularly came to chew there.

Banana peels for the binder was taken from one sellers of banana at Saris around Taxi Station between the road turn to Jimma Inistitute of Technology and the road to St. Gabriel. Eight sack of 100 kg measure used for collected sample of *khat* waste.

List of equipment, and instruments employed for all laboratory applications that were involved given in Table 3.1.

Table 3.1 Materials and tools used

| Equipment | Application | Manufacturer (Model) |
|---|---|---|
| 100kg content Sack | To hold the raw *khat* waste sample | NA |
| Balance | Measure the sample | 100B.B.I-015 |
| 200L content Kiln | Carbonize the sample | NA |
| Infrared | Track temperature | IR2018.cc.-18 |
| Mill | Grind carbonized material for size reduction | NA |
| Engine | Rotate the Mill | 1827376 |
| Extruder | Briquette carbonized and grinded material | NA |
| Digital mass balance | Calibrate sample after briquette | CT6000-S |
| Drying oven | Dry briquetted sample | GG.Q.T.B.J111.02.11.001 |
| Advanced Bomb calorimeter | Measure heat content or to determine energy capacity | PARR1241EF |

## 3.2. Description of the Study Location

### 3.2.1. Sampling Location

The sample taken from Jimma town *khat* waste that produced on the city specifically, from the garbage of one chewing house called Aba Jifar located at Kebele Amist of Jimma town around Jimma Agricultural Engineering Research Center. Jimma is the biggest town in the southwestern Ethiopia. It is located at 335 kilometers away from Addis Ababa with a geographic location of $7^{o}$ 40’ N latitude and $36^{o}$ 60’ E longitudes. The town occupies a total area of nearly 4623 hectares, of which about 26 % is a residential area with the population of 207,573 by 2012 statistics population data. Jimma has a warm and humid climate with daily average temperature of 20 ℃ and mean annual rainfall varying between 1450 and 1800 millimeters with the elevation from mean sea level of 1,780 m (5,840 ft). Hence, Jimma town is very large that *khat* waste and banana peels are everywhere of the town, sample was taken from the city’s garbage.

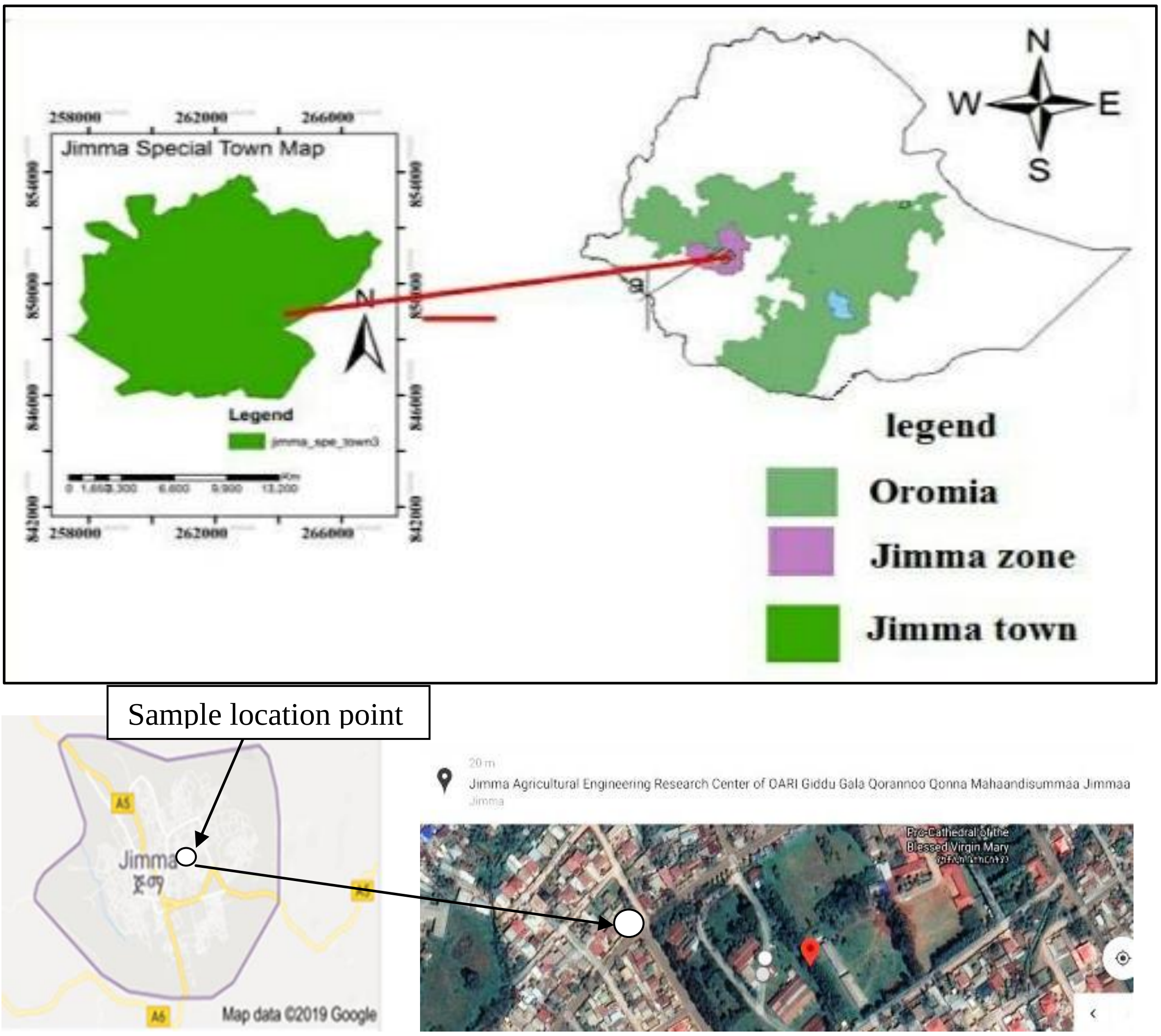


Figure 3.1 Map of sampling location (w.tiptopglobe.com>city map>Ethiopia & researchgate.net)

### 3.2.2. Socio-economic Activity

Jimma town has 17 kebeles which are accountable to the Mayor’s office. Based on the 2007 population and housing census, the population of the town is 120,960 (male 60,824 and female 60,136). The annual population growth rate of the city is estimated to be at 3.75 % (CSA, 2007). In Jimma town and around the major economic activities mainly related with *Khat*, Coffee, and different fruits and vegetables.

## 3.3. Study Period and Design

### 3.3.1. Study Period

The study was required the time to collected and analyzed data of *khat* waste sample that carbonized for analyzing efficiency, determination of proximate characteristics and energy potential. Therefore, it concluded within six month from July 1, 2019 to January 30, 2020.

### 3.3.2. Study Design

The study design was an experimental study type and conducted first by identification of the minimization of *Kha*t waste that contributed in large amount of Jimma town solid waste through changing it to energy. In addition, effects of charcoal on the environment are the case behind the study. As in literature review, desk study on selected journal articles studied. Then from the findings, the necessary data identified and sample collected.

Therefore, the study was combination of experimental as it was based on laboratory, quantitative while result gained from the experiment were numerical values and qualitative data type as the study was also started from observation and take the sample carefully without mixing with another SW. However, the study was more concerned on experimental research type the experimental design illustrated as flow chart on figure 3.2 shown.

Primary data contributed for the research as observing the situation of *Khat* waste of the town, charcoal transported to the town by producing from forest tree species traditionally and collected samples were used. Secondary data collected from various publications and census reports such as different books, articles, journals, documents from conferences hold for related issues and from web pages.

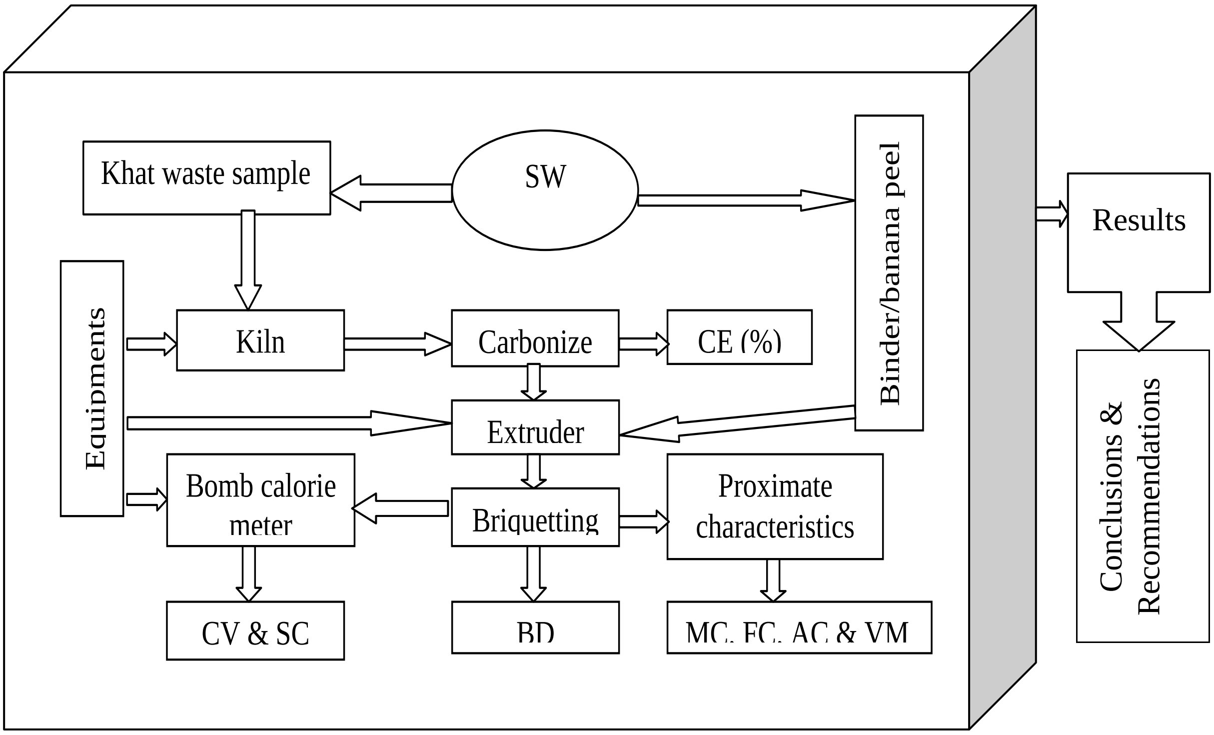


Figure 3.2 Flow chart of study design

## 3.4. Sampling Size and Sampling Techniques

### 3.4.1. Sampling Size

For *khat* waste, scientifically done by (Yusuf, 2014) as liquid fuel and checked its char as solid and it recommended, as it can be possible. This study also designed for alternative energy recovery from 9, 18 and 27 kg of raw *Kha*t waste sample. It was done by producing charcoal using the method of (Bogale, 2017) charcoal from 18 kg of flower waste (Bogale, 2009) charcoal from agricultural waste and (Merete *et al.*, 2014) charcoal from 19 kg of coffee husk and pulp to select amount with the best efficient. The binder carefully taken and must be grinded well and changed to liquid and mixed with the ratio of 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water to banana peel to carbonized *khat* waste) to identify possible amount of binder ratios to produce good briquette.

### 3.4.2. Sampling Techniques

Purposive sampling that is non-probability sampling techniques used to collect the sample for the experiment due to it is the representative of all population of *khat* waste entering to Jimma town is into garbage.

## 3.5. Sampling Procedures

### 3.5.1. Sample Collection

Excess sample of *khat* waste collected from solid waste garbage. Then after, the sample was taken to Jimma Agricultural Engineering Research Center.

### 3.5.2. Sample Pre-treatment

**Drying**

The taken sample were dried well by sun to remove the moisture content before carbonize.

**Chopping**

The samples were chopped to reduce the size after dried well before measuring on balance.

**Measuring the Sample**

After well dried and chopped, the sample was measured for the calculation of, carbonize efficiency. On measuring step 9, 18 and 27 kg of 3 samples for each sample taken and coded as Sample 1, Sample 2 and Sample 3.

**Binder Preparation**

The banana peels were collected and grinded until it became liquid form by adding drop of water in the ratio of 1:2 and 2:1 (water to banana peels). Therefore, for 1 kg of binder material 0.33 kg of water and 0.67 kg of banana peels and 0.67 kg water and 0.33 kg banana used to check proximate characteristics, sulfur content, bulk density and calorific value. It means that, for 1 kg of carbonized materials from *khat* waste, 82.5 and 167.5 g, 167.5 and 82.5 g, 110 and 223.3 g, 223.3 and 110 g, 66 and 134 g, and lastly 134 and 66 of water and banana peels used respectively. It mean that 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:5 and 0.67:0.33:5 (water to banana peels to carbonized *khat* waste) were.

## 3.6. Experimental Procedures

### 3.6.1. Conversion Temperature and Time

To change the raw khat waste to carbonized material time and temperature are the main factors in addition to amount of raw khat waste. During the carbonization, the instrument called Infrared used to calibrate the temperature of the 200 L kiln. Before the sample of *Khat* waste putted into the 200 L kiln, the chimney inserted into the kiln starting from its bottom. After the chimney inserted, the sample become fill in to the 200 L kiln and closed. For carbonize the fire was fired on the bottom part of the kiln and it became closed when the fire get the *Khat* waste in the kiln to avoid oxygen.

At the beginning, the temperature of the kiln was rapidly increased and the smoke from the kiln through chimney became flew rapidly. Lastly, when the digital Infrared reading of temperature of the kiln became fall down and at the same time, the smoke flow out through the chimney stopped the water added to stop the fire in the kiln rapidly. When the temperature of the kiln became cool after the internal fire stopped, the carbonized material grounded under the kiln by opening the bottom opening.

### 3.6.2. Conversion Efficiency of Raw Khat Waste into Carbonized Material

After sample pre-treatment was completed, it carbonized in the 200 L Kiln that found in Jimma Agricultural Engineering Research Center. Samples of khat waste carbonized separately in an oxygen-scarce barrel of 200 L by repeating three times for 9, 18 and 27 kg.

After grounding carbonized, material prepared from *khat* waste sample putted under sun light to remove the moisture added during fire avoiding. It well dried to grinded and changed to powder simply. Also drying well used to measure and calculate of carbonization conversion efficiency.

For each treatment, 9, 18 and 27 kg sample of raw *khat* waste carbonized separately in an oxygen-scarce environment repeating three times for each sample. The conversion efficiency (CE) of row *khat* waste into carbonized material calculated according to (Merete *et al.,* 2014 and Pari *et al.,* 2004).

To calculate the conversion efficiency, the samples grounded from the 200 L kiln measured after dried under sun light well. Drying was needed for removing the moisture added during the release of water from carbonized material. Measuring of the carbonized material for calculation of conversion efficiency was take place after well dried. The calculation of conversion efficiency was for each sample of 9, 18 and 27 kg done.

$$\text{CE of Khat waste } (\%) = \frac{\text{weight of carbonized } khat \text{ waste}}{\text{weight of raw khat waste}} \text{x100}$$

### 3.6.3. Briquetting the Carbonized Sample

After carbonize and measure for conversion efficiency, the samples were grinded into mill that found in Jimma Agriculture Engineering Research Center to reduce the size of carbonized material to the powder, as it is simply bind with binder. The motorized engine machine used to rotate the mill machine. To briquette, the grinded samples the binder produced from banana peels added in the ratio of 1:3, 1:4 and 1:5 (binder to char) and mixed well.

After mixing well, molding was take place using briquette machine that also found in Jimma Agriculture Engineering Research Center. The briquette machine that used was hand manually operated machine.

The molded samples dried into the oven dry machine separately as their code given first and dried for the determination of proximate characteristics, bulk density, sulfur content and calorific value.

#### 3.6.4. Proximate Analysis

**Moisture Content (MC)**

The moisture content of the briquette was determined by heating each sample of briquette in different mixing ratio to 105 ℃ to a constant mass and the moisture computed on weight basis as (Merete *et al.,* 2014). The oven-drying machine that found in Jimma Agricultural Engineering Research Center used to dry the briquetted samples for 1 hour at temperature of 105 ℃.

$$\text{MC (\%)} = \frac{\text{weight of sample (g)} - \text{oven dry weight of sample (g)}}{\text{weight of briquette sample (g)}} x100$$

Where: MC (%) = Moisture content in percent;

Weight of sample = Weight of crucible + weight of briquette sample;

Oven dried weight of sample = Weight of sample at 105 ℃.

**Volatile Matter (VM)**

The volatile matter of the briquette was determined by heating an oven-dried sample in absence of oxygen at 950 ℃ for six minutes. To dry the samples the oven dry machine found in Geological Survey of Ethiopia was used. The volatile matter computed as the difference between the initial and final weight of the sample to the ratio of weight of the briquette samples as (Merete *et al.*, 2014).

$$\text{VM (\%)} = \frac{\text{Weight of sample at 105 ℃ (g)} - \text{Weight of sample (g)at 950 ℃}}{\text{Weight of briquette sample (g)}} \text{x100}$$

Where, VM (%)= Volatile Matter in Percent.

**Ash Content (AC)**

Ash content of the briquette was determined by heating the briquette sample in a crucible at 750℃ for three hours in the oven. The oven dry machine that used to dry the samples found in Geological Survey of Ethiopia. The ash content calculated as the proportion of the weight of the ash in the briquette to the weight of briquette sample as (Merete *et al.,* 2014).

$$AC\ (\%) = \frac{\text{Weight of sample at 750 °C} - \text{Weight of sample (g) at 950 °C}}{\text{Weight of briquatte sample (g)}} x100$$

Where, AC (%) = Ash content in Percent

**Fixed Carbon (FC)**

The percentage of fixed carbon content of the briquettes was computed by subtracting the sum of volatile matter (VM), ash content (AC), and moisture content (MC) from 100 as (Merete *et al.*, 2014). It means that, to calculate the fixed carbon content (FC), calculating other proximate characteristics such as MC, VM and AC needed.

$$\text{FC}\ (\%) = 100 - [\text{MC}\ \% + \text{VM}\ \% + \text{AC}\ \%]$$

Where: FC (%) = Fixed carbon content in percent.

### 3.6.5. Determination of Bulk Density, Sulfur Content and Calorific Values

**Bulk Density (BD)**

The bulk density of the briquetted sample from *khat* waste with each mixing ratio calculated as the ratio of the mass in gram of the briquette to the volume in centimeter cube of the briquette. The volume of the briquette sample gained from measuring the height and diameter of the briquetted sample.

$$\text{BD}\left(\frac{\text{g}}{\text{cc}}\right) = \frac{\text{mass of briquette sample}}{\text{volume briquette sample}}$$

Where: BD$\left(\frac{\text{g}}{\text{cc}}\right)$ = Bulk density in gram per cubic centimeter.

**Sulfur Content (SC)**

Sulfur content of briquetted samples from *khat* waste with each mixing ratio was measured using Parr (1241) Adiabatic Oxygen Bomb calorimeter through calorimetric combustion of the briquette sample as (Merete *et al.,* 2014). The machine called Parr (1241) Adiabatic Oxygen Bomb calorimeter found in Geological Survey of Ethiopia.

$$SC\ (\%) = \frac{[\text{Weight difference} - \text{Blank}] \times 13.73}{\text{Weight of briquette sample}} x100$$

Where: SC (%) = Sulfur content in percent;

Weight difference = Weight at $825^0$C - Weight of crucible;

Blank = 0.0002

**Calorific Value (CV)**

The calorific value of each mixing ratio briquetted sample measured using Parr (1241) Adiabatic Oxygen Bomb calorimeter as Merete *et al.*, 2014 and Bogale, 2017. The machine Parr (1241) Adiabatic Oxygen Bomb calorimeter that used to calculate CV found in Geological Survey of Ethiopia.

$$\text{CV (cal/g)} = \frac{\Delta T \times 2420 - [\text{wire burn} \times 2.3 + \text{Titration} + \text{Sulfur}]}{\text{Weight of briquette sample}}$$

Where: $\text{CV (cal/g)}$ = calorific value in calorie per gram;

$\Delta T$ = Final temperature – Initial temperature and

Sulfur = SC* Weight of briquette sample*13.378.

## 3.7. Study Variables

The sources of the study are different measurement and observation to select the specific location of the variables. In the case of this study, different dependent and independent variables will used to achieve the main and specific objectives of the research as input and as output.

### 3.7.1. Dependent Variables

To address the main and specific object of the research dependent variables are so many advantageous key points. For this study, eco-friendly charcoal production or charcoal production from *khat* waste/ alternative eco-friendly energy production that to proceed using independent variables is termed as dependent variables.

### 3.7.2. Independent Variables

As stated in dependent variables, also independent variables are use full for the research to achieve the main goal as process input or output from starting up to end of the research. For this research, independent variables are amount of *khat* waste, carbonizing temperature, carbonizing time, calorific value, carbon content, ash content, moisture content, volatile matter, carbonize efficiency, bulk density and sulfur content.

## 3.8. Data Quality Assurance

In order to achieve the quality of the sample researcher was prepare a site book to check every day progress. Moreover, assistants was selected to handle the *khat* waste sample carefully and check the calibration of the instruments as it is on standard condition for each step. The collected sample also checked for reliability and accuracy up to results. For the quality of generated data from the sample, calculated and triplicate measurement result was reported in average as $\text{mean}\,(\overline{\text{X}}) \pm \text{standerd devation}\,(\text{SD})$ for carbonize efficiency, for each proximate characteristics and for energy potential.

## 3.9. Ethical Considerations

The research and data collection conducted after approval given from the civil and environmental engineering faculty and JIT to precede the work. Before the collection of the sample, the purpose of the sample collection clearly described to the organizations by the sample collector. The sample collected based on the willingness of the organizations to give information. The sample kept confidential and used only for the research purpose.

# 4. RESULT AND DISCUSSION

## 4.1. Conversion of *Khat* Waste into Carbonized Material

The result of carbonized materials and briquetted charcoal from taken samples of *khat* waste using banana peels as a binder was experimentally, done and shown as on the figure 4.1 below as it is combustible.

Figure 4.1 Combustible charcoal briquettes gained from *khat* waste pyrolysis result

### 4.1.1. Conversion Efficiencies

From 9 kg of dried samples, 4.67 ± 0.09 kg of carbonized material gained and conversion efficiency of raw *khat* waste into carbonized material calculated and 51.89 ± 1.02 % gained. From 18 kg of dried samples, 10.18 ± 0.28 kg of carbonized material gained and conversion efficiency of raw *khat* waste into carbonized material calculated and 56.55 ± 1.57 % was gained. From 27 kg of dried samples, 14.12 ± 0.12 kg of carbonized material gained and conversion efficiency of raw *khat* waste into carbonized material calculated and 52.28 ± 0.46 % was gained.

Therefore, the average conversion efficiencies gained in this research were 52.28 ± 0.46, 56.55 ± 1.57 and 51.89 ± 1.02 % from 9, 18 and 27 kg of raw *khat* waste respectively as shown on figure 4.2. The results show that amount of raw *khat* waste that carbonized has influence on conversion efficiency. The best and give good efficient raw *khat* waste amount to carbonize into 200 L kiln is 18 kg and give 56.55 ± 1.57 % carbonized material. It also meets with the amount of flower waste, which carbonized from 18 kg of raw flower waste by (Bogale, 2017) and gain 10 kg of carbonized material which conversion efficiency was 55.5 %.

Conversion efficiencies gained from this research were greater than that of coffee pulp and husk, which carbonized from 19 kg of raw coffee husk and pulp by (Merete *et al.*, 2014) which gave conversion efficiency of 32.39 and 31.18 % respectively. In addition, it is greater than traditionally used which is less than 15 % (Girmay *et al.*, 2014).

In Ethiopia, charcoal commonly produced using the traditional earth kiln method, earth mound kiln and earth pit kiln. Earth mound kiln were being the most frequent method with an efficiency of 10 – 15 %. It has to note those high amounts of gases and other unburned hydrocarbons released into the atmosphere. This traditional technology is inefficient and leads to deforestation since most of the people use woody biomass to produce charcoal in Ethiopia (Girmay *et al.*, 2014).

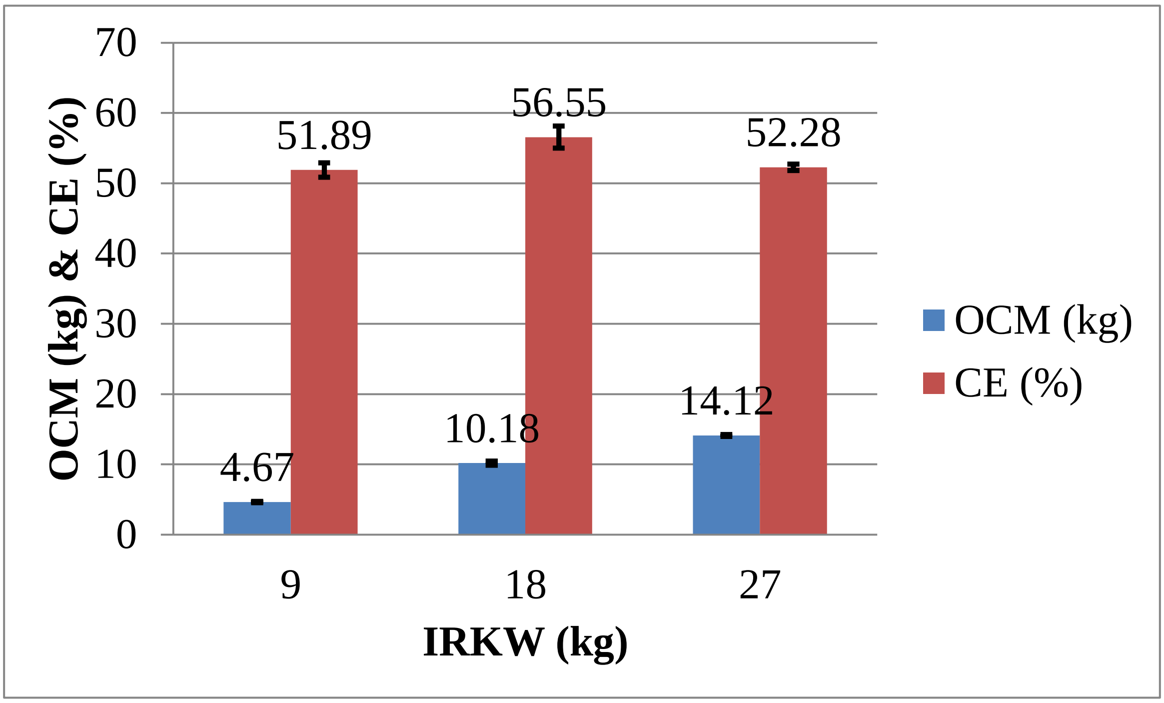


Figure 4.2 Conversion efficiency of charcoal from 9, 18 and 27 kg of RKWS

#### 4.1.2. Conversion Temperature and Time

As shown on the graph of figure 4.3, 4.4 and 4.5 for this study, the temperature of the kiln increased from 25 to 200, 25 to 325 and 25 to 450 °C within the time of 35, 50 and 70 minutes and started declined after that for 9, 18 and 27 kg of the raw khat waste sample respectively.

For 9 kg of *khat* waste sample, temperature variation of the barrel was from 25 to 200 °C within 35 minutes. After 35 minutes, the temperature of the 200 L Kiln decreased starting from maximum temperature of 200 to 192 °C. When the temperature of the barrel read around 200 °C the smoke that comes out from the chimney was stopped as on figure 4.3. For 18 kg of khat waste sample, temperature variation of the barrel was from 25 to 325 °C within 50 minutes. After 50 minutes, the temperature of the 200 L kiln decreased starting from maximum temperature of 325 to 301 °C within 10 minutes as shown on figure 4.4.

Again, when the temperature of the barrel read around 325 °C the smoke that come out from the chimney stopped. As shown on figure 4.5 for 27 kg of *khat* waste sample, temperature variation of the barrel was from 25 to 450 °C within one hour and 10 minutes. After one hour and 10 minutes, the temperature of the 200 L kiln decreased starting from maximum temperature of 450 to 425 °C within 10 minutes. In addition, when the temperature of the barrel read around 450 °C the smoke that out from the chimney stopped again.

In general, from each trial when the smoke come out from the chimney stopped and temperature starting declined, it implies that all raw samples of *khat* waste were become carbonized.

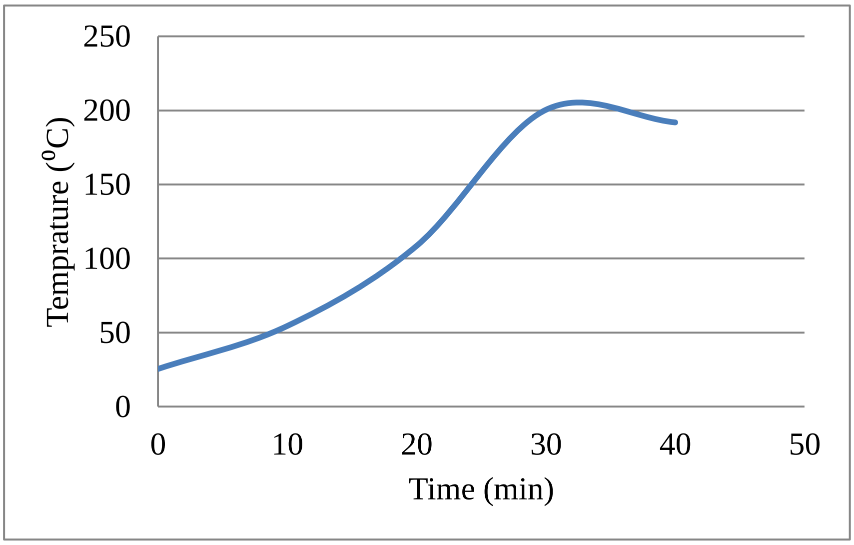


Figure 4.3 Graph shows carbonization temperature and time of 9 kg KWS

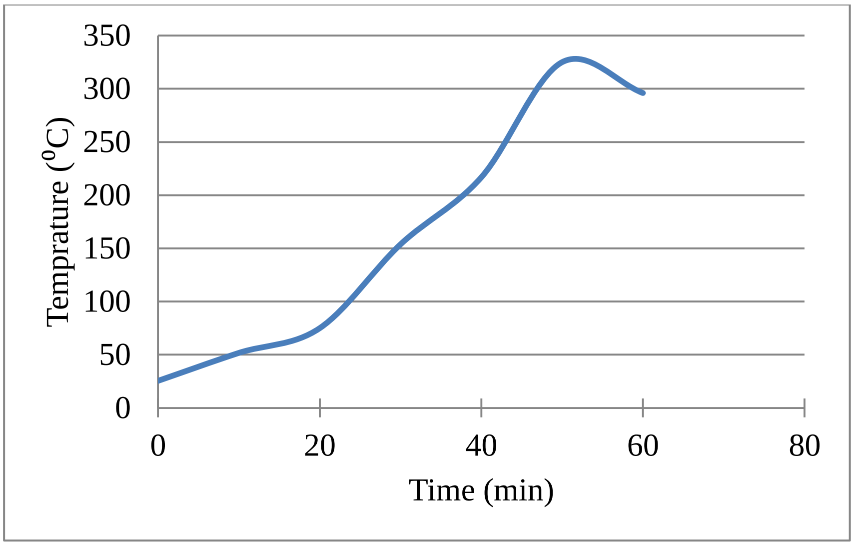


Figure 4.4 Graph shows carbonization temperature and time of 18 kg KWS

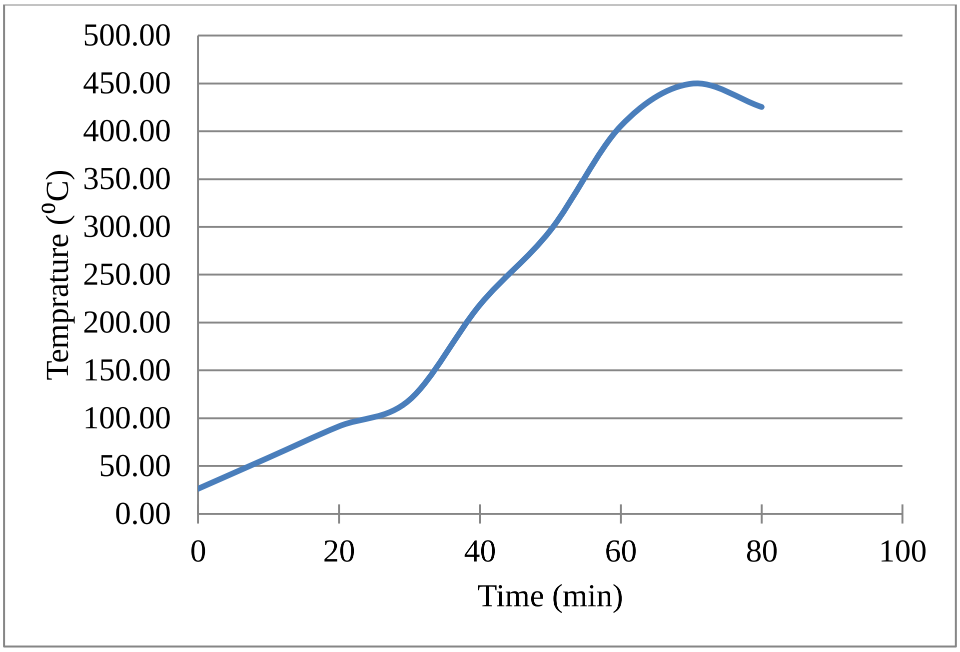


Figure 4.5 Graph shows carbonization temperature and time of 27 kg KWS

## 4.2. Proximate Analysis

### 4.2.1. Moisture Content (MC)

The MC of the briquette was determined by heating each samples of briquette to 105 ℃ to a constant mass and the results are 17.04 ± 0.94, 25.60 ± 0.59, 8.05 ± 0.22, 19.56 ± 0.51, 7.89 ± 0.23 and 17.21 ± 1.47 % for the ratios of 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water to BP to CKWM) respectively as shown by graph on figure 4.6. The average MC of the briquettes produced in this research with the ratios of 0.33:0.67:5 and 0.33:0.67:4 (water-BP-CKWM) are 8.05 ± 0.22 and 7.89 ± 0.23 % which are smaller than the MC of briquettes produced from rice husk and corncob, which were 12.67 % and 13.47 % respectively (Oladeji, 2010). The quality specification of charcoal usually limits the moisture content between 5-15 % (FAO, 1987).

Therefore, the MC of briquettes obtained in this research with the ratios of 0.33:0.67:5 and 0.33:0.67:4 (water to BP to CKWM) are 8.05 ± 0.22 and 7.89 ± 0.23 are in line with FAO 1987 specification while the MC gained from other mixing ratios are failed due to greater than 15 %. However, to facilitate heat transfer, moisture content should be as low as possible (USAID, 2010).

The average MC results done in this research reported as for different mixing ratios of binder and CKWM.

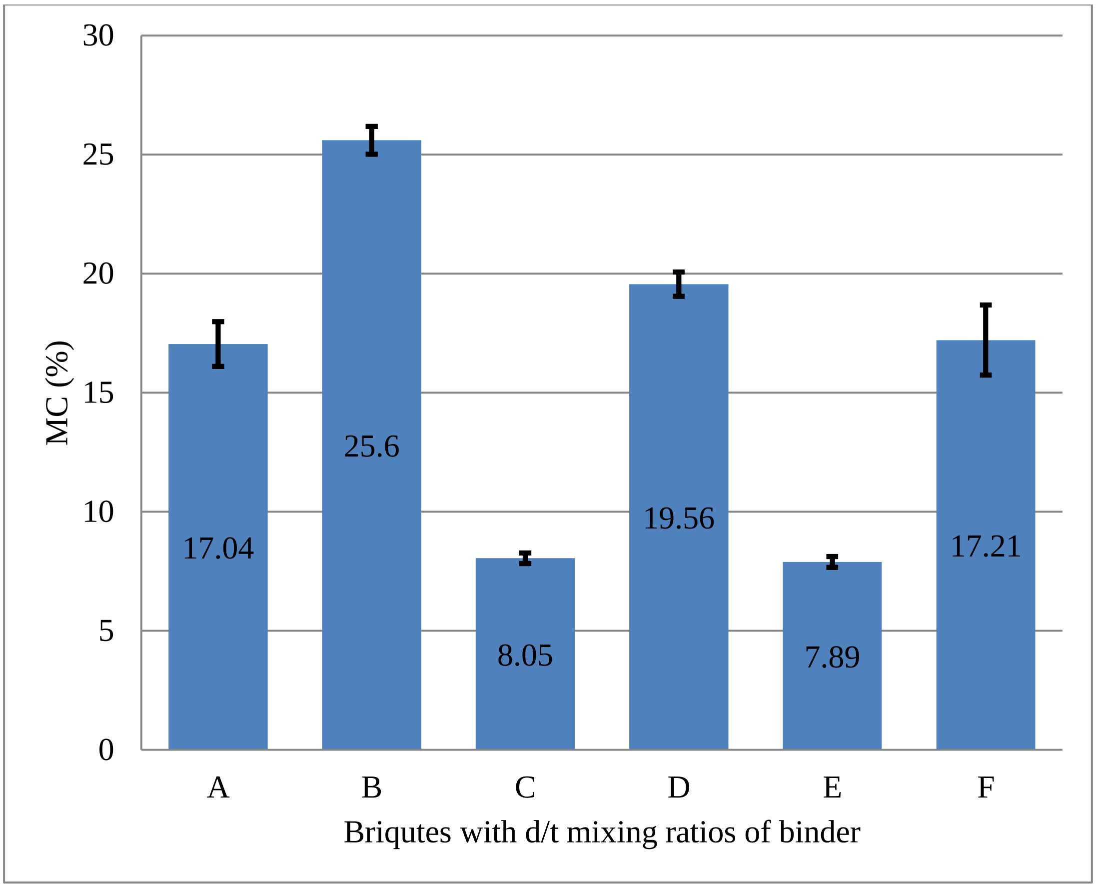


Figure 4.6 Results of MC with different ratios of binder-CKWM

### 4.2.2. Volatile Matter (VM)

The VM gained from the briquetted sample of the different mixing ratios are 14.46 ± 0.69, 12.00 ± 0.26, 18.32 ± 0.27, 12.68 ± 0.35, 21.33 ± 1.25 and 20.08 ± 0.46 % from 0.33 : 0.67 : 3, 0.67 : 0.33 : 3, 0.33 : 0.67 : 4, 0.67 : 0.33 : 4, 0.33 : 0.67 : 5 and 0.67 : 0.33 : 5 (water- BP-CKWM) respectively as shown on figure 4.7. The volatile matters of briquettes gained from this study are lower than the volatile matter of briquettes gained from rice husk, which was 67.98 % (Oladeji, 2010). However, the volatile matter of charcoal can vary from 5 – 40 % but good commercial charcoal has net volatile matter content of about 30 % (FAO, 1987). Hence, the volatile matters of all briquettes obtained from this study are in line with this criterion. Briquettes containing large amounts of volatile matter are highly combustible. However, highly volatile charcoal is easy to ignite but may burn with a smoke flame. Low volatile charcoal is difficult to ignite but delivers very clean heat (Sotannde *et al.*, 2010).

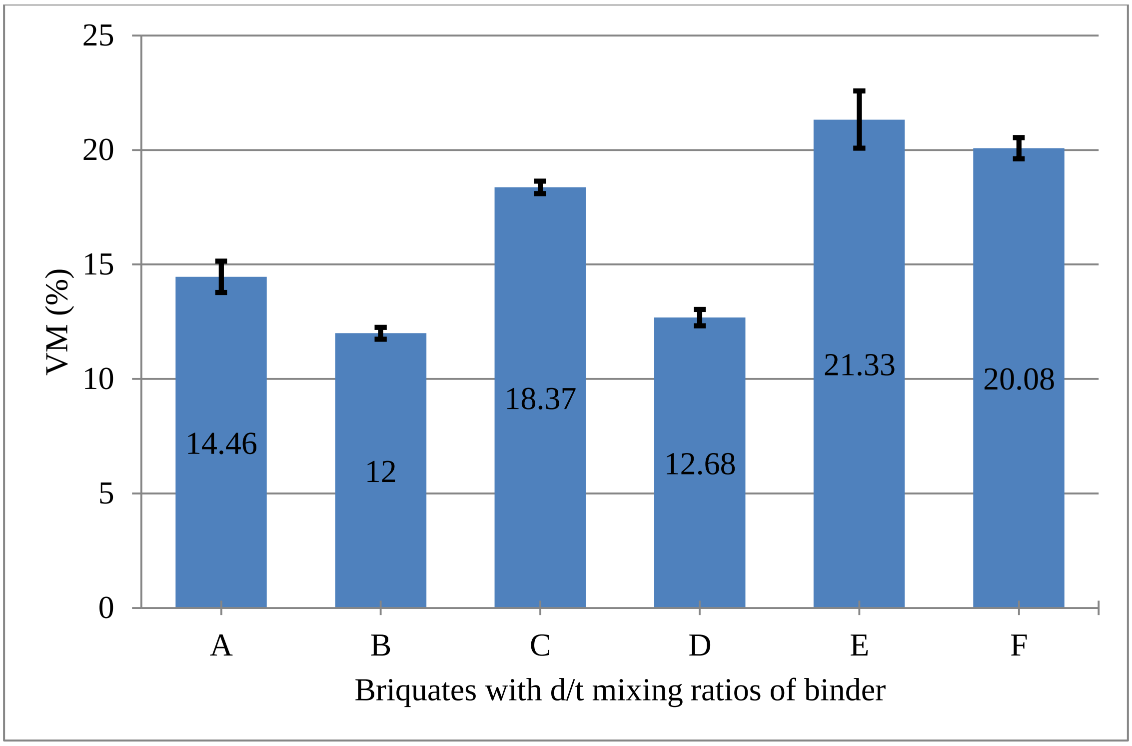


Figure 4.7 Results of VM with different ratios of binder-CKWM

### 4.2.3. Ash Content (AC)

The ash content of the briquettes in this research with different mixing ratios are 20.13 ± 0.53, 17.21 ± 0.59, 16.24 ± 0.34, 14.16 ± 0.36, 16.68 ± 0.47 and 15.56 ± 0.22 % from 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water to BP to CKWM) respectively as shown on figure 4.8.

All gained results are higher than the ash content of briquettes produced from Hazelnut shell, which was 7 % (Yaman, 2010). Yet, a typical ash content of fine, quality lump charcoal is about 3 % (FAO, 1987). However, the ash contents of the briquettes produced in this research were greater than the specified range. This might be due to the effect of the binder used to bind the ground-carbonized material that was not carbonized (raw banana peels waste).

The ash content is an indicator of slugging behavior of the biomass. Hence, the larger the ash content, the larger will be the slugging behavior. However, this is not always true since a slugging behavior can also depends on the temperature of operation, the mineral compositions and their percentage (Mishra, 1996).

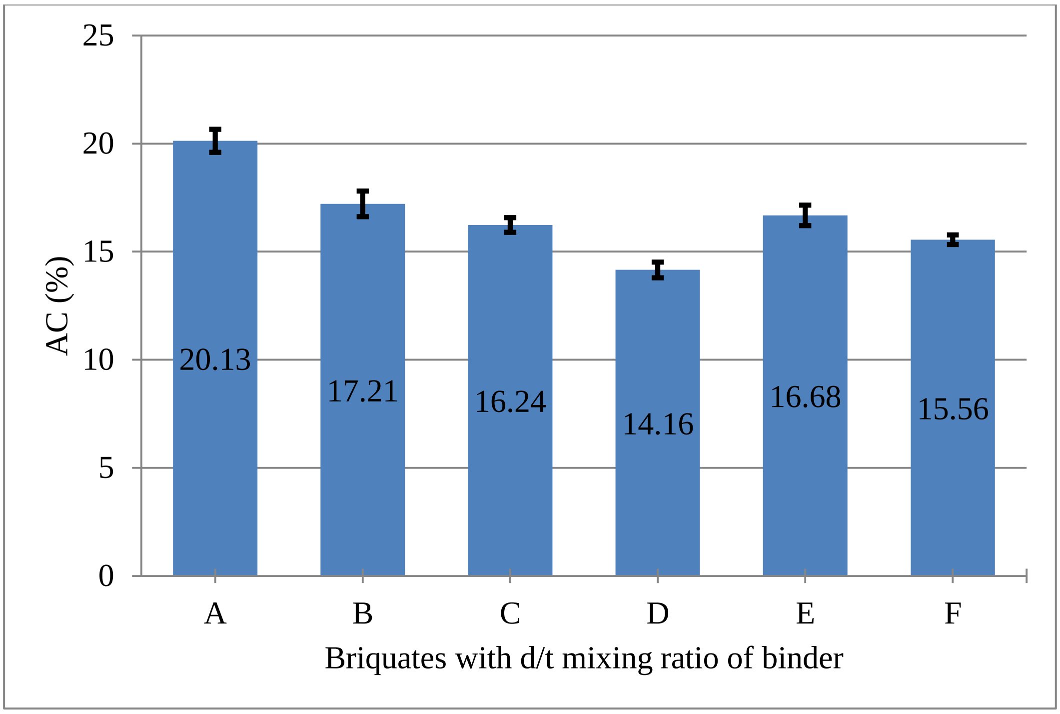


Figure 4.8 Results of AC with different ratios of binder-CKWM

### 4.2.4. Fixed Carbon (FC)

The FC of the briquettes carbonized *khat* waste with different mixing ratios obtained in this research are 48.37 ± 0.86, 45.19 ± 1.24, 57.33 ± 0.38, 53.60 ± 0.52, 54.09 ± 1.40 and 47.15 ± 1.36 % with mixing ratios of 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water- BP- CKWM) respectively as show on figure 4.9.

The FC gained in this research with the mixing ratios of 0.33:0.67:4, 0.67:0.33:4 and 0.33:0.67:5 (water to BP to CKWM) almost related with the fixed carbon content of briquettes produced from Limmu and Teppi coffee husk which were fixed carbon content of 57.71 ± 2.41 and 58.95 ± 2.80 %. However, greater than carbon content of briquettes produced from Limmu and Teppi coffee pulp which were 42.4 ± 1.42 and 45.38 ± 2.77 % respectively (Merete *et al.*, 2014).

Nevertheless, the FC with the ratios of 0.33:0.67:3, 0.67:0.33:3 and 0.67:0.33:5 (water-BP-CKWM) are approach with the results from Limmu and Teppi coffee pulp. In addition, less, than the fixed carbon content produced from flower wastes that a fixed carbon content of 67.91 % (Bogale, 2017).

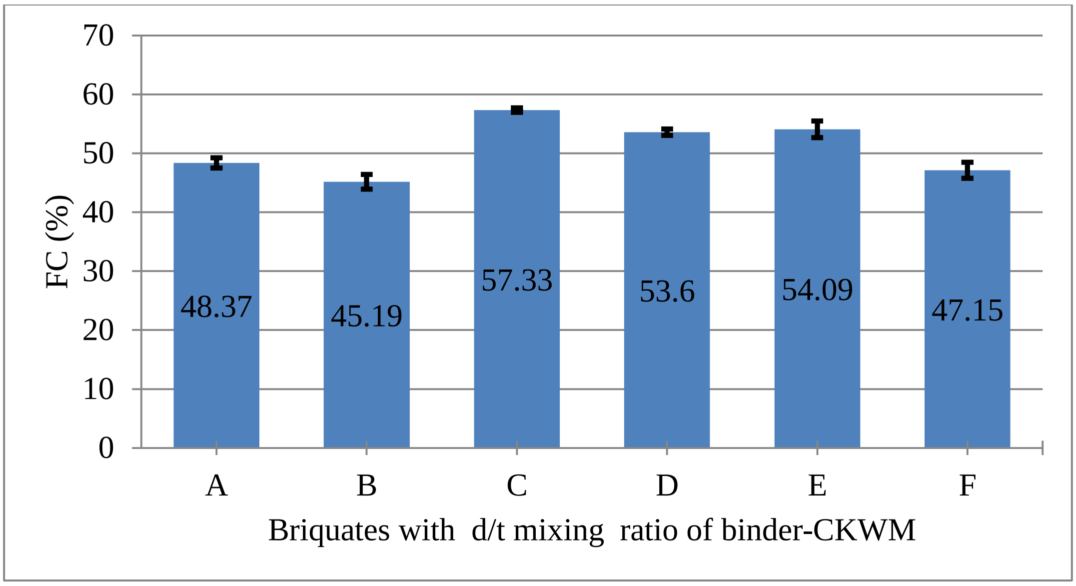


Figure 4.9 Results of FC with different ratios of binder-CKWM

From gained result the mixing ratios of 0.33:0.67:4 (Water to BP to CKWM) is the best option due to the maximum results of FC percentage recorded was the maximum than all other options, which is 57.33 ± 0.38 %. Also, has low MC with relative low AC and high VM, which all these are in line with (FAO, 1987 and USAID, 2010).

Generally, all proximate characteristics changed with changing of mixing ratios of binder and CKWM. As the result shows for this study, MC increased with increasing of water ratios. VM and FC increased with increasing banana peels and char dust while AC increased with increasing of banana peel.

Table 4.1 Result of proximate characteristics analysis with different mixing ratios

| Code | Water : BP : CKWM | MC (%) | VM (%) | AC (%) | FC (%) |
|---|---|---|---|---|---|
| A | 0.33 : 0.67 : 3 | 17.04 ± 0.94 | 14.46 ± 0.69 | 20.13 ± 0.53 | 48.37 ± 0.86 |
| B | 0.67 : 0.33 : 3 | 25.60 ± 0.59 | 12.00 ± 0.26 | 17.21 ± 0.59 | 45.19 ± 1.24 |
| C | 0.33 : 0.67 : 4 | 8.05 ± 0.22 | 18.32 ± 0.27 | 16.24 ± 0.34 | 57.33 ± 0.38 |
| D | 0.67 : 0.33 : 4 | 19.56 ± 0.51 | 12.68 ± 0.35 | 14.16 ± 0.36 | 53.60 ± 0.52 |
| E | 0.33 : 0.67 : 5 | 7.89 ± 0.23 | 21.33 ± 1.25 | 16.68 ± 0.47 | 54.09 ± 1.40 |
| F | 0.67 : 0.33 : 5 | 17.21 ± 1.47 | 20.08 ± 0.46 | 15.56 ± 0.22 | 47.15 ± 1.36 |

## 4.3. Determination of Bulk Density, Sulfur Content and Calorific Values

### 4.3.1. Bulk Density (BD)

The bulk density of the briquettes with different mixing ratios obtained from this research are 0.59 ± 0.02, 0.76 ± 0.05, 0.61 ± 0.01, 0.67 ± 0.03, 0.58 ± 0.00 and 0.70 ± 0.03 cc/g from the relatives mixing ratio of 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water-BP- CKWM) respectively as shown on figure 4.10.

The BDs gained from this research with all used different mixing ratios are greater than the BD of briquettes produced from elephant grass, which had a corresponding value 0.319 cc/g (Onegbu *et al*., 2012).

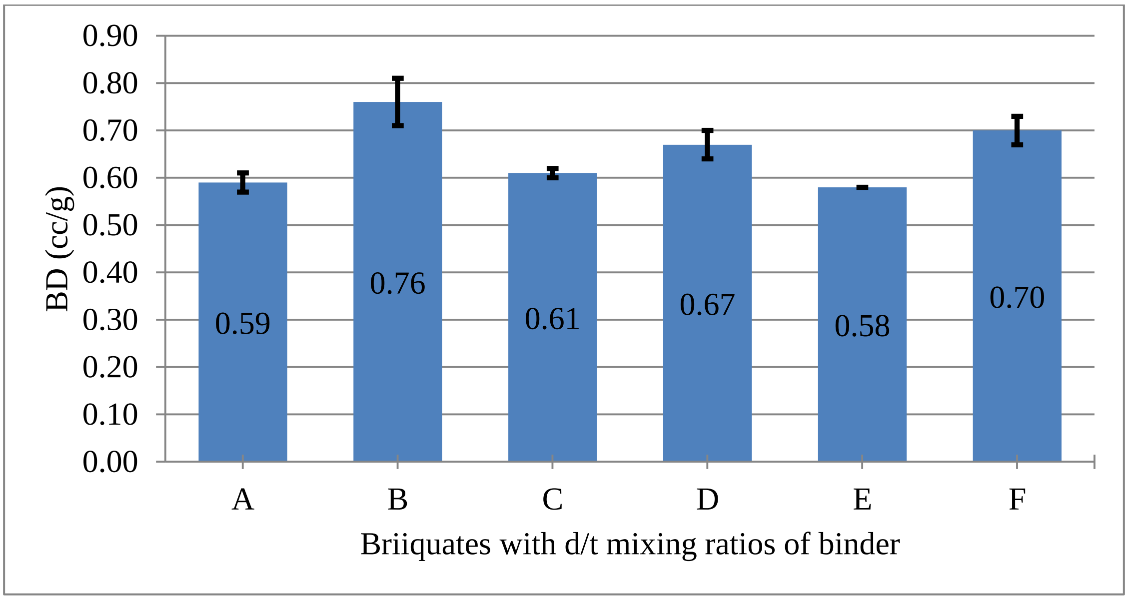


Figure 4.10 Results of BD with different ratios of binder-CKWM

### 4.3.2. Sulfur Content (SC)

Charcoal briquettes produced from *khat* waste in this research have 0.0698 ± 0.0063, 0.0657 ± 0.0029, 0.0602 ± 0.0050, 0.0599 ± 0.0031, 0.0607 ± 0.0030 and 0.0589 ± 0.0051 % sulfur content from the mixing ratios of 0.33 : 0.67 : 3, 0.67 : 0.33 : 3, 0.33 : 0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water- BP- CKWM) respectively as shown on graph of figure 4.11.

The SCs gained from this research in all used mixing ratio are lower than briquettes produced from rice husk that had a sulfur content of 0.82 % (Oladeji, 2010). The lower sulfur content in the charcoal briquettes produced from *Khat* waste is promising in terms of minimal potential to release sulfur, which would reduce indoor air pollution and the formation of acid rain (Ciubota-Rosie *et al*,. 2008).

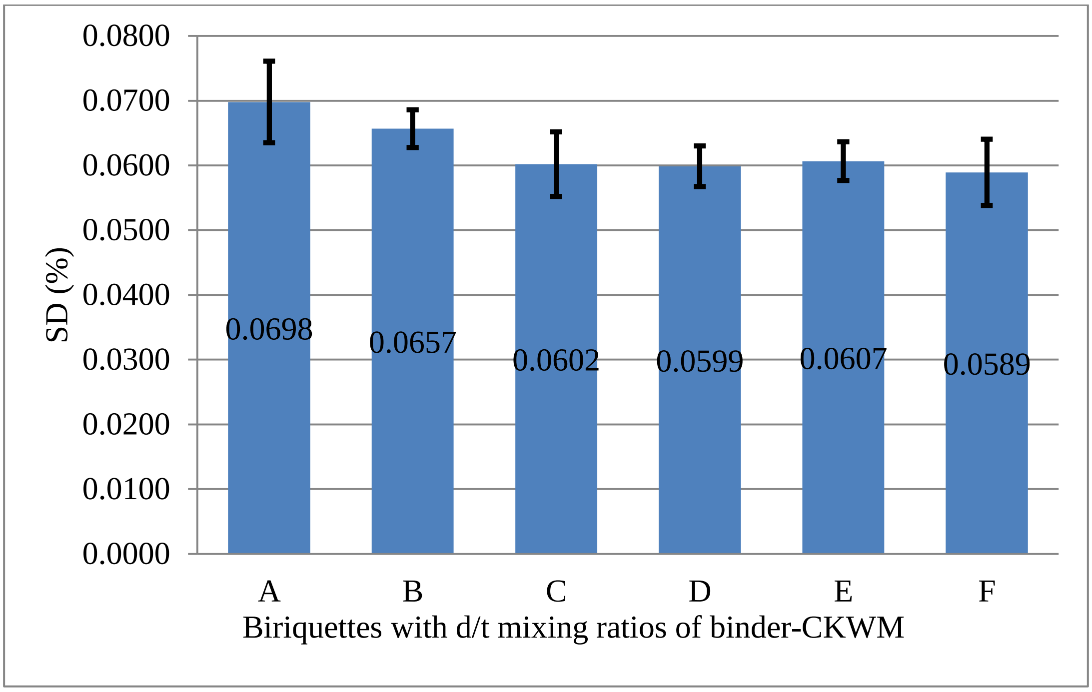


Figure 4.11 Results of SC with different ratios of binder-CKWM

#### 4.3.3. Calorific Value (CV)

The CVs of the charcoal briquettes obtained in this study are 20.29 ± 0.23, 20.66 ± 0.15, 23.80 ± 0.03, 21.16 ± 0.08, 22.92 ± 0.23 and 21.53 ± 0.08 KJ/g with mixing ratios of 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (water-BP-CKWM) respectively as show on the graph of figure 4.12.

All gained values of CV in this research from charcoal briquettes of khat waste are greater than the CV of briquettes gained from Elephant grass that 15.97 (Onuegbe et al., 2012), from coffee husk and pulp which have CV of 21.09 ± 0.71 and 16.89 ± 0.92 KJ/g (Merete et al., 2014). In addition, all charcoal briquettes produced in this study have higher CV than wood, which has a calorific value of 13.79 KJ/g (FAO, 1999).

However, charcoal briquettes produced from Coal-sawdust with the ratios of 50:50, 33:66 and 25:75 with CV of 32.10, 31.6 and 32 KJ/g (Blesa et al., 2003) which have greater CV than gained in this study of all mixing ratios.

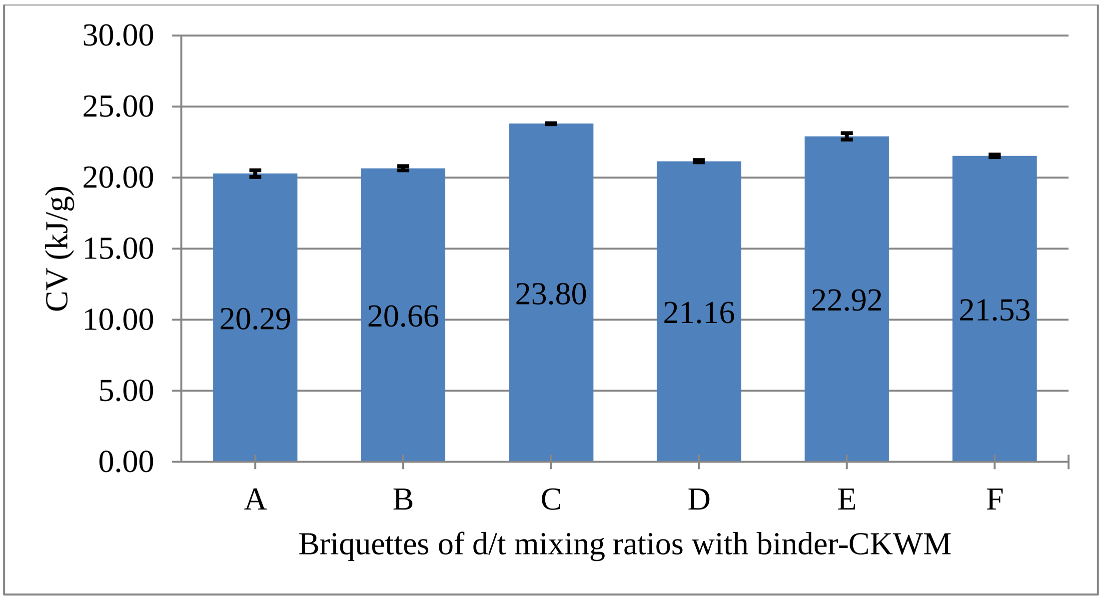


Figure 4.12 Results of MC with different ratios of binder-CKWM

Where; A, B, C, D, E and F are mixing ratios of water-BP-CKWM with 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 respectively.

When compare for such mixing ratios, relatively increasing the water decrease the calorific values and more of less increase sulfur content but increase bulk density. In general, for changing such mixing ratios of briquetted charcoal from *khat* waste, no more changes on BD and SC but some changes on CV.  However, increasing of carbonized *khat* waste material ratios into mix causes crack and not efficiently briquetted.

Generally, the bulk density, sulfur content and calorific value of briquetted charcoal produced from *khat* waste with different mixing ratios of the binder had summarized as in the table 4.10.

Table 4.2 Result of BD, SC and CV with different mixing ratios of binder-CKWM

| Code | Ratios (Water : BP : CKWM) | BD(cc/g) | SC (%) | CV (KJ/g) |
|---|---|---|---|---|
| A | 0.33 : 0.67 : 3 | 0.59 ± 0.02 | 0.0698±0.0063 | 20.29±0.23 |
| B | 0.67 : 0.33 : 3 | 0.76 ± 0.05 | 0.0657±0.0029 | 20.66±0.15 |
| C | 0.33 : 0.67 : 4 | 0.61 ± 0.01 | 0.0602±0.0050 | 23.80±0.03 |
| D | 0.67 : 0.33 : 4 | 0.67 ± 0.03 | 0.0599±0.0031 | 21.16±0.08 |
| E | 0.33 : 0.67 : 5 | 0.58 ± 0.00 | 0.0607±0.0030 | 22.92±0.23 |
| F | 0.67 : 0.33 : 5 | 0.70 ± 0.03 | 0.0589±0.0051 | 21.53±0.08 |

## 4.4. Comparison of the Results with Different Authors

### 4.4.1. Comparison of CE, CT and Ct

Different studies were done on charcoal production from different biomass sources using traditional method from forest trees in earth mound kiln and others use technology such as barrel kiln, bricks mound kiln and metal house kiln to carbonize. During carbonization, the carbonization efficiency, carbonizing temperature and time are different for different carbonized biomass and carbonizing method.

As compared with further study, CE of *khat* waste has good result, which is 56.55 ± 1.57 % that produced from 18 kg of RKW. It meets with the result of CE gained from flower waste done by (Bogale, 2017) from 18 kg of flower waste, which CE was 55.5 % and (Carnaje *et al.*, 2018) produce charcoal briquettes from water hyacinth and resulted CE of 55 %.

In addition, so many studies done on producing charcoal briquettes from different biomass, which their percent of CE are lower than percent CE of charcoal briquettes produced from *khat* waste in this study. Charcoal briquettes produced from coffee husk and pulp by (Merete, 2014) with CE of 31.18 and 32.39 % respectively. Charcoal briquettes produced from cotton stalk (NL Agency, 2017) with CE of 25 %.

In addition to percent of CE, CT of *khat* waste is 325 ℃, which is less than CT of Water hyacinth, which were 425 ℃ by (Carnaje *et al.*, 2018) and CT of flower waste, which were 400 ℃ by (Bogale, 2017).

Therefore, some studies CE, CT and Ct results compared with this study results shown as in the table 4.3.

Table 4.3 Comparison of CE, CT and Ct

| Biomass | Input raw material (kg) | Output carbonized material(kg) | CE (%) | CT (℃) | Ct (min) | References |
|---|---|---|---|---|---|---|
| Water hyacinth | NA | NA | 55 | 425 | | Carnaje *et al.*, 2018 |
| Flower waste | 18 | 9.99 | 55.5 | 400 | | Bogale, 2017 |
| Coffe husk | 19 | 6.05 | 32.39 | NA | NA | Merete *et al.*, 2014 |
| Coffee pulp | 19 | 5.97 | 31.18 | NA | NA | Merete *et al.*, 2014 |
| Cotton stalks | 100 | 25 | 25 | NA | NA | NL Agency, 2017 |
| Bamboo | NA | NA | 30 | NA | NA | NL Agency, 2017 |
| *Khat* waste | 9 | 4.67±0.09 | 51.89±1.02 | 200 | 35 | This research |
| *Khat* waste | 18 | 10.18±0.28 | 56.55±1.57 | 325 | 50 | This research |
| *Khat* waste | 27 | 14.12±0.12 | 52.28±0.46 | 450 | 70 | This research |

#### 4.4.2. Comparison of FC, VM, MC, AC and CV

As it described on different studies the proximate characteristics and heating values of charcoal briquettes are depend on type of biomass that charcoal are made from, type of binder and its mixing ratios. Therefore, different results of charcoal briquettes produced from different biomass with different binder type and different mixing ratios compared as in the table 4.4 shown. When compare charcoal briquettes from *khat* waste with briquettes from other biomass that produced by using different binder type and different ratios briquettes produced from *khat* waste with 1:4 (binder-CKWM) ratios especially with 0.33:0.67:4 (water-BP-CKWM) is the best due to it gives the greatest percent of FC. Charcoal briquettes produced from sawdust by using coal as a binder (Blesa *et al.*, 2003) and from wood sawdust using cow dung as a binder (Emerhi, 2011) have greater FC and CV amount than briquettes from khat waste using banana peels as a binder. But charcoal briquettes from bagasse using clay and molasses as a binder (Onchieku *et al.*, 2012) and from WH using molasses as a binder (Carnaje *et al.*, 2018) have less FC and CV amount than briquettes from *khat* waste using banana peels as a binder with 0.33:0.67:4 mixing ratios.

In generally, the comparison of this study with the other studies for FC, VM, MC, AC and CV summarized as in table 4.4.

Table 4.4 Comparison of FC, VM, MC, AC and CV for different biomass charcoal briquettes using different binders of mixing ratios

| Briquette type (biomass: binder) | BBR | FC (%) | VM (%) | MC (%) | AC (%) | CV (kJ/g) | References |
|---|---|---|---|---|---|---|---|
| Coal-sawdust | 50:50 | 79.5 | 11.0 | 1.7 | 7.83 | 32.10 | Blesa *et al.*, 2003 |
| Coal-sawdust | 33:66 | 85.0 | 7.8 | 0.9 | 6.3 | 31.60 | Blesa *et al.*, 2003 |
| Coal-sawdust | 25:75 | 85.9 | 7.3 | 1.1 | 5.7 | 32.00 | Blesa *et al.*, 2003 |
| Coffee husk-clay soil | 3:1 | 58.25 ±2.8 | 22.32 ±2.8 | 6.18 ±0.2 | 12.5 ±0.5 | 21.09 ±0.71 | Merete *et al.*, 2014 |
| Coffee pulp-clay soil | 3:1 | 42.40 ±1.42 | 24.12 ±1.55 | 11.3 ±2.2 | 22.1 ±1.0 | 16.89 ±0.92 | Merete *et al.*, 2014 |
| Wood sawdust-cow dung | 70:30 | 75.7 | 11.1 | NA | 14.9 | 28.60 | Emerhi, 2011 |
| Bagasse-clay-molasses | 40:1:1 | 36.4 | 27.2 | 4.1 | 36.4 | 18.40 | Onchieku *et al.*, 2012 |
| WH-molasses | 40:60 | 45.8± 0.6 | 13.2± 1.3 | 14.6 ±0.3 | 26.2 ±1.0 | 15.90 ±3.90 | Carnaje *et al.*, 2018 |
| WH-molasses | 30:70 | 47.4± 1.5 | 15.0± 1.2 | 18.1 ±0.1 | 19.5 ±2.6 | 16.60 ±2.10 | Carnaje *et al.*, 2018 |
| WH-molasses | 20:80 | 48.00 ±2.20 | 16.8± 0.8 | 18.6 ±0.2 | 16.5 ±2.3 | 13.45 ±1.60 | Carnaje *et al.*, 2018 |
| Water-BP-CKWM | 0.33:0.67:3 | 48.37 ±0.86 | 14.5± 0.7 | 17.0 ±0.9 | 20.1 ±0.5 | 20.29 ±0.23 | This research |
| Water-BP-CKWM | 0.67:0.33:3 | 45.19 ±1.24 | 12.0± 0.3 | 25.6 ±0.6 | 17.2 ±0.6 | 20.66 ±0.15 | This research |
| Water-BP-CKWM | 0.33:0.67:4 | 57.33 ±0.38 | 18.3± 0.3 | 8.05 ±0.2 | 16.2 ±0.3 | 23.80 ±0.03 | This research |
| Water-BP-CKWM | 0.67:0.33:4 | 53.60 ±0.52 | 12.7± 0.4 | 19.6 ±0.5 | 14.2 ±0.4 | 21.16 ±0.08 | This research |
| Water-BP-CKWM | 0.33:0.67:5 | 54.09 ±1.40 | 21.3± 1.3 | 7.89 ±0.2 | 16.7 ±0.5 | 22.92 ±0.23 | This research |
| Water-BP-CKWM | 0.67:0.33:5 | 47.15 ±1.36 | 20.1± 0.5 | 17.2 ±1.5 | 15.6 ±0.2 | 21.53 ±0.08 | This research |

# 5. CONCLUSIONS AND RECOMMENDATIONS

## 5.1. Conclusions

The study and analysis showed that *khat* waste could carbonize and changed to charcoal briquettes. After carbonized *khat* waste samples the average efficiency of 51.89 $\pm$ 1.02, 56.55 $\pm$ 1.57 and 52.28 $\pm$ 0.46 % were achieved from 9, 18 and 27 kg respectively. However, 9 kg and 27 kg of selected sample have low efficiency than 18 kg sample.

It was seen that during carbonization, the decline of temperature of 200 L kiln starting from 200 ℃ after 35 minutes for 9 kg, from 325 ℃ after 50 minutes for 18 kg and from 450 ℃ after 1 hour and 10 minutes for 27 kg of raw *khat* waste. In addition, the smoke that flows out from chimney stopped immediately when the temperature of the 200 L kiln stopped for all trials.

Charcoal briquette produced by mixing with 1:3, 1:4 and 1:5 (binder to char) ratios and ratio of water to banana peel is 1:2 and 2:1 to bind carbonized material as briquette. In general, the ratio used for water to BP to CKWM is 0.33:0.67:3, 0.67:0.33:3, 0.33:0.67:4, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5. However, from all the ratios 1:4 (binder to char) or 0.33:0.67:4 (water- BP-CKWM) is the best option due to its proximate characteristics meet with of (FAO, 1987 and 1999) and give high calories of heat energy than the rests.

Proximate characteristics, bulk density, sulfur content and calorific value of charcoal briquettes from *khat* waste were determined. This analysis hence made characteristics data available for use as references in future scientific studies.

It concluded that *khat* waste is suitable for application of charcoal briquettes production with mixing ratio of 0.33:0.67:4 (water to BP to CKWM). Because of the produced charcoal briquettes with this ratio has MC of 8.05 $\pm$ 0.22 %, CV of 18.37 $\pm$ 0.27 %, AC of 16.24 $\pm$ 0.34 % and FC of 57.33 $\pm$ 0.38 % by weight that line with the standard of (FAO, 1987 and 1999). In addition, the result shows that the BD of 0.6 $\pm$ 0.1 cc/g, SC of 0.06 $\pm$ 0.005 % and CV of 23.80 $\pm$ 0.03 KJ/g, which were, line with the FAO standard and related results with different studies. Even though, all used mixing ratios meet with the standards, but relative CV percentage gained from 0.33:0.67:4 (water-BP-CKWM) ratio is highest than the ratios of 0.33:0.67:3, 0.67:0.33:3, 0.67:0.33:4, 0.33:0.67:5 and 0.67:0.33:5 (Water to BP to CKWM) which their CV are 20.29±0.23, 20.66±0.15, 21.16±0.08, 22.92±0.23 and 21.53±0.08 KJ/g respectively. Analysis of sulfur content on the other hand, showed the lower sulfur content in the produced charcoal briquettes from *khat* waste would not have any risk of significant SOx emission.

In this study banana, peel used as the best alternative binder since it is also from waste section. It is eco-friendly alternative binder rather than further used binders such as Clay soil and Gum Arabic that are not ecofriendly, molasses and wheat powder that are very costly.

The application of *khat* waste in a conversion process to recover energy investigated in this study. The possibility of managing this waste component, which generated locally in major amount, for the protection of the environment and recovery of valuable products was hence established. Analysis of produced charcoal briquettes from *khat* waste using banana peels as a binder in terms of proximate characteristics, bulk density, sulfur content and calorific value that results important information for scientific applications was also substantial.

## 5.2. Recommendations

Depending on the demonstrated possibility of obtaining charcoal briquette results from *Khat* waste, the following points are recommended.

- As so many studies were done on charcoal briquettes from different agricultural waste, further works are still necessary based on carbonizing, analyzing proximate characteristics, checking bulk density, sulfur content and calorific value. However, the binder they used were not eco-friendly and economically not efficient, banana peel is good alternative binder.
- The study aimed to solve the solid waste problem that caused due to *Khat* 'garaba' threw on the environment, to minimize deforestation due to charcoal production from forest trees and to minimize pollution caused by charcoal manufacturing. Therefore, charcoal briquetting from *khat* waste and from different agricultural waste is the best solution for solving and minimizing environmental pollution.
- In this study different amount of *khat* waste sample were carbonized in 200L kiln to check the most efficient. Therefore, from all of the samples, 18kg of *khat* waste sample is best because it gives greater amount of carbonized material.
- For this study, different mixing ratios were checked to compare with each other and select the best ratios from all of them. Therefore, 0.33:0.67:4 (water to BP to CKWM) mixing ratio is best due to its high value of CV.
- To get good briquetted charcoal briquetting machine must designed well or renewed if damaged. However, the briquetting machine that found in Jimma agricultural engineering research center is old that affect the amount and shape of produced charcoal briquette. Therefore, Jimma agricultural engineering research center should modify the briquette machines since the machine, there are not efficient and old.
- Future studies can study on charcoal briquettes by mixing *khat* waste and other agricultural waste. In addition searching for best eco-friendly binder rather than further used binders and should compare them.

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## ANNEXES

**List of Annexes**

Annex 1 Conversion efficiencies from different amount of raw *khat* waste samples

| Samples | Raw *khat* waste sample in (Kg) | Output carbonized amount in (Kg) | Conversion efficiency in (%) |
|---|---|---|---|
| 1 | 9 | 4.67 ± 0.09 | 51.89 ± 1.02 |
| 2 | 18 | 10.18 ± 0.28 | 56.55 ± 1.57 |
| 3 | 27 | 14.12 ± 0.12 | 52.28 ± 0.46 |

Annex 2 Conversion efficiency of charcoal from 9kg raw *khat* waste

| Sample 1 | Raw *khat* waste sample in (Kg) | Output carbonized amount in (Kg) | Conversion efficiency in (%) |
|---|---|---|---|
| A | 9 | 4.65 | 51.67 |
| B | 9 | 4.77 | 53.00 |
| C | 9 | 4.59 | 51.00 |
| Mean | 9 | 4.67 | 51.89 |
| SD | 0.00 | 0.09 | 1.02 |
| Mean ± SD | | 4.67 ± 0.09 | 51.89 ± 1.02 |

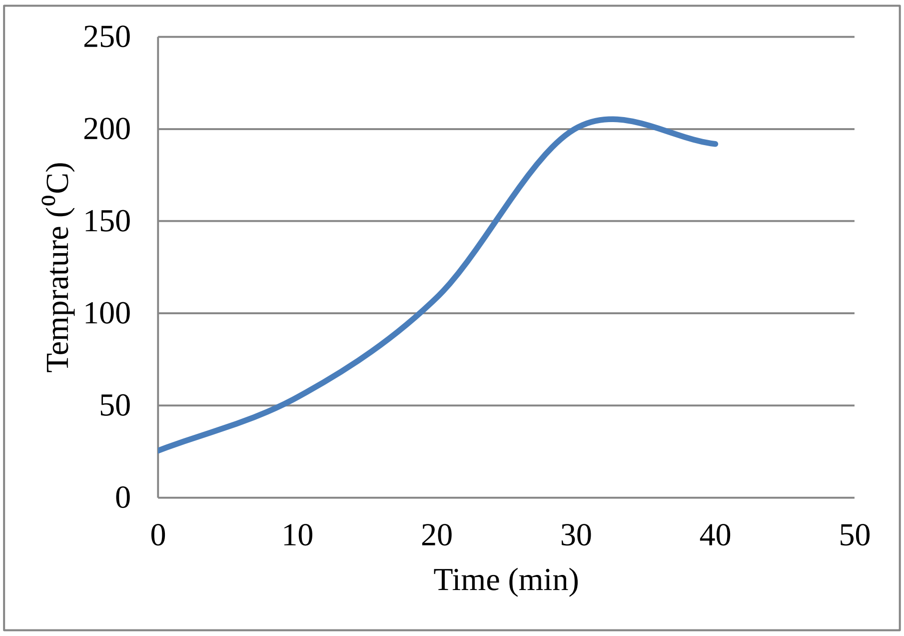
Annex 3 Conversion efficiency of charcoal from 18kg raw *khat* waste

| Sample | Raw khat waste sample in (Kg) | Output carbonized amount in (Kg) | Conversion efficiency in (%) |
|---|---|---|---|
| A | 18 | 10.42 | 57.89 |
| B | 18 | 9.87 | 54.83 |
| C | 18 | 10.25 | 56.94 |
| Mean | 18.00 | 10.18 | 56.55 |
| SD | 0.00 | 0.28 | 1.57 |
| Mean ± SD | | 10.18 ± 0.28 | 56.55 ± 1.57 |

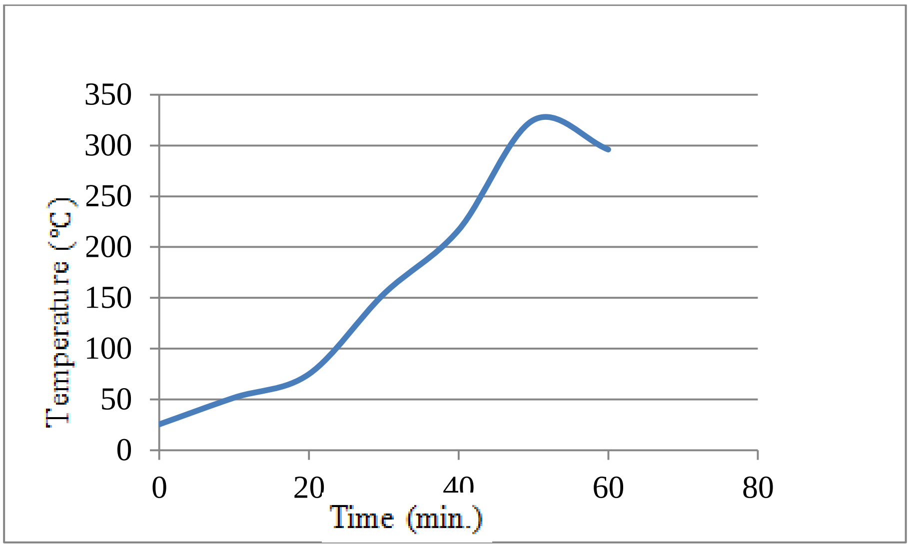
Annex 4 Conversion efficiency of charcoal from 27kg raw *khat* waste

| Sample 3 | Raw *khat* waste sample in (Kg) | Output carbonized amount in (Kg) | Conversion efficiency in (%) |
|---|---|---|---|
| A | 27 | 14.22 | 52.67 |
| B | 27 | 13.98 | 51.78 |
| C | 27 | 14.15 | 52.41 |
| Mean | 27.00 | 14.12 | 52.28 |
| SD | 0.00 | 0.12 | 0.46 |
| Mean $\pm$ SD | | 14.12 $\pm$ 0.12 | 52.28 $\pm$ 0.46 |

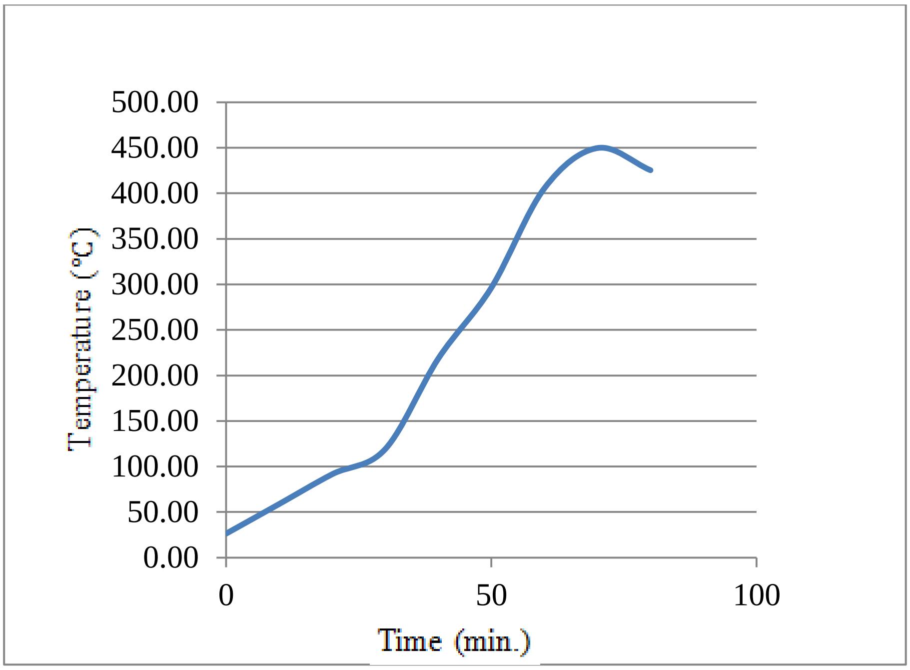
Annex 5 Carbonizing time and temperature for 9kg *khat* waste sample



Annex 6 Carbonizing time and temperature for 18kg *khat* waste sample




Annex 7 Carbonizing time and temperature for 27kg *khat* waste sample



Annex 8 Proximate characteristics of briquetted charcoal from *khat* waste

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 7.81 | 18.68 | 16.62 | 56.89 |
| B | 8.23 | 18.21 | 15.97 | 57.59 |
| C | 8.12 | 18.23 | 16.14 | 57.51 |
| Mean | 8.05 | 18.37 | 16.24 | 57.33 |
| SD | 0.22 | 0.27 | 0.34 | 0.38 |

Annex 9 Determination of moisture content

with ratios 0.33:0.67:3(water-banana peels-carbonized *khat* waste)

| samples | WBS | WC | WS | ODWS 105 | MC (%) |
|---|---|---|---|---|---|
| A | 130.50 | 8.29 | 138.79 | 115.96 | 17.49 |
| B | 125.12 | 9.74 | 134.86 | 114.89 | 15.96 |
| C | 131.13 | 9.01 | 140.14 | 116.98 | 17.66 |
| Average | | | | | 17.04 |
| SD | | | | | 0.94 |

with ratios 0.67:0.33:3 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WC | WS | ODWS 105 | MC (%) |
|---|---|---|---|---|---|
| A | 136.24 | 8.29 | 144.53 | 110.35 | 25.09 |
| B | 137.60 | 9.74 | 147.34 | 111.23 | 26.24 |
| C | 140.26 | 9.01 | 149.27 | 113.54 | 25.47 |
| Average | | | | | 25.60 |
| SD | | | | | 0.59 |

with ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WC | WS | ODWS 105 | MC (%) |
|---|---|---|---|---|---|
| A | 120.00 | 8.29 | 128.29 | 118.92 | 7.81 |
| B | 125.00 | 9.74 | 134.74 | 124.45 | 8.23 |
| C | 123.00 | 9.01 | 132.01 | 122.02 | 8.12 |
| Average | | | | | 8.05 |
| SD | | | | | 0.22 |

with ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WC | WS | ODWS 105 | MC (%) |
|---|---|---|---|---|---|
| A | 126.00 | 8.29 | 134.29 | 110.34 | 19.01 |
| B | 129.54 | 9.74 | 139.28 | 113.82 | 19.65 |
| C | 131.52 | 9.01 | 140.53 | 114.22 | 20.00 |
| Average | | | | | 19.56 |
| SD | | | | | 0.51 |

with ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WC | WS | ODWS 105 | MC (%) |
|---|---|---|---|---|---|
| A | 122.04 | 8.29 | 130.33 | 120.97 | 7.67 |
| B | 123.11 | 9.74 | 132.85 | 122.84 | 8.13 |
| C | 125.32 | 9.01 | 134.33 | 124.45 | 7.88 |
| Average | | | | | 7.89 |
| SD | | | | | 0.23 |

with ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WC | WS | ODWS 105 | MC (%) |
|---|---|---|---|---|---|
| A | 127.52 | 8.29 | 135.81 | 115.74 | 15.74 |
| B | 131.62 | 9.74 | 141.36 | 116.77 | 18.68 |
| C | 133.29 | 9.01 | 142.30 | 119.38 | 17.20 |
| Average | | | | | 17.21 |
| SD | | | | | 1.47 |

$$MC = \frac{Weight\ of\ sample\ (g) - oven\ dry\ weigt\ of\ sample\ (g)}{weight\ of\ briquette\ sample\ (g)} x100$$

Where: Weight of sample (WS) = Weight of crucible (WC) + weight of briquette sample (WBS)

Oven dried weight of sample (ODWS) = Weight of sample (WS) at 105℃

Annex 10 Determination of volatile matter

with ratios 0.33:0.67:3 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WS | ODWS 105 | ODWS 950 | VM % |
|---|---|---|---|---|---|
| A | 131.97 | 230.82 | 118.29 | 98.85 | 14.73 |
| B | 133.10 | 232.47 | 119.31 | 99.37 | 14.98 |
| C | 139.84 | 240.60 | 119.89 | 100.76 | 13.68 |
| Average | | | | | 14.46 |
| SD | | | | | 0.69 |

with ratios 0.67:0.33:3 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WS | ODWS 105 | ODWS 950 | VM % |
|---|---|---|---|---|---|
| A | 135.87 | 235.08 | 115.32 | 99.21 | 11.86 |
| B | 137.62 | 233.95 | 113.25 | 96.33 | 12.29 |
| C | 139.52 | 240.36 | 117.36 | 100.84 | 11.84 |
| Average | | | | | 12.00 |
| SD | | | | | 0.26 |

with ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WS | ODWS 105 | ODWS 950 | VM % |
|---|---|---|---|---|---|
| A | 120.00 | 216.50 | 118.92 | 96.5 | 18.68 |
| B | 125.00 | 227.00 | 124.45 | 102 | 18.21 |
| C | 123.00 | 224.00 | 122.02 | 101 | 18.23 |
| Average | | | | | 18.37 |
| SD | | | | | 0.27 |

with ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WS | ODWS 105 | ODWS 950 | VM % |
|---|---|---|---|---|---|
| A | 126.00 | 225.55 | 115.32 | 99.55 | 12.52 |
| B | 129.54 | 225.83 | 113.25 | 96.29 | 13.09 |
| C | 131.52 | 232.52 | 117.36 | 101 | 12.44 |
| Average | | | | | 12.68 |
| SD | | | | | 0.36 |

With ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WS | ODWS 105 | ODWS 950 | VM % |
|---|---|---|---|---|---|
| A | 131.94 | 228.59 | 125.24 | 96.65 | 21.67 |
| B | 135.63 | 234.51 | 129.23 | 98.88 | 22.38 |
| C | 133.46 | 233.11 | 126.27 | 99.65 | 19.95 |
| Average | | | | | 21.33 |
| SD | | | | | 1.25 |

with ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| samples | WBS | WS | ODWS 105 | ODWS 950 | VM % |
|---|---|---|---|---|---|
| A | 129.15 | 227.58 | 124.68 | 98.43 | 20.33 |
| B | 133.24 | 232.62 | 126.52 | 99.38 | 20.37 |
| C | 130.50 | 229.52 | 124.54 | 99.02 | 19.56 |
| Average | | | | | 20.08 |
| SD | | | | | 0.46 |

$$\text{VM (\%)} = \frac{\text{Weight of sample at 105°C (g)} - \text{Weight of sample (g)at 950°C}}{\text{Weight of briquette sample (g)}} \text{x100}$$

Annex 11 Determination of ash content

with ratios 0.33:0.67:3 (water-banana peels-carbonized *khat* waste)

| Samples | WBS | ODWS 750 ℃ | ODWS 950 ℃ | AC % |
|---|---|---|---|---|
| A | 121.33 | 119.92 | 95.24 | 20.34 |
| B | 120.27 | 118.83 | 94.15 | 20.52 |
| C | 122.47 | 120.13 | 96.22 | 19.52 |
| Average | | | | 20.13 |
| SD | | | | 0.53 |

with ratios 0.67:0.33:3 (water-banana peels-

carbonized *khat* waste)

| Amples | WBS | ODWS 750 ℃ | ODWS 950 ℃ | AC % |
|---|---|---|---|---|
| A | 128.65 | 122.54 | 100.13 | 17.42 |
| B | 131.12 | 124.22 | 101.05 | 17.67 |
| C | 129.85 | 123.32 | 101.84 | 16.54 |
| Average | | | | 17.21 |
| SD | | | | 0.59 |

with ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| Samples | WBS | ODWS 750 ℃ | ODWS 950 ℃ | AC % |
|---|---|---|---|---|
| A | 119.00 | 118.92 | 99.14 | 16.62 |
| B | 123.59 | 120.74 | 101 | 15.97 |
| C | 122.88 | 120.11 | 100.28 | 16.14 |
| Average | | | | 16.24 |
| SD | | | | 0.34 |

with ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| Samples | WBS | ODWS 750 ℃ | ODWS 950 ℃ | AC % |
|---|---|---|---|---|
| A | 123.65 | 121.32 | 103.62 | 14.31 |
| B | 124.98 | 121.61 | 104.43 | 13.75 |
| C | 123.53 | 121.32 | 103.51 | 14.42 |
| Average | | | | 14.16 |
| SD | | | | 0.36 |

with ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| Samples | WBS | ODWS 750 ℃ | ODWS 950 ℃ | AC % |
|---|---|---|---|---|
| A | 121.98 | 119.52 | 99.84 | 16.13 |
| B | 123.31 | 121.55 | 100.63 | 16.97 |
| C | 124.15 | 121.03 | 99.99 | 16.95 |
| Average | | | | 16.68 |
| SD | | | | 0.47 |

with ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| Samples | WBS | ODWS 750 ℃ | ODWS 950 ℃ | AC % |
|---|---|---|---|---|
| A | 126.08 | 122.12 | 102.21 | 15.79 |
| B | 128.32 | 123.52 | 103.82 | 15.35 |
| C | 127.75 | 123.1 | 103.24 | 15.55 |
| Average | | | | 15.56 |
| SD | | | | 0.22 |

Annex 12 Determination of fixed carbon content

With ratios 0.33:0.67:3 (water-banana peels-carbonized *khat* waste)

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 17.49 | 14.73 | 20.34 | 47.44 |
| B | 15.96 | 14.98 | 20.52 | 48.54 |
| C | 17.66 | 13.68 | 19.52 | 49.14 |
| Mean | 17.04 | 14.46 | 20.13 | 48.37 |
| SD | 0.94 | 0.69 | 0.53 | 0.86 |

with ratios 0.67:0.33:3 (water-banana peels-carbonized *khat* waste)

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 25.09 | 11.86 | 17.42 | 45.64 |
| B | 26.24 | 12.29 | 17.67 | 43.79 |
| C | 25.47 | 11.84 | 16.54 | 46.14 |
| Mean | 25.60 | 12.00 | 17.21 | 45.19 |
| SD | 0.59 | 0.26 | 0.59 | 1.24 |

with ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 7.81 | 18.68 | 16.62 | 56.89 |
| B | 8.23 | 18.21 | 15.97 | 57.59 |
| C | 8.12 | 18.23 | 16.14 | 57.51 |
| Mean | 8.05 | 18.37 | 16.24 | 57.33 |
| SD | 0.22 | 0.27 | 0.34 | 0.38 |

with ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 19.01 | 12.52 | 14.31 | 54.16 |
| B | 19.65 | 13.09 | 13.75 | 53.51 |
| C | 20.00 | 12.44 | 14.42 | 53.14 |
| Mean | 19.56 | 12.68 | 14.16 | 53.60 |
| SD | 0.51 | 0.35 | 0.36 | 0.52 |

with ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 7.67 | 21.67 | 16.13 | 54.53 |
| B | 8.13 | 22.38 | 16.97 | 52.53 |
| C | 7.88 | 19.95 | 16.95 | 55.22 |
| Mean | 7.89 | 21.33 | 16.68 | 54.09 |
| SD | 0.23 | 1.25 | 0.47 | 1.40 |

with ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| Samples | MC % | VM % | AC % | FC % |
|---|---|---|---|---|
| A | 15.74 | 20.33 | 15.79 | 48.14 |
| B | 18.68 | 20.37 | 15.35 | 45.60 |
| C | 17.20 | 19.56 | 15.55 | 47.70 |
| Mean | 17.21 | 20.08 | 15.56 | 47.15 |
| SD | 1.47 | 0.46 | 0.22 | 1.36 |

$$FC(\%) = 100 - [MC\% + VM\% + AC\% +]$$

Annex 13 Determination of bulk density

With ratios 0.67:0.33:3 (water-banana peels-carbonized *khat* waste)

| Samples | H (cm) | W (g) | Radius [2] (cm) | $A = \pi r^2$ | Volume ($cm^3$) | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|
| A | 3.95 | 255.65 | 30.25 | 94.99 | 364.92 | 0.70 |
| B | 3.54 | 250.58 | 30.25 | 94.99 | 325.98 | 0.77 |
| C | 3.25 | 240.64 | 30.25 | 94.99 | 298.43 | 0.81 |
| Mean | | | | | | 0.76 |
| SD | | | | | | 0.05 |

With ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| Samples | H (cm) | W (g) | Radius [2] (cm) | $A = \pi r^2$ | Volume ($cm^3$) | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|
| A | 4.54 | 256.67 | 30.25 | 94.99 | 420.96 | 0.61 |
| B | 4.52 | 251.98 | 30.25 | 94.99 | 419.06 | 0.60 |
| C | 4.58 | 262.48 | 30.25 | 94.99 | 424.76 | 0.62 |
| Mean | | | | | | 0.61 |
| SD | | | | | | 0.01 |

With ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| Samples | H (cm) | W (g) | Radius [2] (cm) | $A = \pi r^2$ | Volume ($cm^3$) | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|
| A | 4.25 | 250.35 | 30.25 | 94.99 | 393.42 | 0.64 |
| B | 3.96 | 245.98 | 30.25 | 94.99 | 365.87 | 0.67 |
| C | 3.75 | 242.87 | 30.25 | 94.99 | 345.92 | 0.70 |
| Mean | | | | | | 0.67 |
| SD | | | | | | 0.03 |

With ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| Samples | H (cm) | W (g) | Radius [2] (cm) | $A = \pi r^2$ | Volume ($cm^3$) | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|
| A | 4.68 | 250.84 | 30.25 | 94.99 | 434.26 | 0.58 |
| B | 4.75 | 255.35 | 30.25 | 94.99 | 440.91 | 0.58 |
| C | 4.84 | 259.58 | 30.25 | 94.99 | 449.46 | 0.58 |
| Mean | | | | | | 0.58 |
| SD | | | | | | 0.00 |

With ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| Samples | H (cm) | W (g) | Radius [2] (cm) | $A = \pi r^2$ | Volume ($cm^3$) | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|
| A | 3.98 | 245.95 | 30.25 | 94.99 | 367.77 | 0.67 |
| B | 3.77 | 240.36 | 30.25 | 94.99 | 347.82 | 0.69 |
| C | 3.52 | 238.67 | 30.25 | 94.99 | 324.08 | 0.74 |
| Mean | | | | | | 0.70 |
| SD | | | | | | 0.03 |

Annex 14 Determination of Sulfur content

With ratios 0.33:0.67:3 (water-banana peels-carbonized *khat* waste)

| Samples | ODWS at 825 $^0$C | Blank | WC | WBS | WD | SC (%) |
|---|---|---|---|---|---|---|
| A | 97.0000 | 0.0002 | 96.3200 | 121.3500 | 0.6800 | 0.0769 |
| B | 103.8700 | 0.0002 | 103.2500 | 126.2100 | 0.6200 | 0.0674 |
| C | 102.7000 | 0.0002 | 102.1100 | 124.5600 | 0.5900 | 0.0650 |
| Mean | | | | | | 0.0698 |
| SD | | | | | | 0.0063 |

With ratios 0.67:0.33:3 (water-banana peels-carbonized *khat* waste)

| Samples | ODWS at 825 $^0$C | Blank | WC | WBS | WD | SC (%) |
|---|---|---|---|---|---|---|
| A | 97.79 | 0.0002 | 97.22 | 118.48 | 0.57 | 0.066031 |
| B | 102.70 | 0.0002 | 102.15 | 120.54 | 0.55 | 0.062624 |
| C | 103.15 | 0.0002 | 102.54 | 122.35 | 0.61 | 0.068431 |
| Mean | | | | | | 0.065696 |
| SD | | | | | | 0.002918 |

With ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| Samples | ODWS at 825 $^0$C | Blank | WC | WBS | WD | SC (%) |
|---|---|---|---|---|---|---|
| A | 96.8900 | 0.0002 | 96.4100 | 120.3100 | 0.4800 | 0.0548 |
| B | 102.5600 | 0.0002 | 102.0020 | 125.2500 | 0.5580 | 0.0611 |
| C | 101.6100 | 0.0002 | 101.0300 | 123.1700 | 0.5800 | 0.0646 |
| Mean | | | | | | 0.0602 |
| SD | | | | | | 0.0050 |

With ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| Samples | ODWS at 825 $^0$C | Blank | WC | WBS | WD | SC (%) |
|---|---|---|---|---|---|---|
| A | 97.8100 | 0.0002 | 97.2200 | 127.6500 | 0.5900 | 0.0634 |
| B | 102.7100 | 0.0002 | 102.1500 | 131.3600 | 0.5600 | 0.0585 |
| C | 101.7500 | 0.0002 | 101.2000 | 130.9800 | 0.5500 | 0.0576 |
| Mean | | | | | | 0.0599 |
| SD | | | | | | 0.0031 |

With ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| Samples | ODWS at 825 $^0$C | Blank | WC | WBS | WD | SC (%) |
|---|---|---|---|---|---|---|
| A | 97.90 | 0.0002 | 97.35 | 123.42 | 0.55 | 0.061163 |
| B | 102.83 | 0.0002 | 102.25 | 125.66 | 0.58 | 0.063351 |
| C | 102.55 | 0.0002 | 102.03 | 124.25 | 0.52 | 0.057439 |
| Mean | | | | | | 0.060651 |
| SD | | | | | | 0.002989 |

With ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| Samples | ODWS at 825 $^0$C | Blank | WC | WBS | WD | SC (%) |
|---|---|---|---|---|---|---|
| A | 99.5100 | 0.0002 | 98.9400 | 121.6500 | 0.5700 | 0.0643 |
| B | 102.7710 | 0.0002 | 102.2500 | 132.0500 | 0.5210 | 0.0542 |
| C | 102.6800 | 0.0002 | 102.1200 | 131.7800 | 0.5600 | 0.0583 |
| Mean | | | | | | 0.0589 |
| SD | | | | | | 0.0051 |

$$SC\ (\%) = \frac{[\text{Weight difference} - \text{Blank}] \times 13.73}{\text{Weight of briquette sample}}$$

Where: Weight difference = Weight at 825$^0$C - Weight of crucible;

Blank = 0.0002

Annex 15 Determination of calorific value

With ratios 0.33:0.67:3 (water-banana peel-carbonized *kha* waste)

| Samples | $T_i$ ($^o$C) | $T_f$ ($^o$C) | ΔT | SC (%) | WBS (g) | WBS*13.378 | Wire burn*2.3 | Titration | Sulfur | CV (KJ/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 25.98 | 1200.00 | 1174.02 | 0.0597 | 585.5515 | 7833.5080 | 2.3000 | 1.0000 | 467.7518 | 20.30 |
| B | 26.21 | 1200.00 | 1173.79 | 0.0587 | 584.2488 | 7816.0804 | 2.3000 | 1.0000 | 458.9031 | 20.34 |
| C | 26.78 | 1200.00 | 1173.22 | 0.0642 | 587.2112 | 7855.7114 | 2.3000 | 1.0000 | 504.5538 | 20.23 |
| Mean | | | | | | | | | | 20.29 |
| SD | | | | | | | | | | 0.06 |

Wth ratios 0.67:0.33:3 (water-banana peels-carbonized *khat* waste)

| Samples | $T_i$ ($^o$C) | $T_f$ ($^o$C) | ΔT | SC (%) | WBS (g) | WBS*13.378 | Wire burn*2.3 | Titration | Sulfur | CV (KJ/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 27.12 | 1200.00 | 1172.88 | 0.0511 | 570.5500 | 7632.8179 | 2.3000 | 1.0000 | 390.2049 | 20.81 |
| B | 27.19 | 1200.00 | 1172.81 | 0.0512 | 574.4300 | 7684.7245 | 2.3000 | 1.0000 | 393.4579 | 20.67 |
| C | 27.21 | 1200.00 | 1172.79 | 0.0621 | 578.9600 | 7745.3269 | 2.3000 | 1.0000 | 480.9848 | 20.51 |
| Mean | | | | | | | | | | 20.66 |
| SD | | | | | | | | | | 0.15 |

With ratios 0.33:0.67:4 (water-banana peels-carbonized *khat* waste)

| Samples | $T_i$ (°C) | $T_f$ (°C) | ΔT | SC (%) | WBS (g) | WBS*13.378 | Wire burn*2.3 | Titration | Sulfur | CV (KJ/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 22.89 | 1200.00 | 1177.11 | 0.0549 | 501.3703 | 6707.3319 | 2.3000 | 1.0000 | 368.2132 | 23.77 |
| B | 23.25 | 1200.00 | 1176.75 | 0.0613 | 499.9292 | 6688.0528 | 2.3000 | 1.0000 | 409.7687 | 23.83 |
| C | 23.45 | 1200.00 | 1176.55 | 0.0647 | 500.5229 | 6695.9954 | 2.3000 | 1.0000 | 433.3699 | 23.80 |
| Mean | | | | | | | | | | 23.80 |
| SD | | | | | | | | | | 0.03 |

With ratios 0.67:0.33:4 (water-banana peels-carbonized *khat* waste)

| Samples | $T_i$ (°C) | $T_f$ (°C) | ΔT | SC (%) | WBS (g) | WBS*13.378 | Wire burn*2.3 | Titration | Sulfur | CV (KJ/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 24.64 | 1200.00 | 1175.36 | 0.0511 | 560.9800 | 7504.7904 | 2.3000 | 1.0000 | 383.6599 | 21.21 |
| B | 24.78 | 1200.00 | 1175.22 | 0.0512 | 561.1700 | 7507.3323 | 2.3000 | 1.0000 | 384.3754 | 21.20 |
| C | 25.22 | 1200.00 | 1174.78 | 0.0621 | 564.5200 | 7552.1486 | 2.3000 | 1.0000 | 468.9884 | 21.07 |
| Mean | | | | | | | | | | 21.16 |
| SD | | | | | | | | | | 0.08 |

With ratios 0.33:0.67:5 (water-banana peels-carbonized *khat* waste)

| Samples | $T_i$ (°C) | $T_f$ (°C) | ΔT | SC (%) | WBS (g) | WBS*13.378 | Wire burn*2.3 | Titration | Sulfur | CV (KJ/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 26.29 | 1200.00 | 1173.71 | 0.0549 | 523.6800 | 7005.7910 | 2.3000 | 1.0000 | 384.5977 | 22.69 |
| B | 26.55 | 1200.00 | 1173.45 | 0.0613 | 513.3100 | 6867.0612 | 2.3000 | 1.0000 | 420.7363 | 23.14 |
| C | 26.97 | 1200.00 | 1173.03 | 0.0647 | 518.2400 | 6933.0147 | 2.3000 | 1.0000 | 448.7100 | 22.92 |
| Mean | | | | | | | | | | 22.92 |
| SD | | | | | | | | | | 0.23 |

With ratios 0.67:0.33:5 (water-banana peels-carbonized *khat* waste)

| Samples | $T_i$ (°C) | $T_f$ (°C) | ΔT | SC (%) | WBS (g) | WBS*13.378 | Wire burn*2.3 | Titration | Sulfur | CV (KJ/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 26.21 | 1200.00 | 1173.79 | 0.0511 | 554.4300 | 7417.1645 | 2.3000 | 1.0000 | 379.1803 | 21.43 |
| B | 27.27 | 1200.00 | 1172.73 | 0.0512 | 550.7400 | 7367.7997 | 2.3000 | 1.0000 | 377.2313 | 21.56 |
| C | 27.29 | 1200.00 | 1172.71 | 0.0621 | 549.7400 | 7354.4217 | 2.3000 | 1.0000 | 456.7096 | 21.60 |
| Mean | | | | | | | | | | 21.53 |
| SD | | | | | | | | | | 0.08 |

$$\text{CV (cal)} = \frac{\Delta T \times 2420 - [\text{wire burn} \times 2.3 + \text{Titration} + \text{Sulfur}]}{\text{Weight of briquette sample}}$$

Where: Final temperature – Initial temperature and

Sulfur = SC* Weight of briquette sample*13.378.

Annex 16 Observed *khat* market and produced its waste in Jimma town

Annex 17 Charcoal produced traditionally from forest tree species and transported to Jimma town

Annex 18 Produced combustible charcoal briquettes from *khat* waste using banana peels as a binder

Annex 19 Prepared binder from banana peels and bio-char from *khat* waste

Annex 20 Manual mechanical molder found in JAERS