PRODUCTION AND CHARACTERIZATION OF FUEL BRIQUETTE FROM KHAT (*CATHA EDULIS FORSK*) RESIDUE FOR DIVERSIFICATION OF HOUSEHOLD ENERGY SOURCES

MSc. THESIS

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APPROVAL SHEET-1

This is to certify that the thesis entitled "Production and Characterization of Fuel Briquette from Khat (*Catha Edulis Forsk*) residue for Diversification of Household Energy Sources'' submitted in partial fulfillment of the requirements for the degree of Master of Science in 'Renewable Energy Utilization and Management'. It is an original research carried out by Endale Fekadu Gebreyes (ID.No. MSc./ReUM/R006/09). Under my supervision and no part of it has been submitted for any other degree or diploma. The assistance and help received during the courses of this investigation have been duly acknowledged. Therefore, I recommended it to be accepted as fulfilling the thesis requirements.

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Name of major advisor	Signature	Date
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Name of post graduate coordinator	Signature	Date

APPROVAL SHEET-2

We, the undersigned, members of the Board of Examiners of the final open defense by Endale Fekadu Gebreyes have read and evaluated his thesis entitled “Production and Characterization of Fuel Briquette from Khat (*Catha Edulis Forsk*) Residue for Diversification of Household Energy Sources”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Utilization and Management.

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ACRONYMS AND ABBREVIATIONS

%	Percent
AC	Ash Content
AREAP	African Renewable Energy Access Program
ASTM	American Society for Testing and Materials
BD	Bulk Density
CRGE	Climate Resilient Green Economy
CSA	Central Statistics Agency
CV	Calorific Value
EEA	Ethiopian Energy Authority
FAO	Food and Agriculture Organization
FCC	Fixed Carbon Content
GHG	Green House Gas
Kg	kilogram
KJ	Kilo joule
MC	Moisture Content
MOWIE	Minister of Water, Irrigation, and Electricity
SD	Standard Deviation
SNNPRS	South Nation's Nationalities and People Regional State
VM	Volatile Matter
WEC	World Energy Council
WGCF-NR	Wondo Genet College of Forestry and Natural Resource

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ABSTRACT

Ethiopia's energy consumption predominantly depends on traditional biomass such as firewood, agro-residues, dung, and charcoal. The objectives of the study were to produce fuel briquette from Khat residue branches and leaves generated from Hawassa city as well as to evaluate the fuel quality of the briquettes produced, estimate their potential through determination of charcoal. The Khat branch and leaves residue were carbonized in an oxygen-scarce environment separately by using carbonizing kiln at Alternative Energy Development and Promotion Directorate, Minister of Water, Irrigation, and Electricity. Then the carbonized resources were crushed to fine particles and mixed with a binder and transformed to briquettes by using a beehive briquette machine. Triplicate samples were taking for laboratory analysis and carried out by using American Society for Testing and Materials procedure. The laboratory analysis revealed that the fixed carbon content and calorific value of briquettes made from carbonized Khat branch, carbonized Khat leaves, a mixture of carbonized branch with carbonized leaves and a mixture of carbonized branch with un-carbonized leaves were 49.48 ± 2.45 %, 36.17 ± 1.33 %, 43.08 ± 0.58 %, 4.81 ± 1.42 % and 19,891 ± 748 kJ/kg, 13,837 ± 995 kJ/kg, 16,985 ± 793 kJ/kg, 1,988 ± 62 kJ/kg respectively, and through transformation of estimated total amount of wet Khat residues which were on average 4,549,595 kg/yr. from Khat branch, Khat leaves, a mixture of carbonized branch with carbonized leaves and a mixture of carbonized branch with un-carbonized leaves into briquette, annually the city could produce about 10, 6, 16 and 4 billion kilo Jules of energy which substitutes around 310, 198, 508, and 133 tonnes of charcoal or reduce approximately, 1,024, 652, 1,676 and 439 tonnes of carbon dioxide that release to the environment. In addition to this, the result indicated that fuel briquette produced from the carbonized Khat branch have higher quality in terms of lower values of moisture content, volatile matter, ash content but higher values of fixed carbon content, calorific value and bulk density than results obtained from other fuel briquettes produced, and also the fuel briquette produced from a mixture of carbonized branch and leaves have higher total energy, charcoal substitution and reduced carbon dioxide emission than other fuel briquette produced. Further analysis showed that the carbonized Khat branch and leaves briquettes were strong heat which got on average 23 min and 35 min to boil one latter of water and carbonized Khat branch and leaves fuel briquettes had total CO emissions of 728 (0.07%) ppm and 831 ppm (0.08%) respectively. It is concluded that fuel briquette produced from Khat residue could be used as an alternative source of energy, reduce alarming rate of deforestation and improve waste management.

Keywords: *Binder; Carbonized; Charcoal; Deforestation; Fuel quality;*

1. INTRODUCTION

1.1. Background

Almost half of the world's population and 81% of Sub-Saharan African households depend on wood-based biomass energy in particular firewood and charcoal for heating and cooking purpose (AREAP, 2011). Correspondingly, Ethiopia's energy consumption predominantly depends on traditional biomass such as firewood, agro-residues, dung, and charcoal. Traditional biomass supplies more than 92.4% of the total energy demand in the country while the remainder is supplied by oil products, hydro and geothermal (MOWIE, 2014). Consequently, the heavy dependence on traditional biomass in Ethiopia is leading to different environmental and socio-economic problems including soils erosion, water pollution, and indoor air pollution and most importantly deforestation which affecting the limited forest resources of the country (Bizzarri, 2010).

The Climate-Resilient Green Economy (CRGE) of Ethiopia has visions to achieve middle-income status by 2025 in a climate-resilient green economy one of the pillars is protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks. Therefore, one of the mechanisms to fulfill this strategic plan is improving energy use instead of deforestation use waste resources for alternative energy sources in addition to this improve waste management system.

Charcoal is one of the most important cooking fuels used in urban households and it has high energy density fuel than other unprocessed biomass fuels like wood and has physical properties that make it easier to hand, transport and store. Essentially, charcoal can be produced from any biomass materials; however, the most common resource used in charcoal making in Ethiopia, as in most countries, is wood. On the other hand, charcoal briquettes are solid fuel made from carbonized biomass or densified biomass that is successively carbonized. In spite of clear advantages of charcoal briquettes that include burning time, price, environmental sustainability and potential for product standardization, their acceptance as a substitute for wood charcoal in Sub-Saharan Africa remains very limited (Mwampamba *et al.,* 2013). Similarly, the production of charcoal briquettes from different agricultural and/or forest wastes has started by the Ethiopian Rural Energy Development and Promotion Center (EREDPC) on a limited scale. Biomass wastes like bamboo, cotton stake, Chat (Khat) stem and coffee husks has shown encouraging results. Given its great potential changing waste biomass into fuel for household use in an affordable and environmentally friendly manner, the fuel briquette using agricultural wastes and other materials can be a sustainable alternative to wood charcoal (Bekele and Girmay, 2013). Therefore, this study focuses on the production and characterization of fuel briquette from Khat residue for the substitution of charcoal and to improve waste management system in Hawassa city.

1.2. Statement of the Problem

Biomass is the main source of energy in Ethiopia. Effective utilization of biomass leads to sustainability and reduces deforestation problems. In order to reduce reliance on indigenous and other valuable trees as energy sources for charcoal making, it is better to use solid organic wastes as raw material. One of these alternatives is 'Khat' residues from which fuel briquette can be produced. There are some research papers done regarding fuel briquette production and characteristics in Ethiopia, like fuel briquette production from coffee husk and pulp (Merete *et al.*, 2014), and briquettes from Sesame Stalk (Gebresas *et al.*, 2015) etc. However, there is a gap in production, and characteristics of other organic wastes like Khat residue in Ethiopia, especially in Hawassa. Now days, in developing cities in Ethiopia the number of Khat chewers are increasing at alarming rate and so most drainage systems were filled by Khat residue with plastic bags. In addition to this, there is no proper method of collecting this resource. Because of this, a number of flooding in these cities (like Hawassa, Adama, Dira Dawa, Addis Ababa etc.) were happened due to Khat residues and their plastic bag used by most Khat chewers which was thrown away as a waste in to the drainage system. Therefore, this study focuses on Khat residues from solid urban organic wastes in Hawassa city due to the availability of Khat residue and the production of fuel briquette from Khat residue are better and expected to be preferable. Furthermore, the understandings of the community and briquette producers are low in which waste is as an alternative sources of fuel energy which is environmental friendly (Gebrekidan and Belete, 2015).

1.3. Objective of the Study

1.3.1. General Objective

The general objectives of the study were to produce fuel briquette from Khat residue branches and leaves as well as to evaluate the fuel quality of the briquettes produced, estimate their potential through determination of charcoal substitution.

1.3.2. Specific Objectives

The specific objectives of the study were:

- To estimate the total Khat supply and residue generation in Hawassa city from 2012-2016;
- To determine the carbonization efficiency of Khat residue generation;
- To evaluate its fuel quality through determination of proximate analysis;
- To estimate the energy potential of briquette produced from Khat residue through determination of calorific value;
- To determine charcoal substitution potential of briquette produced from Khat residue;

1.4. Significance of the Study

Biomass as a source of energy used like briquette has its own contribution to the expansion of alternative energy, for waste utilization and for multi socio-economic benefits (WEC, 2016). In Ethiopia traditional charcoal production greatly depends on indigenous forest like acacia species, invasive species-*Prosopis juliflora* for the quality they constitute of and the production of charcoal from this species delivered from rural area to urban areas like Addis Ababa, Hawassa etc. Moreover, related to increasing population growth, urbanization and economic development on one hand the absence of affordable suitable modern energy sources on the other, the shift from firewood to charcoal will continue at higher rates. Besides its suitability and acceptability at reasonable cost at household energy source charcoal trade produce an important opportunity for income generation. Hence, charcoal is expectedly the most cooking fuel in the future for most people in the country's towns and cities (Bekele and Girmay, 2013). Therefore, the importance of this study are decreasing the alarming rate of deforestation for the purpose of firewood and production of charcoal in addition to that improve the absence of affordable convenient modern alternative energy sources by improving the efficiency and also improve the problem of land degradation, indoor air pollution, employments and serious damage to the environment . Furthermore, the study is one of the options to reduce the waste management problem of cities. Generally, this study contributes to meet the CRGE strategic plan of the country.

1.5. Scope and Limitation of the Study

This study is limited only production and characterization of fuel briquette produced from Khat residue which does not considered its economic analysis. In addition to this, it does not attempt the production of briquettes form other wastes that are scattered in the study area and it focus only on taxable Khat supply to the city. On the other hand, the role of changing Khat residue to fuel briquette location is not exclusively bounded to the target study area, its benefit and beneficiary community may extend beyond the study area.

2. REVIEW OF RELATED LITRATURE

2.1. Khat (Catha Edulis Forsk)

Khat is evergreen perennial plant that belongs to the Celastraceae family. It initiated from Ethiopia, explicitly in Hararghe zones with a continuing growth to various areas of Ethiopia, Yemen, and distributed to different parts of the world (Huffnagel, 1961). The plant is known with different language names: Khat in English and in Arabic, Jimaa in Oromiffaa and Chat in Amharic. Khat commonly cultivates up to 7 meters but sometimes reaches as high as 15 to 25 meters (Dechassa, 2001). Leaves are simple, elliptic, oblong and shiny green above but lighter below, leathery and stiff narrowing to both ends. The flowers and leaves contain an alkaloid and are chewed in a fresh or dried form as a stimulant. Flowers are white and small. The fruit is narrow and smooth splitting to release narrowly winged reddish seeds when matured. The stem is slender and straightforward; the bark has different colors liable on the variety and age of the branches and stem. The young branches are green and flat to reddish pink but grey and occasionally darker and rougher on older branches and stems. The root part can grow as deep and as extended as 3-5 m (Dechassa, 2001). In Ethiopia, Khat is a significant and profitable cash crop. Now days it earnings annually 200 million USD and it is the fourth largest exported crop (CSA, 2012/13). In both rural and urban areas find guilty the practice of chewing Khat, the amount of people use this plant is growing, mostly among the youth. In urban areas, chewing Khat is becoming a common time-out activity (Dechassa, 2001). Moreover, millions of Ethiopians, regardless of belief, education, job, attitude, livelihood, and gender use Khat (Dessie, 2013).

2.2. Charcoal Production from Agricultural Residue

The solid residue remaining when agro-industrial wastes, wood species, and other forms of biomass are carbonized or burned under controlled conditions in a limited space such as a kiln is called charcoal. The bulk densities of agricultural residues have naturally less than 100 kg/m^3. Because of these specific physical characteristic agricultural residues makes expensive to transport, store and use in simple combustion devices. Therefore agricultural residues are produced in large quantity and the potential use of agricultural residues for the substitution of traditionally produced commercial biomass fuel is high, the production of charcoal briquette could be accepted (BTG, 2004). To increase the amount of production of briquette charcoal and charcoal, it is recommended that not only limited to the commonly known species (raw material) like Acacia. There is a need to assess and evaluate other opportunities such as short rotation species trees like Eucalyptus and industrial process residues and other wastes.

For the preparation of briquette charcoal organic material such as wood, straw, coconut husks and shells, rice husks, cotton stalks, coffee husks, castor husks, bagasse, sawdust, bones, and others. Among woods, usually, the hardwood species are preferred for briquette charcoal (BTG, 1999). Biomass species used for making charcoal briquette production and charcoal include from fast-growing trees like bamboo or Acacia, Mangrove, oak, Beech, Birch, Hard maple, hickory, and Prosopis. Certain tree species and agro-industrial wastes used for quality charcoal or charcoal briquette making in Ethiopia are mentioned in table 2.1. But crop residues have little alternative use for the production of charcoal.

Table 2.1: Comparison of properties of biomass and biomass waste most commonly used for charcoal and fuel briquettes

Charcoal Type	Suitability for Charcoal Production	Availability of Biomass	Cost	CV (Kcal/kg)
Acacia	Any carbonization technology can be used	Availability reduced in most countries Long period to mature. For example, Acacia nilotica takes 15 years to develop for charcoal in Sudan	Expensive	7900
Eucalyptus	Any carbonization technology can be used	Available in abundance in many countries develop in 4-5 years	Relatively inexpensive	6100
Prosopis juliflora	Any carbonization technology can be used	In African countries, Like Ethiopia, Kenya, and Sudan, it is an invasive exotic tree	Inexpensive	7150
Bamboo	Brick kiln, metal kiln or retort	Abundant in Latin America, Asia (China and India) and Africa. (More than 1 million ha is available in Ethiopia). In many African countries, it is neglected and not utilized at all	Inexpensive	6920
Cotton stalk	Metal kiln or retort	Can be freely collected since it is generally burned on-site	Freely collected	5300
Coffee husk	Improved pit kiln or retort	Can be freely collected since it is generally dumped in rivers.	Freely collected	5100
Sawdust	Improved pit kiln or retort	Can be freely collected since it is generally burned on-site.	Freely collected	4980

Source: (Yisak Seboka and Negusse Mequanint, 2006) ;(FAO, 1993)

2.2.1. Charcoal Making Process

The charcoal making process is different from country to country and the technology they use is also different. Some are being well adjusted but the other less. The conversion biomass through the process of pyrolysis is charcoal making. There are four stages in the process of charcoal making depend on the temperature.

Stage 1: Drying it is an endothermic reaction that takes place at a temperature between 110-200^oC. Air-dry wood contains 12-15% of absorbed water; after this stage the water completely removed.

Stage 2: Pyrolysis process is an endothermic reaction (170-300°C) known as the "pre-carbonization stage". During this stage, some pyroligneous liquids such as methanol and acetic acid, and a few non-condensable gases such as carbon monoxide and carbon dioxide, are produced.

Stage 3: Carbonization takes place in an exothermic reaction (250-300°C). At this stage, pyroligneous acids and the bulk of the light tars produced in the pyrolysis process are out from the biomass.

Stage 4: The temperature is greater than 300°C. During this stage, the biomass is converted into charcoal, the fixed carbon of the charcoal is increased, and this is one of the characteristics in this stage. The charcoal does, on the other hand, still contain considerable amounts of tarry residue, together with the ash of the original biomass.

About 3-5% of the charcoal has ash content; the tarry residue may extend to about 30% by weight and the fixed carbon balance is approximately 65-70%. Additional heating increases the fixed carbon content by driving off and decomposing more of the tars. The maximum working temperatures are about 500^{o}C. At this temperature, volatile content is 10% and the fixed carbon content is approximately 85% (FAO, 1987).

2.2.2. The Efficiency of the Charcoal Production Process

The charcoal production is influenced by the following major factors: Moisture content of the biomass (drier is better), type of kiln, size of the kiln (larger is better), type of biomass, loading of the biomass (denser is better), skill and experience, climatic conditions, temperature, oxygen supply, pressure and weight-based carbonization efficiency (based on charcoal yield) is a percentage rate expressing the ratio between the weight of the charcoal output and the weight of the air dry sample input. For instance, at 15 % moisture content the typical yield of a brick kiln is around 30%.

2.2.3. Charcoal Production Technology

Types of charcoal kiln include kiln (batch) method, earth kilns (earth mound (traditional)), improved earth mound (Casamance), pit kilns (traditional pit kiln, improved pit kiln), brick kilns, metal kilns (mark v metal kiln, drum charring units). Most commonly known charcoal kiln use for the production of briquette charcoal in Ethiopia is mark v metal kiln and drum charring units.

Mark v metal kiln: It is one of the best-known metal kilns has a main body of two cylinders joined with a slightly conical lid and top and its lid have a hole in the center which is covered except during ignition.

Drum charring units: Drum charring units are metal charcoal kilns made from 200-liter oil drums. This kind of kilns are used to carbonized fast-burning raw materials such as agro-industrial wastes (coffee husks, cotton stalks, bamboo waste, sawdust, etc.) successfully and it has the conversion efficiency on average 25%. Different types of carbonization technique can be used for charcoal production depending on the type and quantity of residue available and among others market price of wood charcoal. The drum carbonizing units and metal kilns techniques are simple, low cost and manually operated. On the other hand, there are techniques that are not suitable for small-scale production systems, they are more expensive and continuously operated charcoal production technologies and require skill manpower operators and technicians charcoal made from agricultural residue must be densified to appropriate size and shape for the purpose of household uses otherwise it is not suitable for use in household stoves and also very difficult to handle (Seboka, 2009).

2.2.4. Briquetting Technologies

There are different types of briquettes technologies that are comfortable for the preparation of carbonized and non-carbonized biomass. The main briquette technologies are suitable for charcoal briquette production, different from very small to medium capacity (BTG, 2013).

Hand presses: Briquetting can be done by hand, using a simple mold and hammering the charcoal dust together. D-Lab of the MIT developed a tool that costs about 2 USD and can produce 10-12 briquettes per minute (Desta *et al.*, 2014). Hand briquettes require only a low investment but are very labor intensive.

Piston Press: It is also known as ram and die technology and it is high compaction or binder less technology, In this circumstance, the biomass is pressed into a die by a reciprocating ram with a very high pressure thereby compacting the mass to get a briquette.

Screw press: The raw material is compressed uninterruptedly by a screw through a die heated from outside, usually electrical. The hole in the screw increases the surface area of the briquette and helps efficient combustion. It produces strong briquette and it has very good burning characteristics. To use the Screw press the raw material needs maximum 12% moisture content and practical size should be uniform. It needs regular maintenance and is not suitable for briquetting of charcoal. They are typically used for briquetting of non-carbonized biomass. It is high compaction technology or binder less technology and the biomass is pressed in a die by a reciprocating ram at a very high pressure, the biomass is extruded continuously by a screw through a heated taper die.

Hydraulic piston press: it is different from mechanical piston press. In this case, the energy to the piston is transferred from an electric motor through a high pressure hydraulic oil system and it is light and compact. Since, of the slower press cylinder compared to that of the mechanical machine, it results in lower outputs. The briquettes produced have a bulk density lower than 1000 kg/m³ due to the fact that pressure is limited to 40-135 kg/hr. This machine can tolerate higher moisture content than the usually accepted 15% moisture content for mechanical piston presses (Grover and Mishra, 1996).

Agglomerators: In several developing countries agglomeration technology applied for small-scale briquette. The charcoal is crushed to powder, binders are added, the components are mixed together, and the mix is then agglomerated. This technology involves size enlargement of a nucleus/balls of charcoal formed within a rotating cylinder. Agglomerated charcoal briquettes are created using a motor-driven agglomerator, the typical small capacity of which is 25-50 kg/hour. Agglomerated charcoal briquettes usually have diameters between 20-30 mm and they are spherical. The briquettes can be used for household cooking besides for fuelling industrial furnaces. From most other briquette types Agglomerated briquettes are stronger. Agglomeration technology applied for small-scale briquette in several developing countries (BTG, 2013).

Roll press: From different types of biomass roll press is used for the production of briquette charcoal. To produce pillow-shaped briquettes a mixture of charcoal and binders are fed to the tangential pockets of two roller presses. For the smooth production of briquette, high-quality rollers with smooth surface require on which the briquettes are shaped. The current minimum available capacity of roll press is in the range of 1-4 tonnes/hour (BTG, 2004).

Beehive/honeycomb briquette machine: To produce uniform, high packed briquettes in a uniform mode it uses simple mechanical and electrical part and it is also cost-effective. It produces one briquette per minute and suitable for small and medium sizes. The consumer uses short time cooking or boiling in order not to waste the briquette for small-size beehive briquettes and they use large-size beehive briquettes for the purpose of longtime cooking. Normally, 2 briquettes of 500g each are produced at a time. Beehive briquettes have excellent burning qualities; the energy release is gradual and uniform, giving a blue flame. It requires special stove (beehive stove) to use the produced beehive briquette charcoal, this is the main problem. It is less well-known in Africa, but which is readily available in Vietnam, China, and Thailand. Generally, the most successful briquetting processes used in many developing countries are the agglomerated charcoal briquette and the honeycomb charcoal briquette (Seboka, 2009).

2.2.5. Common Binders used in Biomass Densification

Charcoal is a material completely missing elasticity and hence needs the addition of a sticking or agglomerating material to enable a briquette to be formed (BTG, 2013). Binders are substances, organic or inorganic, natural or synthetic, that can hold (bind) two things or something together. There are two classifications of most important binders; these are organic and inorganic binders. Organic binders include molasses, coal tar, bitumen and starch and inorganic binders like clay, cement, lime and sulfite liquor. Many of them are proposed and used to produce briquette. The binder has required the properties include produce a strong and a waterproof briquette, does not weaken the quality of the coal, does not affect the use of the coal and economically viable and environmentally acceptable (Raju *et al.*, 2014).

Table 2.2: Overview of properties of main binders

Binder	Clay	Starch	Gum	Molasses	Wood tar/pitch
Percentage of final product	15%	4-8%	<10%	20%	<10%
Price	Low	high	Medium-high	Medium-high	Low - medium
Alternative uses	no	Food/feed	Food/feed	Food/feed	Energy
Contributes to calorific value of the briquette	no	yes	yes	yes	yes
Thermal treatment needed to avoid smoke	no	no	no	Preferably	yes
Increases ash content	yes	no	no	Yes	No
Waterproof briquettes	no	no	no	After curing	After curing

Source Estimation (BTG, 2013)

2.2.6. Carbonization and Briquette Making

During direct heating of carbonization at the beginning, the raw material is balanced and note down. To protect the produce heat loss during carbonization it need to test leakage the selected kiln and then, at the bottom of the kiln there is a need to use the wire mesh grate for the purpose of heat media for the partial oxidation process and the heat flow inside the kiln become more effective. After placing the carbonize material for carbonization the selected kiln was closed (Sanger *et al.,* 2011) and there is a need to using firing material like loose glass to initially start-up the firing (Quaak *et al.*, 1999).

To know the transfer of heat uninterrupted visualization is done and based on the changes observed at the exhaust essential to fix the air inlet of the kiln. In every 60 minutes, the temperature of the material used inside the kiln, outside of the kiln and exhaust smoke is recorded. The carbonization stage changes are observed and time is recorded. To know the selected raw material is changed into charcoal there is a need for continuous observation of the smoke color. The color of the smoke that is the blue and the light blue indicates the selected material is changed into charcoal or not. During this stage when the raw material is changed into charcoal primarily blue smoke is changed into light blue and then it became purer. Finally, the kiln needs 8 hours to cool down after carbonization and there is a need to divide the charcoal and the ash then, their weight must be noted (Sanger *et al.*, 2011).

Similar research work also indicated about the carbonization of Rubber seed shell was that first they used in the material collection and preparation stage is that the collected material (Rubber seed shell) are cleaned and sun dried for 5 days to minimize the moisture content and then the weight of the selected sample is balanced. The carbonizer used to produce the charcoal at low oxygen environment is 24 cm high and 23 cm in diameter and this is divided into two that are firing chamber and carbonization chamber. For the purpose of loading the carbonized material the top part of the drum is opening and the bottom part is also open for the purpose of both the removal of the smokes and firing. The carbonization process of this paper visualized that the sun-dried biomass material is loading into the drum by the top part of the opening and then to fire easily used paper and the rubber seed shell inside the cylinder and the air enters in to the cylinder within the holes at the bottom of the drum, for the selected material used burned time in the range about 10 to 15 minutes. Furthermore, to know the effectiveness of carbonization observes the smoke clearness and then, blocks the top and the bottom opening by the prepared soil to block the entrance of air into the drum. Then after, for the period of 2 hours, the carbonization process is continued without interruption in the absence of air. For the purpose of binding used starch that is made up of cassava tuber, the reason is that it is easily available in the study area, support combustion and in addition to that it is inexpensive and the ratio used in this study was 3:1 (i.e. three percent the carbonized powder and one percent the binding). And finally, they concluded the briquette making process is that the mixture is transported into the mold and the sample briquettes are produced and then dried for 2 weeks in a natural environment under an average temperature of 35 ^{0}C (Emmanuel *et al*, 2014).

2.2.7. Characteristics of Briquettes

Briquettes have many advantages, this includes the net calorific value per unit volume increases during the process, it is easy to transport and store because it is a densified, and the problem of residue disposal solved during the process and the size and the quality of the produced fuel are uniforms. Before using briquettes for consumption, their moisture content (MC), volatile matter (VM), ash content (AC), fixed carbon content (FC), calorific value (CV), and bulk density (BD) must be studied and characterized (Oladeji, 2010).

2.2.7.1. Proximate Analysis

The proximate analysis is the characteristics of fuel briquette that have a close relation to combustion behavior and which is an idea of the bulk components that make up the fuel standard procedure. VM, MC, AC and FC content of the briquettes are determined by the proximate analysis (Chaney, 2010).

Moisture Content: Moisture present in the biomass accelerates starch gelatinization, protein denaturation, and fiber solubilization processes during extrusion, pelleting, or briquetting. The initial moisture content, temperature, and pressure affect the final moisture content of the briquette. MC of the raw material biomass greater than 15% result higher MC in the final product (Tumuluru and Wright, 2010).

Volatile Matter: It is the charcoal elements excluding moisture, which are liberated at high temperature in the oxygen scares of air. This is generally a combination of short and long chain hydrocarbons, aromatic hydrocarbons and some sulfur. To produce a good quality briquettes the pyrolysis temperature must be optimize. Moreover, a small amount of VM is necessary to produce economically acceptable briquette for the local market by giving good ignition of the combustion (Debdoubi and Colacio, 2005).

Ash Content: Ash is solid residue which is produced by the chemical breakdown of a biomass fuel. It is produced after a complete combustion and it is non-combustible inorganic residue. The thermochemical conversion process and particularly combustion are affected by the ash because it produces the chemical compound content in the ash react to form slag. The higher quality briquette has low ash amount. Ash is expected to have values for commercial fuels from 0.6% to 9.8%, energy crops from 1% to 9.6%, cereals from 1.8% to 4.8% and industrial waste from 0.4% to 22.6%. General values may appear in a range of levels below 5–20% (Maia *et al.*, 2014).

Fixed Carbon: The FC of the briquette, which is the percentage of carbon (solid fuel) available for char combustion after VM, is distilled off. It gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning (Akowuah *et al.,* 2012). The FC content of the charcoal is different from the coal ultimate carbon content that is why certain carbon is omitted in hydrocarbons with the volatile and it is also used to assess how much amount of coke will be found in a given sample of charcoal. The greater the FC, the greater the amount of element existing for combustion, therefore, the greater the amount of heat released (Cuaresma *et al.,* 2015).

2.2.7.2. Physical Property

Bulk Density (BD)

For domestic and industrial use, direct burning of agricultural residues efficiency is very low. Additionally, some of the disadvantages of transportation, storage, and handling problems are also related to its use. In order to produce pellets or briquettes use densification which is one of the approaches, being actively followed worldwide towards improved and efficient utilization of agricultural and other biomass residues. BD is the most important physical property in designing the logistic system for biomass handling in addition to this; it is an important characteristic of biomass that impacts directly the cost of feedstock distributed to a bio-refinery and storage cost (Bhagwanrao and Singaravelu, 2014). But it is affected by the following factors like shape, size, particle density, moisture content, and surface characteristics. The BD of the briquette was expressed as the ratio of the mass of the briquette to the volume of the briquette (Yaning *et al.*, 2012).

Calorific Value (CV)

The physical and chemical composition of the biomass influences the energy content. Particularly, the water and hydrogen content, the measure of the energy content of the biomass without any free water is known as “higher heating value” or “gross calorific value”. In this case, the complete dry biomass still contains chemically bonded water and the water produced in chemical reactions during combustion (Rosillo-Calle *et al.,* 2012).

It is the combustion test that is the amount of heat energy released during the complete combustion of a unit mass of biomass or it is the amount of energy per kg it gives off when burned and one of the most important characteristics of a fuel and useful for planning and control of the combustion plants this is measured with oxygen in a standardize calorimeter by using about one gram of sample and taking water as much as two litters then, before putting the samples into the instrument, 400 psi pressure oxygen is given, then 8 cm long wire length and fuse combustion heat of 4.1 Btu /cm, then finally the change in temperature (ΔT) and the heat out by burning briquettes will be calculated and recorded using installed program in a Bomb Calorimeter (S Suryaningsih *et al.,* 2017). The increasing of temperature during pyrolysis results the increasing the power CV caused by the elimination of MC, some VM and an increasing in the amount of FC thereby providing a higher energy per volume ratio (Debdoubi and Colacio, 2005).

2.2.7.3. Previous Work on Proximate and Physical Properties of Briquettes

According to Romallosa and Hornada, (2014) the growth of using biomass resource and urban wastes for briquette production is due to the increase in fuel prices. They also indicated that changing them into briquette create a chance to organize wastes and clean the environment from unwanted wastes, prevent the forest from deforestation, and decrease greenhouse gas (GHG) emission and it gives alternative energy for poor urban and rural community. This study also shows that waste materials previous which have low density to be changed in to briquette is compacted to produce higher bulk density, lower moisture content and the same shape and size making these materials simple package and store, low cost to transport, comfortable to use, and the combustion characteristics are better than the original waste material. The major steps for briquette production need four procedures, namely: preparation of materials used, mixing of the prepared materials by hand compaction of the materials using the selected molder, and finally drying the briquette to produce the end product. They also concluded that the most viable mixture to produce briquette is that paper with sawdust, the combination of paper, carbonized rice husk and sawdust and individually paper. The reason for their selections is such as production requirement and high production rate, better-produced fuel quality, rapid operating performance in terms of boiling water and cooking rice and the potential for income generation.

Other related study shows that the production of briquette from sesame stalk can have the potential to solve health problem and energy poverty at the same time it can solve deforestation. Their laboratory analyses showed that the calorific value produced from sesame stack with 15% optimal possible clay binding have 4647.75 Cal/gm. and minimum ash content, this value decrease with increasing the ratio of binding (clay) material and this value is satisfactory energy content for cooking. In addition to that the paper also shows that the main factors for the quality of briquette are ignition time, % of volatile matter, % of sulfur availability, % of fixed carbon, and % of moisture content of sesame stalk briquettes, they also compared with that time on-use biomass briquettes and they showed that for cooking and heating purpose sesame stalk briquettes is the best from the others (Gebresas *et al.*, 2015).

According to Windi *et al.* (2015), they used the method that sample household wastes are collected, the organic wastes are settled for different days in order to analyze composting then after that they pressed to reject the fluid wastes and analyze the water content and heating value and their result shows that within one day the heating value in the range of 1956.832 to 3257.24 Cal/gm. and the water content at the starting ranging 53-65% an average 1.631% moisture content. In the end product (briquettes) the calorific value increased. They also indicated that because of municipal solid waste have different material, the composition of heterogeneous mixture and size, there are a lot of briquettes process such as household waste collection, drying, binder preparation and mixing, Briquette production, Drying and packing and finally analyzing. And lastly they concluded that to get well quality briquette, it is better to put the wet briquette in windy place in order to minimize energy that is necessary for drying, the calorific value of the household waste composition must be checked whether the material has higher caloric value (such as paper, sawdust etc.) or not and the household waste should be sliced before mixing with binding to get well briquette.

Other research paper studied by Raju *et al.* (2014) indicated that first, they selected that sawdust, almond leaf, and cocopeat as a raw material for the conversion to briquettes their reason for the selection is that the raw material availability. This helps in reducing economic and environmental problems and the growing regions also get a renewable, clean and sustainable source that can substitute firewood and charcoal that was produced in a traditional way. They used proximate analysis moisture content, ash content, volatile matter, and the fixed carbon is determined. They also used the briquette sample size was fixed as 6*3*3 inches and they used for the binding purpose 125g plain flour per each briquette in addition to this they also determined calorific value, porosity, ultimate analysis, x-ray diffraction, scanning electron microscope. They first did to the biomass collection, and then after the collected materials are dried for a period of 10 days until its moisture content was around 10-15%, later they determined initial characteristics properties like calorific value, volatile matter and ash content within three intervals, then after the initial moisture content, proximate and ultimate analysis carried out. Their result showed that the proximate analysis for fuel briquettes of sawdust contains moisture content 15.71%, ash content 10.3%, volatile matter 54.59%, fixed carbon 19.42%, and badam leaves contains moisture content 18.20%, ash content 15.8%, volatile matter 47.3%, fixed carbon 18.7% and cocopeat contains moisture content 18.65%, ash content 9.8%, volatile matter 53.55%, and fixed carbon 18.1%. From their result, they visualized that moisture content of cocopeat 18.65 was the highest, on the other hand, the sawdust moisture content has the lowest, from this they concluded that cocopeat was taken more time for heating and it has lower calorific value. In addition to this they also showed that when the biomass concentration increases the ignition time also increases, they also reported that coal contains lower volatile matter than the biomass. Therefore maximizing its concentration in the briquette will absolutely increase the ignitability of the briquette. They also analyzed that the calorific value produced from sawdust, almond leaf, and cocopeat is 4654 kcal, 42.37 kcal, and 41.46 kcal respectively. And they conclude that briquettes are more efficient than wood charcoal. Finally, they strongly reported that the technology has a great potential for converting waste biomass into a superior fuel for household use, in an affordable, efficient and environment-friendly manner.

Generally, converting waste material into fuel briquettes are improving the fuel price, waste collection problem, prevent the forest from deforestation, decrease greenhouse gas (GHG) emission and it gives alternative energy for poor urban and rural community.

2.3. Environmental and Socio Economic Benefits of Fuel Briquette

Fuel briquettes charcoals are a smokeless fuel this is because during carbonization the smoke removes. The smoke produced from wood charcoal cause various respiratory illnesses and decreased pulmonary function (Tzanakis *et al.*, 2001). It is possible to use all degradable wastes for the production of charcoals including waste banana leaf, however, the output of the charcoal different from waste to waste. Carbonized organic matters are changed into char briquettes which are smokeless and efficient during burning. In addition, to reduce the deforestation by eliminating the need to cut down trees for fuel wood it has also another advantage to reduced smoke pollution to the environment and producing fuel briquettes from wastes increase the income, wealth of individual entrepreneurs and the country in general (Bogale, 2009).

In developing counties fuel briquette can give significant and considerable environmental and socio-economic benefit by resolving the problem of deforestation and shortage of fire wood. Therefore, the developing country like Ethiopia used their vast forest and agro residues environmentally friendly manner by generating energy (Gebrekidan and Belete, 2015). In general, the implementation and promotion of briquette produce the following environmental, social and economic benefits:

- It is suitable for stoves and burners because which have uniform size, shape and quality.
- It avoids health impacts by providing smokeless fuel and reduces indoor air pollution.
- It increases the net calorific values of the biomass per unit volume.
- The handling, transportation, and storage are comfortable after changing into briquette.
- The procedure minimizes the residual disposal and sanitation problems.
- It increase the burning time and reduce fuel consumption related to that solve the reliance on fuel wood and deforestation.
- The production and marketing of briquettes create profits and job opportunity.

- Briquette fuels produced from waste biomass have lower costs for the users.

Generally, briquette fuel is the most significant biomass technology contributing by civilizing domestic energy supply, increasing environmental protection and sanitation and reducing GHG emissions (Tekle, 2017).

3. MATERIALS AND EXPERIMENTAL METHODS

3.1. Description of the Study Area

The study was conducted in Hawassa city located at latitudes 6°55'12"- 7°4'48" N and longitudes 38°25'48"- 38°33'54" E with an altitude of 1680 – 1813 meter above sea level and covers total area of 157.2 km^2. Hawassa is the capital city of Southern Nations, Nationalities and Peoples Regional state (SNNPRS) of Ethiopia and Sidama zone, located 273 km from Addis Ababa, capital of Ethiopia. It is surrounded by Lake Hawassa in the west, Hawassa zuria woreda in the south and east part and Oromiya Region in the north (CSA, 2007). It is subdivided into 8 sub-cities, namely Tabore, Hayekdar, Menaharia, Misrak, Bahale adarash, Addis Ketema, Mehale Ketema and Awela Tula in which the present study was carried out and 32 kebeles.

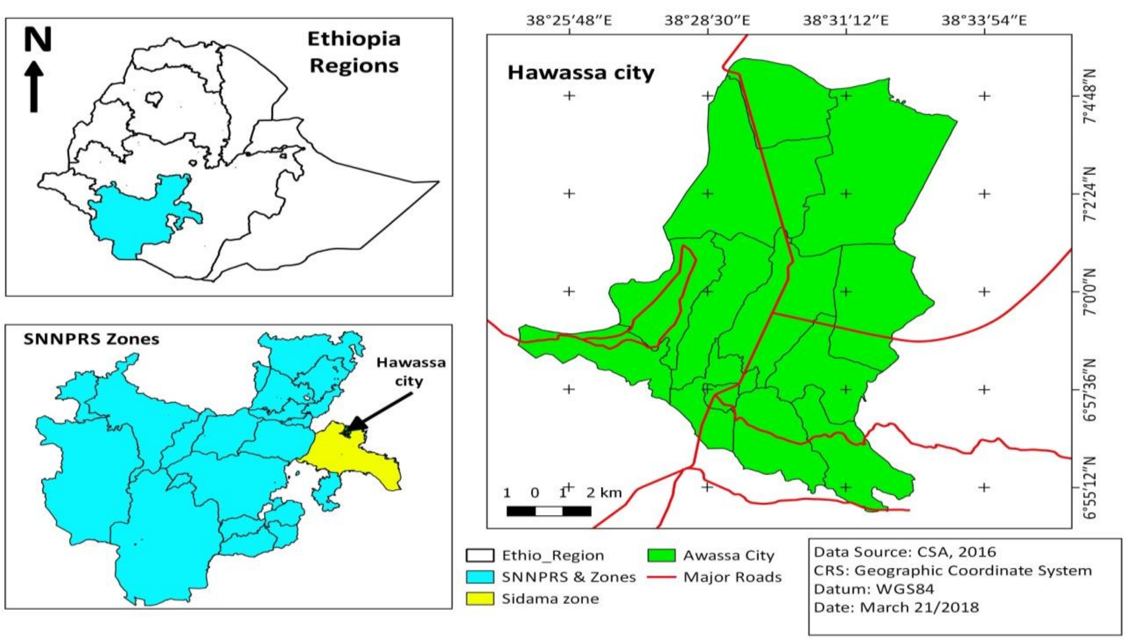


Figure 3.1: Administrative Map of Hawassa City

3.1.1. Elevation and Climate

The average elevation of the town reaches 1700 m.a.s.l. The elevation of the higher ground (Tabour hill) is 1813 m.a.s.l while it is 1750 meters at the foot of the same hill and its lowest lakeside is 1680 m.a.s.l (CSA, 2007). According to the City Administration Office, Hawassa has a moderate type of climate; the mean annual precipitation of the city is 998.2 mm. It has the highest, the lowest and the mean annual temperature of 32^{o}C, 6^{o}C, and 20.3^{o}C, respectively (CSA, 2007; SNNPRS, 2005).

3.1.2. Population

According to the census conducted in May 2008, Hawassa City Administration has a total population of 259,803, out of which 133,637 are male and 126,166 are female. Out of the total number of the population of the City Administration, 159,803 people live in the urban area, while the remaining 100,000 people live in the rural area of the City Administration.

3.1.3. Vegetation

The types of vegetation found in the city have not yet well documented but some areas like squares, streets, parks and recreational areas are covered by some indigenous and exotic tree species. From the field observation point of view, most of the urban green infrastructures such as street, squares, etc. of the city are dominated by exotic tree species. Moreover, other green infrastructure such as urban parks predominately contains indigenous woody plant species.

3.2. Work Flow of the Study

Major process includes Khat residues collection up to the produced fuel briquette and laboratory work process flow chart is as shown in figure 3.2.

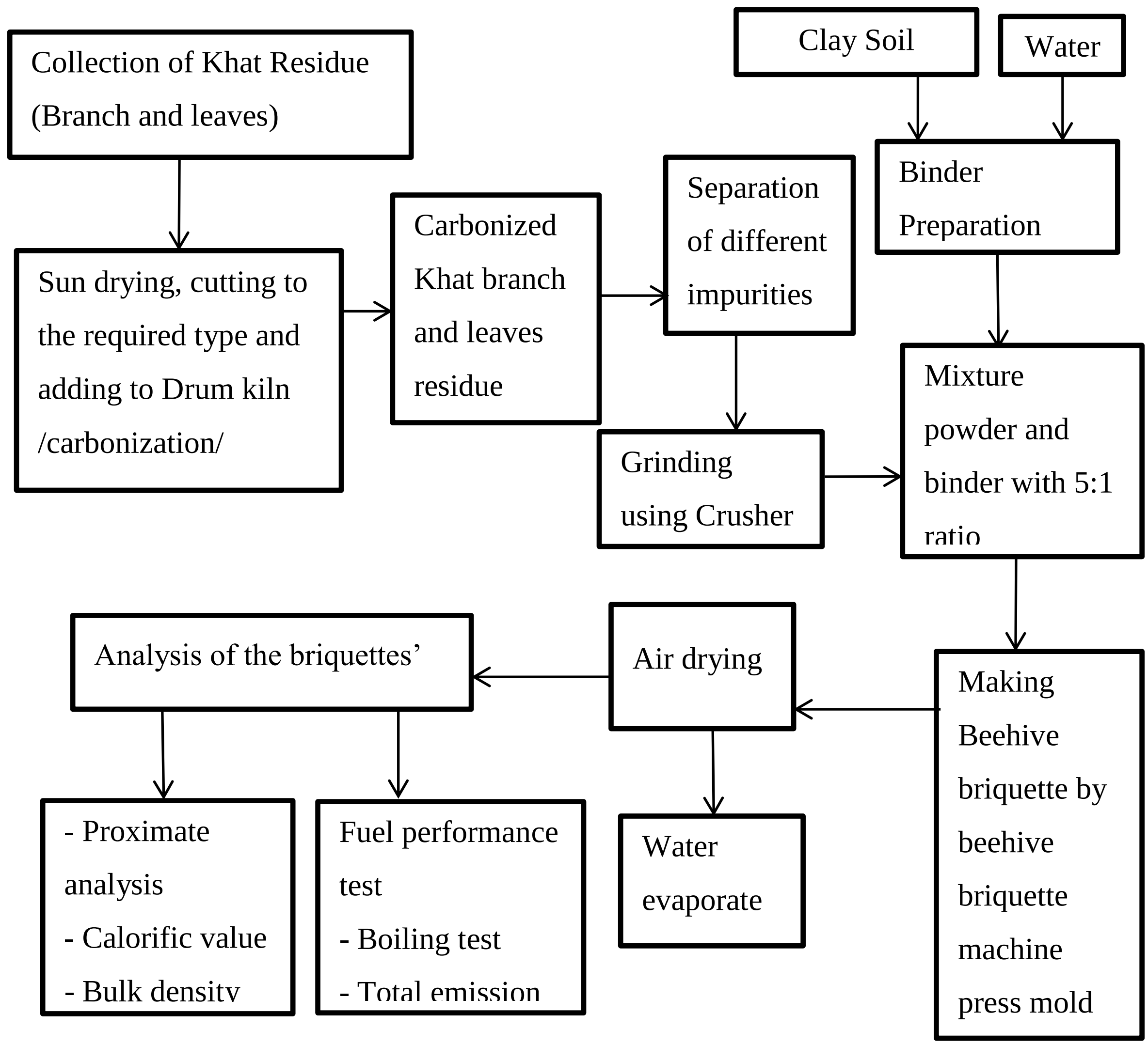


Figure 3.2: Production and analysis flow chart of fuel briquette

3.3. Sample Preparation for the Carbonization Process

The Khat residue is available mainly in both Khat shop and waste dump area. But there are different types of Khat consumed in Hawassa cities such as Seqa, Belecha, Wondo, and Chanqa. So, the samples were collected purposely from the selected area that is Awela Tula, Menaharia, and Misrak sub-city, the reason was that Khat consumption in this sub-city was very high compared to others according to the information provided by SNNPRS Hawassa City Administration Revenue Authority. The collected 200 kg Khat residue was purified from other wastes and sun-dried until the moisture content becomes less than 15% of absorbed water according to the recommendation provided by (Tumuluru and Wright, 2010).

Figure 3.3: Sample preparation for briquette production

The leaves and the branch part of the Khat residue were separated and the branch part of the residues were chopped into small pieces which were equal to 10 cm through the use of locally available material like big knife for the purpose of equal distribution of heat.

3.3.1. Material

Khat (*Catha edulis forsk*) residue, clay soil, and water were materials used for this work.

3.3.2. Equipment

Drum Charring Units, Oven, Electrical Furnace (more than heat 30-3000 ^{0}C), Hood, Testo 330 Emissions Analyzer, Calipers, Analytical balance (sensitive to 0.0001g), Sieves, Cutter and Beehive Briquette Machine Press Mold, Digital Balance (0.5g-16 kg), Stopwatch, Crucibles, Crucible Tongs, Meter, Desiccators, Stove (Merchayae-Stove), Metal Pots and Oxygen Bomb Calorimeter (Parr 6200) were the equipment's used to characterize Khat residue fuel briquette.

3.4. Carbonization Process

Before the carbonization process begun, first weight the sun-dried Khat residue (i.e. the leaves and the branch part separately), to know the conversion efficiency of Khat residue which had moisture content of 10.85% for branch residue and 11.48% for leaves residue. The carbonization of the leaves and the branch part of Khat residue was carried out using the Drum kiln which was made in MOWIE workshop which accommodates 15 kg of branch and 15 kg of leaves Khat residue separately for one cycle. Drum kiln was selected because it is suitable for small amount of burning, easily fabricated from a local material and low cost (Sanger *et al.*, 2011). The sun-dried Khat residue was compactly full into the inner drum through the opening at the top and fire for 45 minutes to 1hr according to (Bogale, 2009). The smoke color would be continuously observed to estimate the selected raw material was changed into carbonized material. The color of the smoke the blue and the light blue indicates the burning material was changed into carbonized material or not. If the raw material was changed into carbonized material primarily blue smoke was changed into light blue and then it became purer. At this time to block the air entrance, the bottom part of the drum was covered by the prepared soil, the side was covered by mud and consequently, the top side was covered by the metal cover (Emmanuel *et al.,* 2014). Finally, the kiln needs stay until cool down after carbonization and separate the carbonized material and the ash then; their weight was note as stated by (Sanger *et al.*, 2011). And the conversion efficiency of Khat leaves and branch residues into carbonized material was computed according to (Emrich, 2013), as follows:

Carbonization efficiency of Khat leaves residue (%) = weight of carbonized Khat leaves residue / weight of raw Khat leaves residue × 100 (3.1)

Carbonization efficiency of Khat branch residue (%) = weight of carbonized Khat branch residue / weight of raw Khat branch residue × 100 (3.2)

Figure 3.4: During carbonization

3.5. Binder Preparation and Mixing

Clay soil was selected as a binder because its availability, inexpensive and no alternative use and the importance of the clay soil was to act as a binder and it was added in same amounts to the samples 20% (i.e. 1:5 ratio 1 kg clay soils with 5 kg carbonized powder). This binder was used to increase the bonding between the carbonize Khat residues. It also increases the heating time and strength of the output. Mixing of the carbonize Khat residue powder with clay soil, it was done manually after carbonizing Khat residue was changed to a powder using crusher; while mixing (Gebresas *et al.*, 2015).

a) Weight the clay soil b) Mixing clay soil with water

Figure 3.5: Binder preparation and mixing

3.6. Briquette Making

Every particle of carbonized material was treated with a binder to enhance briquette sticking together and produced identical briquettes. The mixture was converted into briquettes by using a beehive briquette machine press mold. Finally, the briquettes were placed on a suitable material for dry under the sun for two days according to the recommendation provided by (Seboka, 2009).

a) Beehive Briquette Machine

b) Produced Briquettes

Figure 3.6: Briquette making

3.7. Data Quality Control

During collection of the feedstock (Khat residue) extraneous materials like grasses, leaves, soil, sand, wood branches etc. were removed. After production, the briquettes were pack and kept in a dry and clean environment and subject to laboratory analysis. The laboratory analysis was done after calibration of the instrument following standard procedure of the American Society for Testing and Materials ASTM.

3.8. Laboratory Analysis

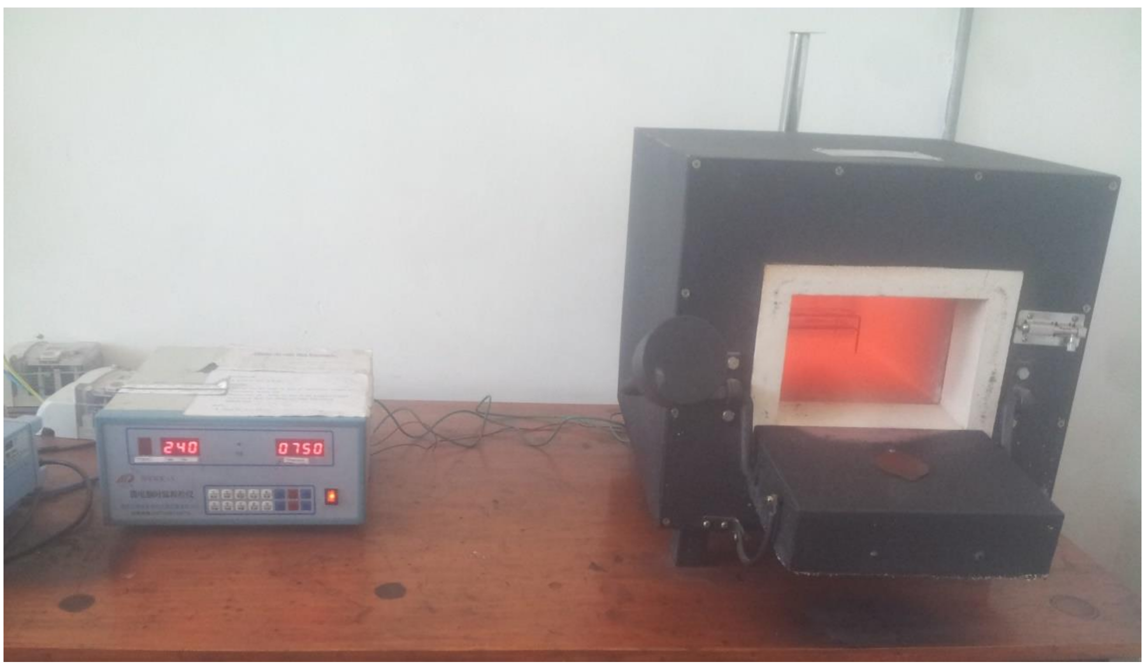
From each treatment, triplicate samples of the dry briquettes were brought to MOWIE workshop for determination of MC, VM, AC, FC, CV and BD.

3.8.1. Proximate Analysis

The determination of all proximate analysis was conducted using the standard test method (ASTM D1762 – 84, 2007).

a) Sample preparation for laboratory work

b) Oven, Crucibles and Crucible Tong



c) Muffle Furnace

Figure 3.7: Testing of combustion properties of samples

Determination of Moisture Content

The crucibles used for the determination of MC of raw Khat residue, carbonized material and the briquette produced from Khat residue was began, first preheating the muffle furnace to 750^{o}C for 10 min and then cool them in a desiccator for 1h then, weighed the crucible and add 1g of sample in each crucible using the nearest 0.1 mg balance. After the above procedure placed the samples in the oven at 105^{o}C for 2h, then placed the dried samples in a desiccator for 1h and the weight was recorded. The procedure was repeated until constant mass of sample was record. The same specimen used for VM and AC determination. Then, the MC was calculated by the following equation.

$$\text{Moisture, \%} = [(A - B)/A] \times 100 \qquad (3.3)$$

Where: A = grams of air-dry sample used, and B = grams of sample after drying at 105°C.

Determination of Volatile Matter

In this test procedure, determined the percentage of gaseous products, exclusive of moisture vapor. The VM content of raw Khat residue, carbonized material and briquettes were determined by preheating the crucibles used for the moisture determination at 950^{o}C by preheating the crucibles, covers and samples in the muffle furnace door open, for two minute on the outer edge of the furnace at 300^{o}C, then heating for three minute on the edge of the furnace at 500^{o}C, then move the samples to the rear of the furnace for six minute with the muffle furnace door closed at 950^{o}C in covered crucible of specimen by lid or metal box prepared for this purpose. Finally, cool the samples in a desiccator for one hour and weight. The VM was computed as follows.

$$\text{Volatile matter, \%} = [(B - C)/A] \times 100 \tag{3.4}$$

Where: C = grams of sample after drying at 950^oC

Determination of Ash Content

The AC in this sample is the approximate measure of the mineral content in the sample. In order to do this, place the lids and the uncovered crucible used for the VM determination, and containing the sample in the muffle furnace at 750^oC for 6 hour. Finally, the crucibles were cool with lids in placed in a desiccator for 1 hour and then, the weight was recorded. The AC was calculated as follows:

$$\text{Ash, \%} = [(C - D)/A] \times 100 \tag{3.5}$$

Where: D = grams of residue at 750^oC

Determination of Fixed Carbon

The percentage of carbon present in a particular sample is mentioning to carbon content. During combustion, the percentage of available carbon is the fixed carbon of fuel that is not equal to the total amount of carbon because there is also a significant amount that was released as hydrocarbons in the volatiles. The FC of the sample in this study was computed by subtracting the sum of VM, AC, and MC from 100.

$$\text{FC (\%)} = 100 - (\text{MC\%} + \text{VM\%} + \text{AC \%}) \tag{3.6}$$

3.8.2. The Physical Property of Fuel Briquette

3.8.2.1. Determination of Calorific Value

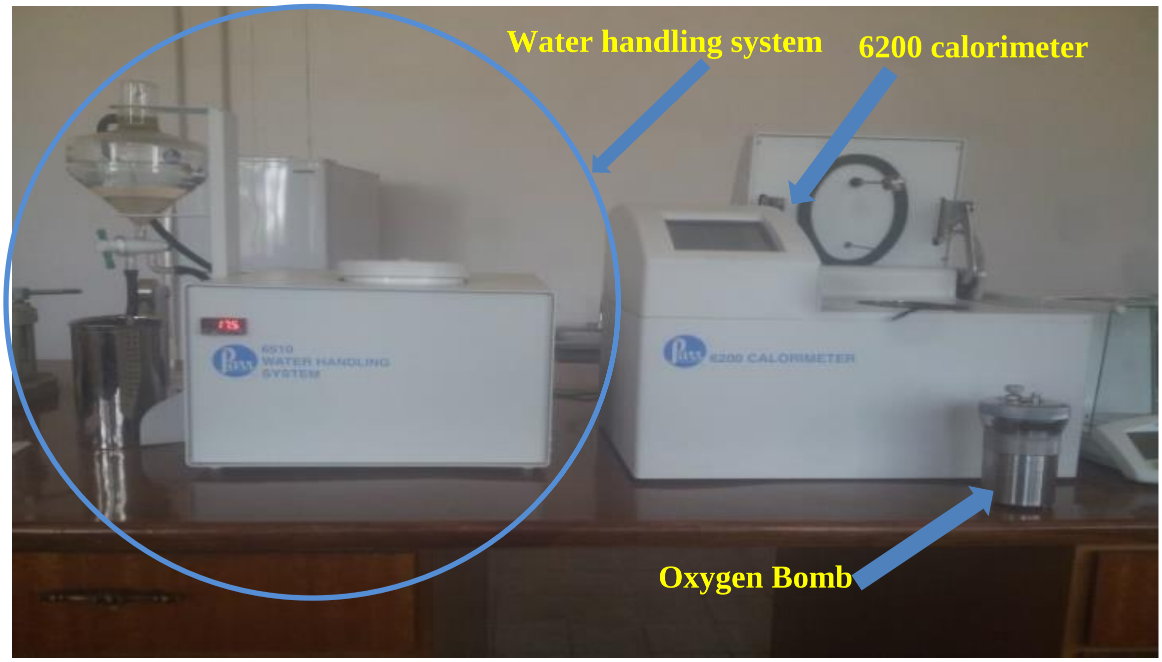


Figure 3.8: Adiabatic Oxygen Bomb Calorimeter (Parr 6200)

In order to measure the CV, Parr 6200 Calorimeter with a standard 1108 Oxygen Bomb at Alternative Energy Development and Promotion Directorate Laboratory, MOWIE, the briquette samples investigated by an Adiabatic Oxygen Bomb Calorimeter Parr 6200 Calorimeter of Parr M39889 and Parr M39805 Oxygen Bomb, which were used following the Parr instruction manual according to (ASTM D-5865-95, 1996). The briquette samples pulverized with 0.7-1 gram and then placed in a capsule and combusted in and investigated by an Adiabatic Oxygen Bomb Calorimeter Parr 6200-calorie meter and the resulting CV measured (Abebe *et al.*, 2017).

3.8.2.2. Determination of Bulk Density

Bulk density of the briquette was determined by taking 10 randomly selected briquettes and the weights of the produced briquettes were determined using digital balance, while the volume of the briquette was also determined by taking the average diameters and heights of the sample briquettes from two different positions using Calipers (0.1 mm precision) (Rabier *et al.,* 2006). It is calculated by $V = (\pi D^2 H)/4$.

Where, $\pi = 3.14$, D = diameter and H = height

$$BD\ (g/cm^3) = (\text{mass of briquette sample}) / (\text{volume of briquette sample}) \quad (3.7)$$

3.8.3. Fuel Performance Test

3.8.3.1. Combustion and Water Boiling Capacity Test

In this study, the property of the produced fuel briquette such as flame color, production of dangerous spark formation, smoke and odor was check by combustion test. To know the water boiling capacity or heating efficiency test one litter (1L) of water and 500g of briquettes was used and then boiled, from this predicted the practical cooking time, efficient application or usage of the produced briquette (Abebe *et al.,* 2017). The combustion and boiling tests, for the produced briquettes, were done using Merchayae-Stove (The “Merchaye” an improved briquette charcoal stove has an efficiency of more than 75% and a fuel saving stove compared with traditional charcoal stoves). The stove is popular among urban dwellers and now a day such briquette charcoal and stoves have been disseminated by many micro investor / entrepreneur / and energy sake holder in urban and rural part of Ethiopia (Seboka, 2009).

Figure 3:9: Combustion and Water boiling capacity test on produced briquettes

Total Emission Test

The total emission of the produced briquettes was measured using Merchayae-Stove with the produced briquettes of 500 g from Khat branch and leaves placed inside a closed standard Hood system (the hood closed on all sides except the front) it has dimensions 1000 mm width×750 mm diameter × 2820 mm height and it also had gas mixing chamber with gas analyzer connecter and a continuous measurement of CO, CO_2, O_2, NO, and NO_X was measured using Testo 330-2 L_L model multi component gas analyzer then record was took with 3 minutes interval according to Indian standard for portable solid biomass cook stove.

Figure 3.10: Total emission test on produced Khat residue briquettes

3.9. Amount of Khat Residue Calculation

The Khat residue amount was determined by taking one kilogram of Khat from randomly selected ten Khat sellers and by estimated how much Khat residues were found from one kilogram Khat and hence, their average was taken to determine the amount of Khat residue. It was assumed that all Khat legally supplied to the city were fully consumed.

3.9.1. Potential of Khat Residue to Produce Fuel Briquettes

To know the amount of fuel briquettes produced, first by taking 200 kg wet Khat residue from the selected study area and then, how much amount of dried Khat residue was found from this amount after one month sun or air dried Khat residue after this the carbonization yield of the dried Khat residue branch and leave was calculated by taking the average carbonization efficiency of 15 kg sun dried Khat residue separately (i.e Khat branch and leaves) and then, mixed this amount with 20% clay soil binder the amount of fuel briquettes produced from Khat branch and leaves was determined and finally, the total amount of fuel briquettes produced from the total amount of the Khat residue was calculated.

3.10. Data Collection and Analysis

Data were gathered from carbonization process, governmental organizations and laboratory analysis of briquettes it was conducted in MOWIE at Alternative Energy Development and Promotion Directorate Energy laboratory and workshop section, located at Gurd Sholla Addis Ababa. The result were recorded, processed and analyzed using Microsoft excels. Descriptive statistics and chart graph was used to compare means and standard deviation (SD) of the result. All the analysis tests were done in triplicate (Merete *et al.*, 2014).

4. RESULTS AND DISCUSSION

4.1. Total Amount of Fuel Briquettes Produced from Khat Residue

4.1.1. Average Amount of Khat Residue from 1kg Khat

The result of the study in table 4.1 below shows that, from the selected 10 Khat Shops and Chewers taken on average from 1 kg Khat 0.7 kg Khat residues were found.

Table 4.1: Amount of Khat residues from one kilogram (1kg) Khat

Trial No	Amount of Khat (kg)	Amount of Khat residues (kg)
1	1.00	0.70
2	1.00	0.80
3	1.00	0.79
4	1.00	0.69
5	1.00	0.65
6	1.00	0.62
7	1.00	0.63
8	1.00	0.72
9	1.00	0.65
10	1.00	0.76
Mean ± SD	1.00	0.70 ± 0.06

4.1.2. Average Amount of Khat Supply and Residue Potential from 2012-2016

According to the information provided by SNNPRS Hawassa City Administration Revenue Authority, from 2012 to 2016 total volume of taxable Khat supplied to Hawassa was estimated to 32,497,109.4 kg and the corresponding estimated wet residue potential was 22,747,976.58 kg. However, not all Khat residue generated is available. Some part is collected and used as cooking fuel while some part is disposed as part of the solid waste removed from the cities. Table 4.2 shows yearly taxable Khat consumption from 2012-2016.

Table 4.2: Calculated total Khat supply, revenue, and Khat residue generation

Year	Khat Supply (kg)	Revenue (birr)	Khat Residue (kg)
2012	4,852,509	24,262,543	3,396,756.02
2013	5,984,150	29,920,751	4,188,905.14
2014	6,863,476	34,317,381	4,804,433.34
2015	7,950,227	39,751,136	5,565,159.04
2016	6,846,747	34,233,736	4,792,723.04
Mean ± SD	6,499,422 ± 1,033,038	32,497,109 ± 5,165,189	4,549,595.32 ± 723,126

4.1.3. Carbonization Yield

The conversion efficiency of raw feedstock (un-carbonized Khat branch and leaves residue into carbonized material) reached 28.33%, for that of Khat branch residue (i.e. from 100 kg of air dry Khat branch residue net average carbonized branch residue amounts 28.33 kg). On the other hand, 27.89% for that of Khat leaves residue (i.e. from 100 kg of air dry khat leaves net average carbonized leaves residue amounts 27.89 kg).

Table 4.3: Summary of results of Khat residues carbonization yield using Philippine model carbonization drum kiln.

Sample of feed stock	Treatment	Input (kg)	Output (kg)	Conversion efficiency of feedstock into carbonized material (%)
Raw Khat branch	TB_1	15.00	4.10	27.33
	TB_2	15.00	4.22	28.13
	TB_3	15.00	4.42	29.47
	Mean ± SD	15.00	4.25 ± 0.13	28.33 ± 0.88
Raw Khat leaves	TL_1	15.00	3.90	26.00
	TL_2	15.00	4.26	28.40
	TL_3	15.00	4.39	29.27
	Mean ± SD	15.00	4.18 ± 0.21	27.89 ± 1.38

Where TB - Treatment of branch and TL – Treatment of leaves

The results in this study showed that the carbonization of the Khat branch and leaves residue have about 28.33% and 27.89% at 10.85% and 11.48% respectively (Table 4.3 and 4.5). The typical yield of a metal kiln at 15% moisture sample content is about 30% (Seboka, 2009). Hence, the carbonization yield in this study was small difference from the above idea this could be due to the moisture difference and type of kiln used in this study which is Philippine model carbonization drum kiln. Previous study confirmed that the carbonization efficiency can be affected with several aspects such as the moisture contents of the input sample, type of the kiln (the number of holes in the kiln that control the amount of air for the appropriate carbonization), cooling personal skill, weather condition. One of the major factors that affect the quantity and quality of fuel charcoal or fuel briquette production is the moisture of the sun dried sample (Abebe *et al.*, 2017).

Generally, the solid carbonaceous char yield varies from 24.87 to 32.49% by weight for different pyrolysis condition (Belay and Gabbiye, 2015). Therefore, the results of the carbonization yield in line with the above criteria.

4.1.4. Amount of Briquette Produced from the Average Amount of Khat Residue

The result indicated that from 200 kg total samples of wet Khat residues, 120 kg air dried Khat residues were found (i.e. from 100% of wet Khat residue 60% is air dried Khat residue), from this amounts 51.76% was air dried branch and 48.24% was air dried leaves (i.e. 62.40 kg air dried branch and 57.60 kg air dried leaves) and on the other hand, on average from each 15 kg air dried Khat branch and leaves residues 4.25 kg and 4.18 kg of carbonized branch and leaves respectively (Table 4.3). In addition to this, the mixture of 4.25 kg carbonized branch and 4.18 kg carbonized leaves with the specified measured binder (i.e. 1:5 ratios) had 5.10 kg branch briquette and 5.02 kg leaves briquette. Therefore, from the above results, the average estimated taxable Khat supply fuel briquette recovery potential of Hawassa from 2012-2016 (Table 4.4).

Table 4.4: Estimated charcoal recovery potential of Hawassa city

Year	2012-2016 (kg/yr.)
Khat inflow	6,499,422
Wet Khat residue generated	4,549,595
Air-dry Khat residue	2,729,757
Air-dry Khat branch residue	1,412,922
Air-dry Khat leaves residue	1,316,835
Carbonized Khat residue branch	400,281
Carbonized Khat residue leaves	367,265
Amount of briquette produced from Khat branch with specified binder (i.e. 1:5 ratio)	480,337
Amount of briquette produced from Khat leaves with specified binder (i.e. 1:5 ratio)	441,069
A mixture of carbonized branch and carbonized leaves briquette with specified binder (i.e. 1:5 ratio)	921,406
A mixture of carbonized branch and un-carbonized Khat leaves briquette with specified binder (i.e. 1:5 ratio)	2,060,539

4.2. Proximate Analysis and Physical Property

4.2.1. Proximate Analysis and Gross Calorific Value of Raw Khat Residue

Table 4.5 showed the results of the testing of the proximate analysis and gross calorific value of the raw Khat branch and leaves. On average the Khat branch had a MC of 10.85%, a VM of 70.00%, an AC of 4.35%, a FC of 14.80% and a GCV of 15,851.23 kJ/kg and Khat leaves had MC, VM, AC, FC and GCV of 11.48%, 71.00%, 7.23%, 10.29% and 17,204.36 kJ/kg respectively.

Table 4.5: The proximate analysis and gross calorific value of raw Khat residues

Samples	Treatments	Proximate analysis				Calorific Value
		MC (%)	VM (%)	AC (%)	FC (%)	CV (kJ/kg)
Raw Khat branch	TB_1	10.67	71.00	4.46	13.87	16,043.82
	TB_2	11.33	68.67	4.10	15.90	15,633.51
	TB_3	10.56	70.33	4.48	14.63	15,876.35
	Mean ± SD	10.85 ± 0.34	70 ± 0.98	4.35 ± 0.17	14.8 ± 0.84	15,851.23 ± 168.45
Raw Khat leaves	TL_1	11.44	73.00	7.77	7.79	16,880.26
	TL_2	11.67	70.00	7.14	11.19	17,469.34
	TL_3	11.33	70.00	6.79	11.88	17,263.47
	Mean ± SD	11.48 ± 0.14	71 ± 1.41	7.23 ± 0.41	10.29±1.79	17,204.36 ± 244.10

Where TB - Treatment of branch and TL – Treatment of leaves

4.2.2. Proximate Analysis and Gross Calorific Value of Carbonized Khat Residue

The carbonized Khat branch on average had a MC of 2.67%, a VM of 18.85%, an AC of 3.48%, a FC of 75% and a GCV of 24,863.31 kJ/kg and carbonized Khat leaves had MC, VM, AC, FC and GCV of 3.20%, 26.57%, 5.79%, 64.44% and 17,295.86 kJ/kg, respectively as shown in table 4.6.

Table 4.6: The proximate analysis and gross calorific value of carbonized Khat residues

Samples	Treatments	Proximate analysis				Calorific Value
		MC (%)	VM (%)	AC (%)	FC (%)	CV (kJ/kg)
Carbon-ized Khat branch	TB_1	3.20	18.16	3.57	75.07	23,925.58
	TB_2	2.40	19.84	3.28	74.48	24,524.60
	TB_3	2.40	18.56	3.58	75.46	26,139.76
	Mean ± SD	2.67± 0.38	18.85± 0.72	3.48± 0.17	75.00± 0.40	24,863.31± 935.13
Carbon-ized Khat leaves	TL_1	3.09	26.67	6.22	64.02	17,311.79
	TL_2	3.38	25.01	5.71	65.90	15,764.14
	TL_3	3.14	28.04	5.43	63.39	18,811.66
	Mean ± SD	3.20± 0.13	26.57 ± 1.24	5.79± 0.33	64.44 ± 1.07	17,295.86 ± 1244.20

Where TB - Treatment of branch and TL – Treatment of leaves

From the above results the carbonized branch and leaves residue had lower MC, VM and AC and higher FC and GCV than, raw Khat branch and leaves (Table 4.5 and 4.6).

4.2.3. Proximate Analysis and Physical Properties of Fuel Briquettes

Table 4.7 showed the results of the testing of the proximate analysis and physical properties of the briquettes made from Khat residue. Briquette made from carbonized Khat branch had a MC of 3.33%, a VM of 23.57%, an AC of 23.62%, a FC of 49.48%, a BD 0.73 g/cm^3 and a GCV of 19,890.65 kJ/kg, and briquettes produced from carbonized Khat leaves had a MC of 4.00%, a VM of 33.22%, an AC of 26.62%, a FC of 36.17%, a BD 0.71 g/cm^3 and a GCV of 13,836.70 kJ/kg, and briquettes produced from a mixture of carbonized branch powder with carbonized leaves powder had MC, VM, AC, FC, BD and GCV of 3.65%, 28.21%, 25.06%, 43.08%, 0.72 g/cm^3 and 16,984.75 kJ/kg respectively, and briquette produced from a mixture of carbonized branch powder and un-carbonized leaves powder had MC, VM, AC, FC, BD and GCV of 9.45%, 58.98%, 26.76%, 4.81 %, 0.48 g/cm^3 and 1,988.27 kJ/kg, respectively.

Table 4.7: The proximate analysis and physical properties of briquettes made from carbonized Khat residue with clay soil binder (1:5 ratios).

Samples	Treatments	Proximate analysis				Physical property	
		MC (%)	VM (%)	AC (%)	FC (%)	BD(g/cm^3)	CV(kJ/kg)
Briquette made from carbonized branch	T_1	4.00	22.70	25.26	48.04	0.67	19,140.46
	T_2	3.00	24.80	19.28	52.92	0.77	19,619.68
	T_3	3.00	23.20	26.33	47.47	0.75	20,911.81
	Mean ± SD	3.33 ± 0.47	23.57 ± 0.90	23.62 ±3.10	49.48 ± 2.45	0.73 ± 0.04	19,890.65 ± 748.10
Briquette made from carbonized leaves	T_1	3.86	33.34	28.38	34.28	0.69	13,849.43
	T_2	4.22	31.26	27.67	37.07	0.73	12,611.31
	T_3	3.92	35.05	23.80	37.15	0.71	15,049.33
	Mean ± SD	4.00 ± 0.16	33.22 ± 1.55	26.62 ±2.01	36.17 ± 1.33	0.71 ± 0.02	13,836.70 ± 995.36
Briquette made from carbonized branch and leaves	T_1	3.44	29.74	23.07	43.75	0.65	16,934.78
	T_2	3.69	28.96	25.01	42.34	0.76	16,039.02
	T_3	3.82	25.92	27.10	43.16	0.76	17,980.46
	Mean ± SD	3.65 ± 0.16	28.21 ± 1.65	25.06 ±1.65	43.08 ± 0.58	0.72 ± 0.05	16,984.75 ± 793.38
Briquette made from carbonized branch and raw leaves	T_1	9.26	57.78	28.24	4.72	0.48	2,000.62
	T_2	9.19	59.29	24.93	6.59	0.44	2,057.24
	T_3	9.90	59.87	27.12	3.11	0.53	1,906.96
	Mean ± SD	9.45 ± 0.32	58.98 ± 0.88	26.76 ± 1.37	4.81 ± 1.42	0.48 ± 0.04	1,988.27 ± 61.97

Moisture Content

The moisture content of raw Khat branch and leaves were 10.85% and 11.48%, respectively, and moisture content of carbonized branch and leaves were 2.67% and 3.20% respectively, and also moisture content of the fuel briquette produced from Khat branch was the lowermost with the value of 3.33%, whereas the uppermost value of moisture content was 9.45% which was the briquette produced from a mixture of carbonized branch powder with un-carbonized leaves powder, although moisture content of briquette produced from carbonized Khat leave and briquette produced from a mixture of carbonized branch powder with carbonized leaves powder were 4.00% and 3.65%, respectively (Figure 4.1).

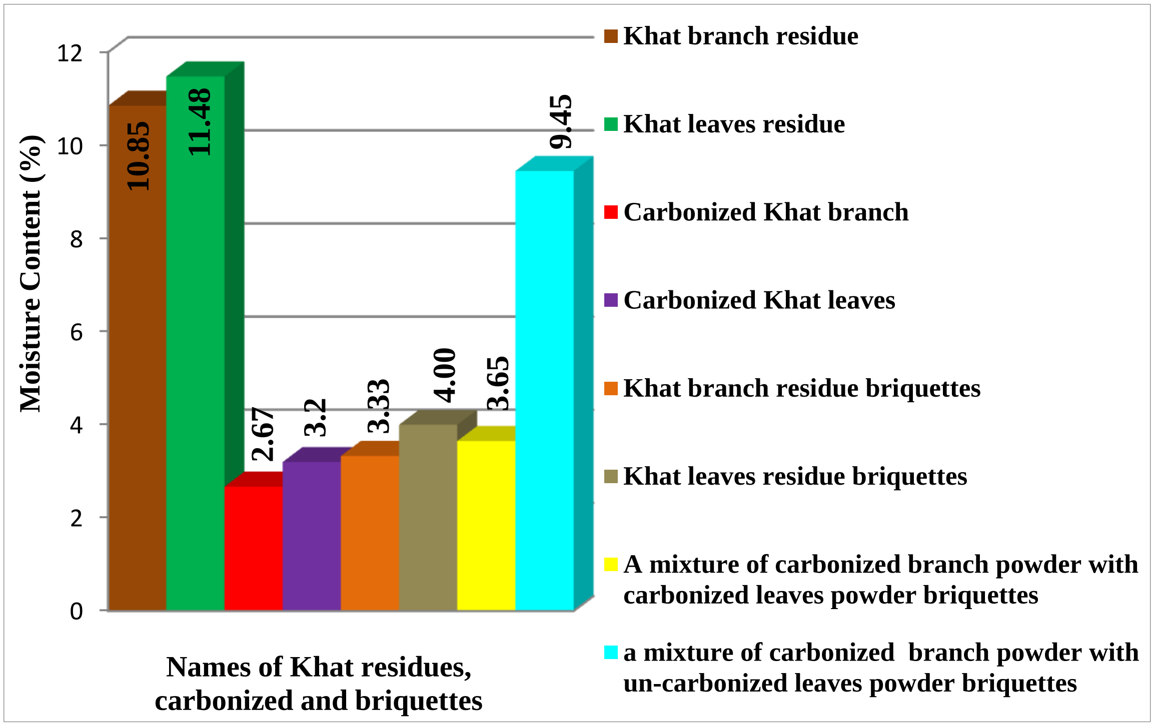


Figure 4.1: Moisture content of Khat residues, carbonized and briquettes

All except briquette produced from a mixture of carbonized branch powder with un-carbonized leaves powder were less than the moisture content of the briquettes produced from cashew nut shell which were 5 to 6 % (Sanger *et al.*, 2011) and all the produced briquette were less than rice husk and corncob briquettes which were 12.67% and 13.47%, respectively (Oladeji, 2010). The results full fill the quality specification of charcoal which restricts between 5 to 15% moisture content and to smooth heat transfer, moisture content should be as low as possible (FAO, 1987). Moisture content is one of the key parameters that regulate briquette quality. A lower moisture content of briquettes indicates a higher calorific value (Akowuah *et al.,* 2012). Also, this study showed that the branch briquette had 3.33% moisture content which was the lowest from the others and that could be had higher calorific value compared with others produced briquettes in this study.

Volatile Matter

Volatile matter of raw Khat branch and leaves residue were almost had the same value which was 70% and 71% respectively, and the volatile matter of carbonized branch and leaves residue had 18.85% and 26.57% respectively, however the volatile matters of the briquettes produced from carbonized Khat branch, carbonized Khat leaves, a mixture of carbonized branch powder with carbonized leaves powder and a mixture of carbonized branch powder with un-carbonized leaves powder were 23.57%, 33.22%, 28.21% and 58.98% respectively. From the result, a mixture of carbonized branch powder with un-carbonized leaves powder had the highest volatile matter and the carbonized Khat branch had the lowest one (Figure 4.2).

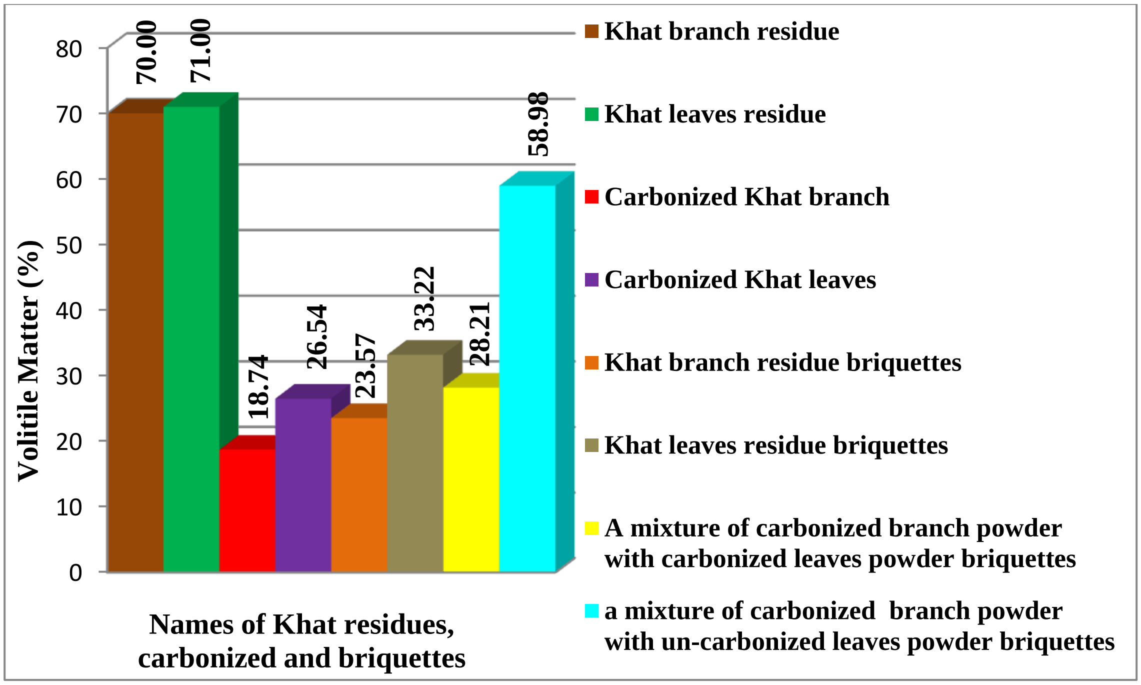


Figure 4.2: Volatile matters of Khat residues, after carbonization and briquettes

The volatile matter is the constituents of hydrogen, carbon, and oxygen present in the biomass that heated turn to vapor, generally a mixture of short and long chain hydrocarbons. It influences the thermal behavior of solid fuels, but the structure and bonding behavior also influence it. The weight of the dry biomass normally contains volatile content in the range 70 to 86% Koppejan and Van Loo, (2012). This characteristics makes the biomass a more volatile fuel giving a much faster combustion rate during the devolatisation phase than other fuels like coal and a briquette with high volatile content, have a tendency to complete combustion which leads to insignificant amount of smoke and release of toxic gas (Koppejan and Van Loo, 2012). The result of the raw material used in this study also in line with the above idea (Figure 4.2).

Good marketable charcoal has net volatile matter content of about 30%. But the volatile matter of charcoal can fluctuate from maximum 40% or it may lower up to 5% or less than 5% (FAO, 1985). Good quality charcoal should have volatile matter between 20 to 25% (FAO, 1987). The charcoal briquette produced from Khat branch full fill good quality charcoal by (FAO, 1987). On the other hand, a mixture of carbonized branch powder with carbonized leaves powder full fill good marketable charcoal by (FAO, 1985). But the briquette produced from carbonized Khat leaves residue and a mixture of carbonized branch powder with un-carbonized leaves powder are not in line with the described criteria by (FAO, 1985) and (FAO, 1987). There might be the Khat leaves residue was not properly carbonized because of this the carbonized Khat leaves briquettes have higher volatile matter that is not in line with the described criteria by (FAO, 1985) and (FAO, 1987).

The higher the volatile content indicates the quicker will be the ignition but with smoke (Sotannde *et al.,* 2010). This showed that the briquette produced from a mixture of carbonized branch powder with un-carbonized leaves powder had the characteristics of faster ignition and more smoke than the other briquettes produced in this study. On the other hand, the fuel briquette produced from Khat branch residue have low ignition than the other briquettes produced in this study. From the result, a mixture of carbonized branch powder with un-carbonized leaves powder has more indoor air pollution than other briquettes produced in this study.

Ash Content

The air dried raw Khat branch and leaves had the ash content of 4.35% and 7.23% respectively, and the ash content of carbonized Khat branch and leaves were 3.48% and 5.79% respectively, but the ash content of the produced briquettes increased after mixed with clay soil as a binder which had carbonized Khat branch (23.62%), carbonized Khat leaves (26.62%), a mixture of carbonized branch powder with carbonized leaves powder (25.06%) and a mixture of carbonized branch powder with un-carbonized leaves powder (26.76%) respectively (Figure 4.3).

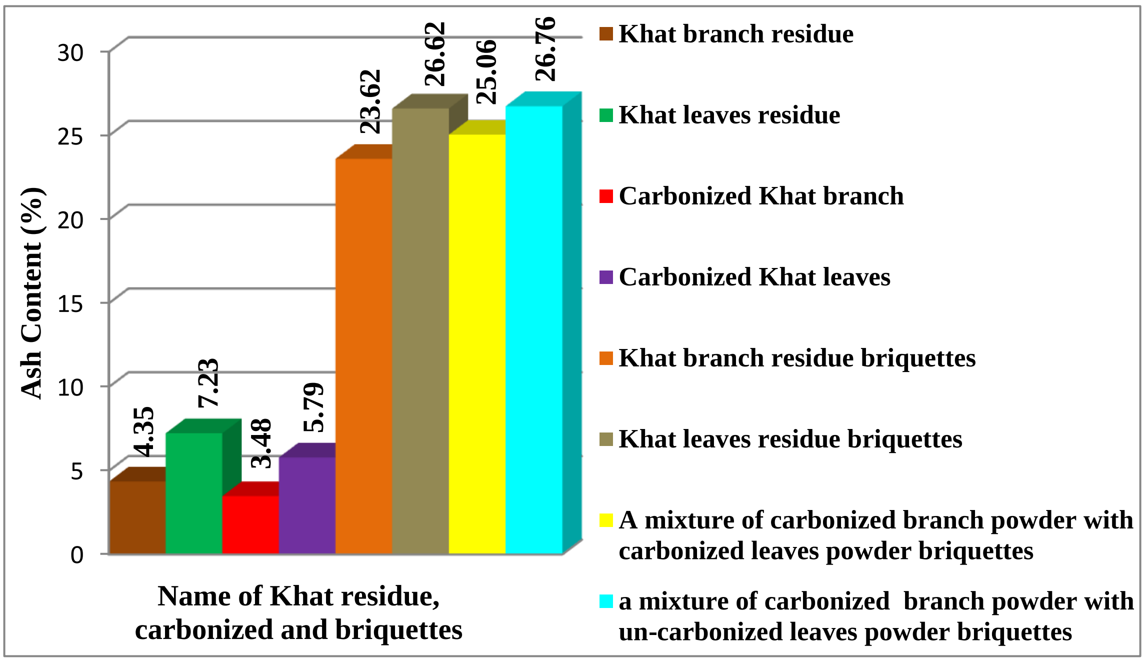


Figure 4.3: Ash contents of Khat residues, carbonized and briquettes

The ash is the non-combustible inorganic residue remains after complete combustion. It indicates that the bulk mineral matter after oxygen, carbon, sulfur, and water has been driven off during combustion (Cuaresma *et al.*, 2015).

According to FAO (1985), the ash content of charcoal fluctuated from 0.5 to 5% or more than 5% that based on the wood species. The good quality charcoal should have usually the ash content fluctuated from 3 to 4% (FAO, 1987). The ash content of the carbonized Khat branch residue fulfills good quality charcoal described by (FAO, 1987). But, carbonized Khat leaves fail the good quality charcoal criteria by (FAO, 1987) (Figure 4.3) this might be due to improper carbonization. For better utilization of briquette, the lower ash content is preferable which increase the combustion efficiency (Akowuah *et al.,* 2012). The binder used to bind the produced briquette was clay soil which is non-combustible which increase ash content (BTG, 2013). Therefore, the binder used in this study, the clay soil increases the ash content of the produced briquettes.

The ash content of the produced briquettes in this study were higher than the ash content of the bio-briquette made from coffee husks and rice husks which was 0.60 and 15.63% respectively (S Suryaningsih *et al.,* 2017). This difference could be caused because of the type of the binder used but the Khat branch briquette had lower ash content than other briquettes produced in this study. In this finding the ash value is less than the briquette made from 50% Jatropha (*Jatropha curcas L.*) husk and 50% pressed cake which was 26.21% and the Khat leaves briquette is comparable with the briquette made from Jatropha (*Jatropha curcas L.*) husk and 50% pressed cake (Cuaresma *et al.,* 2015) and all the briquettes produced in this study, had lower ash content than the briquette produced from sawdust which was 28.13% (Murali *et al.*, 2015).

Fixed Carbon Content

Fixed carbon in the raw Khat branch and leaves were 14.80% and 10.29% respectively, and the fixed carbon in carbonized Khat branch and leaves were 75.00% and 64.44% respectively, but this were changed into briquettes mixed with clay soil binder (1:5 ratio) the fixed carbon of carbonized Khat branch (49.48%), carbonized Khat leaves (36.17%), a mixture of carbonized branch powder with carbonized leaves powder (43.08%) and a mixture of carbonized branch powder with un-carbonized leaves powder (4.81%) respectively (Figure 4.4).

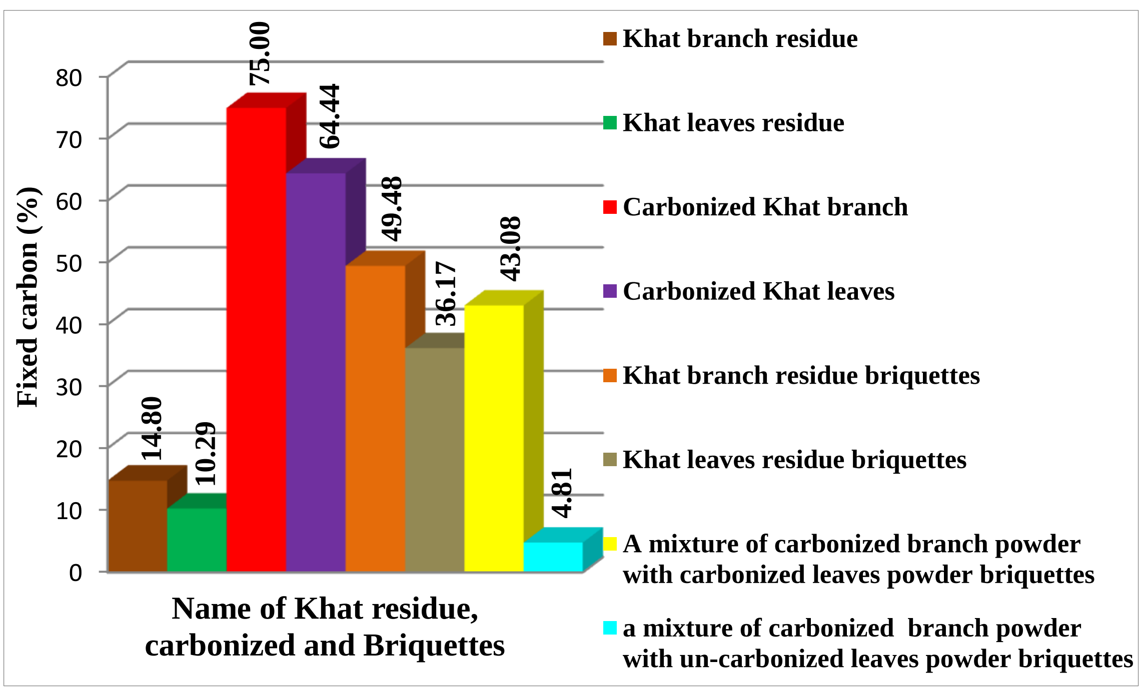


Figure 4.4: Fixed carbons of Khat residues, carbonized and briquettes

According to FAO (1985), the fixed carbon of charcoal fluctuates nearly between 50% up to 95% thus the charcoal hold mostly of carbon and it also recommend that the charcoal produced from mixed tropical hardwood had fixed carbon fluctuated 68.6% and 69.8%. The charcoal produced in this study fulfills the described criteria by (FAO, 1985). However, the produced briquettes in this study fail the described criteria by (FAO, 1985). The higher the fuel's ash contains, the lower is its calorific value (Loo and Koppejan, 2008) and the high fixed carbon content gives the result of high calorific value (FAO, 1985). From the above concept the fixed carbon content of the produced briquettes in this study had lower, because of higher ash amount was found in to the produced briquettes this is also related to the clay soil used as a binder in this study.

The produced briquettes in this study are much less than the fixed carbon content of charcoal briquette produced from Neem wood residue bonded with gum Arabic and starch which was a fixed carbon content of 84.38% and 84.31% respectively, (Sotannde *et al.,* 2010) this might be the binder difference used to produce the fuel briquettes. The Khat branch fuel briquette is greater than the fixed carbon content of the charcoal briquette produced from Sesame stalk and a mixture of carbonized branch powder with carbonized leaves powder is comparable with Sesame stalk which was a fixed carbon content of 44.40% (Gebresas *et al.,* 2015). All except a mixture of carbonized branch powder with un-carbonized leaves powder are greater than the fixed carbon content of the charcoal briquette produced from sawdust briquette which was a fixed carbon content of 20.7% (Akowuah *et al.,* 2012) and the whole produced briquette in this study, are greater than the fixed carbon content of briquette produced from wood which had the corresponding value of 1.6% stated by (Malatji *et al.*, 2011).

Bulk Density (BD)

The bulk density of the produced briquettes in this study had carbonized Khat branch residue briquettes (0.73 g/cm^3), carbonized Khat leaves residue briquettes (0.71 g/cm^3), a mixture of carbonized branch powder with carbonized leaves powder briquettes (0.72 g/cm^3) and a mixture of carbonized branch powder with un-carbonized leaves powder briquettes (0.48 g/cm^3) respectively, (Figure 4.5).

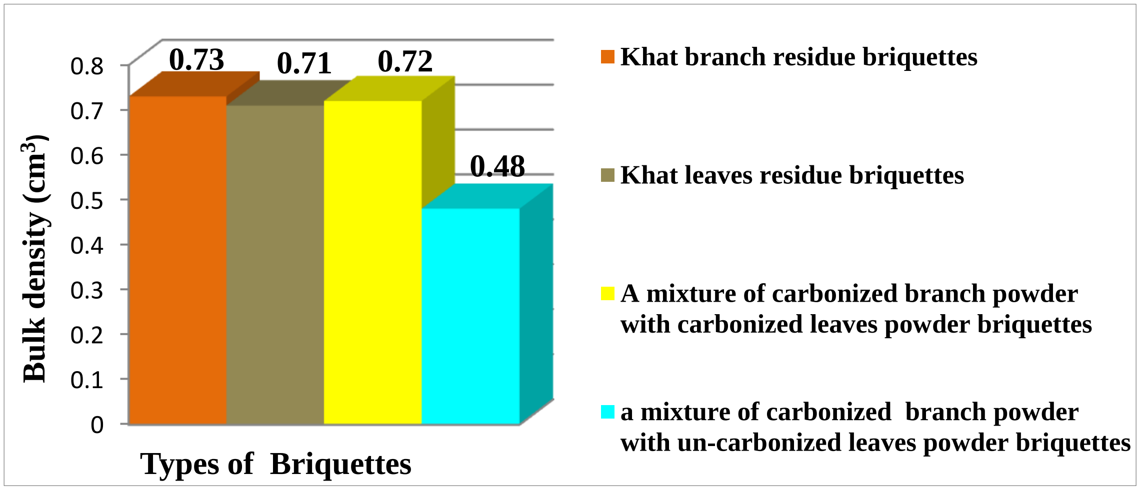


Figure 4.5: Bulk densities with types of briquettes

Bulk density is one of the most important parameter of briquettes, where the higher the density, the higher is the energy per volume ratio and its slow burning property. Therefore, high density crops are required in terms of transportation, handling, and storage. The densities of bio-waste briquette depend on the density of the original bio-waste, the briquetting pressure and, to a certain extent, on the briquetting temperature, and time (Križan *et al.,* 2011).

The bulk density achieved from this study were much higher than that of *Eupatorium* spp. with bulk density 0.33 g/cm^3 (Ritesh *et al.,* 2009) and less than the charcoal briquette produced from coconut husks and sawdust which had bulk density of 0.76 g/cm^3 and 0.89 g/cm^3 respectively, (S Suryaningsih *et al.,* 2017) and the charcoal briquette produced from banana leaves briquette which was in the range 0.99 to 1 g/cm^3 (Maia *et al.,* 2014). The lower bulk density in this study was briquettes produced from a mixture of carbonized branch powder with un-carbonized leaves powder (Figure 4.5) that might be due to the combination of carbonized and un-carbonized raw material used to produce the briquette.

Gross Calorific Value

The mean gross calorific value of raw Khat branch residue had lower gross calorific value of 15,851.23 kJ/kg than, the mean gross calorific value of raw Khat leaves residue which had 17,204.36 kJ/kg and both values were increased after carbonization the carbonized Khat branch had gross calorific value of 24,863.31 kJ/kg and the carbonized Khat leaves had gross calorific value of 17,295.86 kJ/kg. However, Significance differences of the gross calorific value were found between the produced briquettes. The carbonized Khat branch briquette contained the highest gross calorific value of 19,890.65 kJ/kg and the next one was a mixture of carbonized branch powder with carbonized leaves powder briquettes which was 16,984.75 kJ/kg and carbonized Khat leaves briquettes was 13,836.70 kJ/kg and a mixture of carbonized branch powder with un-carbonized leaves powder briquettes have lowest gross calorific value which was 1,988.27 kJ/kg (Figure 4.6).

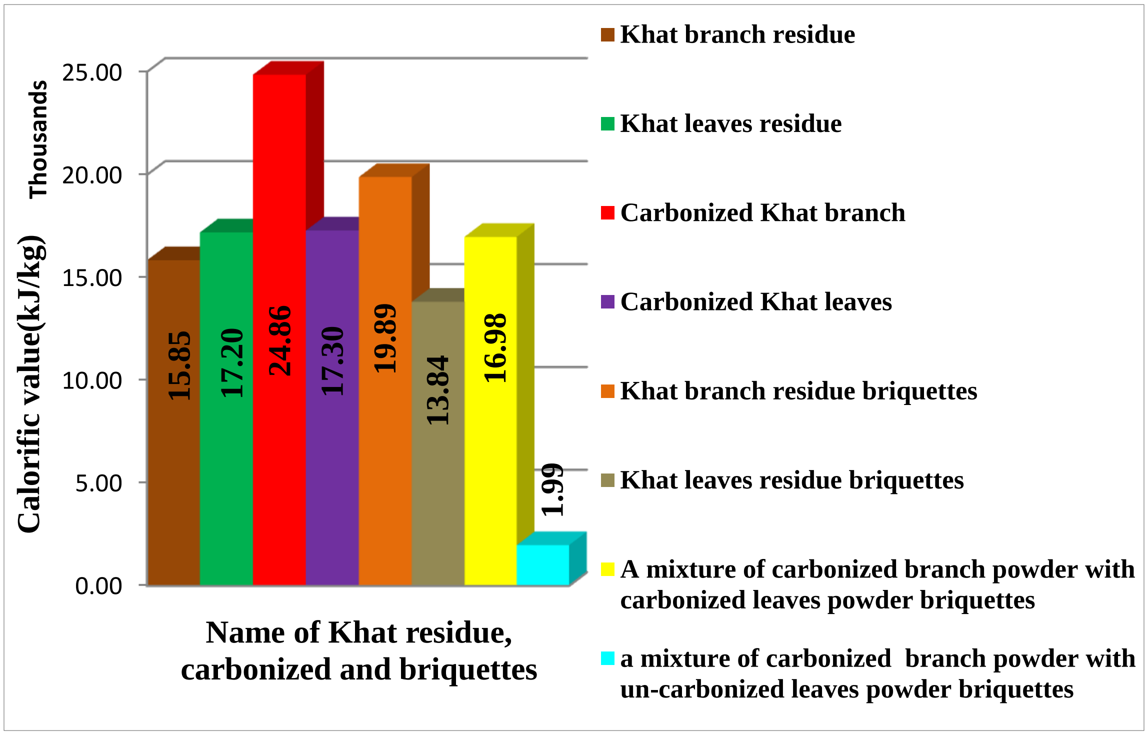


Figure 4.6: Gross calorific value of raw Khat residues, carbonized and briquettes

Calorific value or heating value regulates the energy content of a fuel. It is also the property of biomass fuel that can be influenced by its moisture content and chemical composition. In addition to this, it is the most important fuel property (Aina *et al.*, 2009). The gross calorific value of the raw Khat branch was less than the carbonized Khat branch and carbonized Khat branch briquettes and the carbonized Khat branch was greater than the carbonized Khat branch briquettes this could be because of the clay soil used in this study. Similarly, the gross calorific value of the raw Khat leaves was less than the gross calorific value of carbonized Khat leaves but greater than the gross calorific value of carbonized Khat leaves briquettes this was because of the clay soil used as a binder in this study. It was also might be due to the characteristics of the Khat leaves, as observed from the leafy part there is looks like oil that might be increase the gross calorific value of the Khat leave residue but after carbonization, this looks like oil part evaporate with volatile matter. Therefore, the Khat leaves characteristics need farther study. High percentage of volatile matter doesn't mean will decrease the burning capacity. If its composition contains flammable gas, it will increase burning capacity by proportionately increases flame length, and helps in easier ignition of coal (S Suryaningsih *et al.*, 2017). In addition to this during carbonization process the difference of the environmental conditions like the temperature difference also one factor influence the significantly different in gross calorific value (Musabbikhah *et al.*, 2016). The calorific value after carbonization was higher than fuel briquette which was used clay soil as a binder (Abebe *et al.*, 2017).

Carbonized Khat branch briquette, a mixture of carbonized branch powder with carbonized leaves powder briquettes had greater gross calorific value than charcoal briquette made from coffee pulp which was 16,905.62 kJ/kg (Figure 4.6) but less than the gross calorific value of the charcoal briquette made from coffee husk which was 21,106.08 kJ/kg (Merete *et al.*, 2014). All briquettes made from this study except a mixture of carbonized branch powder with un-carbonized leaves powder briquettes had greater calorific value than wood which was 13,803.12 kJ/ kg (FAO, 1999).

4.3. Fuel Performance Test

4.3.1 Combustion and Water Boiling Capacity Test

The test result showed that the carbonized Khat branch and leaves briquettes are strong heat which got on average 23 min and 35 min to boil one litter of water at the first time respectively, and the fastest fuel briquette changing the water into vapor was the carbonized Khat branch which was on average 1hr and 11 Min and carbonized Khat leaves fuel briquette was 1hr and 22 Min and also fuel briquettes made from carbonized Khat branch, carbonized Khat leaves had average time taken to turn to ash were 2hr and 48 Min, 2hr and 14 Min respectively (Table 4.8).

The result for fuel performance test of the produced fuel briquette made from carbonized Khat branch showed that there is no smoke (smoke free) except at a startup, no spark formation, no soot production, no smell or odor but Khat leaves residue have smoke and smell or odor until 20 min after startup. Furthermore, the study indicated that the time taken to boil a given amount of water highly related to the calorific value (i.e. the higher calorific value the fastest to boil the water).

Table 4.8: Relative time taken to boil one litter of water; done using Merchaye-stove

Briquette type	Average time taken to boil one litter Water in Minutes	Average time taken to change the water into vapor in (Hour & Minutes)	Average time taken to turn to Ash (Hour & Minutes)	Average Calorific Value (kJ/kg)
Carbonized	23.00	1hr and 9 Min	2hr and 46 Min	19,140.46
Khat branch	22.00	1hr and 12 Min	2hr and 48 Min	19,619.68
briquette	24.00	1hr and 11 Min	2hr and 50 Min	20,911.81
Mean ± SD	23 ± 1.00	1hr and 11Min ± 1.53	2hr and 48 Min ± 2.00	19890.65 ± 565.88
Carbonized	36.00	1hr and 19 Min	2hr and 14 Min	13,849.43
Khat leaves	33.00	1hr and 24 Min	2hr and 10 Min	12,611.31
briquette	37.00	1hr and 22 Min	2hr and 19 Min	15,049.33
Mean ± SD	35 ± 2.12	1hr and 22 Min ± 2.52	2hr and 14 Min ± 4.51	13836.70 ± 1219.07

The carbonized fuel briquette made from Khat branch had almost similar qualities when compared with sesame stalk which was 20 min (Gebresas *et al.*, 2015) and lower than the briquette made from *Lantana Camara L.* fuel briquette root, steam, branch and leaves with trunk fuel briquette which had 9, 10, 13 and 15 min to boil one litter of water (Abebe *et al.,* 2017).

4.3.2 Total Emission Test

Table 4.9 showed a comparison between the total gas emissions of Khat residue fuel briquette with the recommended preferable range of CO, $CO_{2,}$ and O_2. The table clearly indicated that the gas emission produced by the fuel briquettes confirms to the recommended range of Indian standard for portable solid biomass cook stove.

The hardiness of the briquettes is related to the dust and CO emission. The highest hardiness of the briquette results in lower dust and CO emission and higher amounts of fixed carbon increase the probability of more complete oxidation and extensive combustion in addition to these briquettes having high amounts of fixed carbon have low dust and CO emission (Mopoung and Udeye, 2017). The results found in this study, in line with the above described idea.

Table 4.9: The selected toxic emissions with the maximum exposure limit

Emissions (avg)	CO_2 (%)	CO (PPM)	O_2 (%)	NO (%)	NO_X (%)
Khat branch briquette (500 g)	0.37	728	20.20	2.27	0
Khat leaves briquette (500 g)	0.48	831	20.08	7.21	0
Preferable standard range	0-20	0-1000	0-25	-	-

Where 1% CO = 10,000 ppm

Carbonized Khat branch and leaves fuel briquettes had total CO emissions of 728 (0.07%) ppm and 831 ppm (0.08%) respectively. The carbonized Khat branch and leaves fuel briquettes had lower CO emission than charcoal briquettes produced from banana peel and banana bunch which had total CO emission of 3463 ppm (0.35%) and 1568 ppm (0.16%) respectively, (Mopoung and Udeye, 2017). Gas mixtures of atmosphere with a low concentration of CO in the range up to 4,947 ppm (0.5%) do not present any toxic threat to consumers according to international standard for the Determination of Toxicity of Gases as cited by (Mopoung and Udeye, 2017). Hence the produced fuel briquettes from Khat branch and leaves do not cause any threat to consumers.

The result of the investigation also indicated that the carbonized Khat branch fuel briquette burning within dimensions 1000 mm width × 750 mm diameter × 2820 mm height area if the consumer exposed to 1-2 hr. after this exposure limit the consumer had symptoms of headache and nausea. On the other hand, at similar situation the carbonized

Khat leaves fuel briquette used by the consumer after 45 min he/she has symptoms of headache, nausea, and dizziness in addition to this after 1 hour of exposure the consumer collapse and unconsciousness (NFPA, 2007). Therefore, it is recommended that the produced fuel briquettes in this study used in well ventilated Rome to reduce the above impacts.

4.4. Evaluation of the Energy Potential of the Fuel Briquettes

The result showed that the average calorific mean value of the briquette produced from carbonized Khat branch was found to be 19,891 kJ/ kg (Table 4.7). If 400,281 kg carbonized Khat branch (Table 4.4) was mixed with the same ratio (20%) of the clay soil binder used in this study, the city could possibly produce 480,337 kg of briquettes from the branch residues only (Table 4.4), which would amount to a total energy of approximately 9.56×10^9 kJ.

As shown in table 4.7, the average calorific mean values of the briquette produced from carbonized Khat leaves was 13,837 kJ/ kg. If 367,265 kg of carbonized Khat leaves (Table 4.4) was mixed with the same ratio (20%) of the clay soil binder used in this study, the city could possibly produce 441,069 kg of briquettes from the leaves residues only (Table 4.4), which would amount to a total energy of approximately 6.09×10^9 kJ.

On the other hand, the average calorific mean values of the briquette produced from a mixture of carbonized Khat branch with carbonized Khat leaves was 16,985 kJ/ kg (Table 4.7). If the total amount of carbonized Khat branch and leaves gives a combination of (400,281 kg + 367,265 kg) 767,546 kg of carbonized Khat branch and leaves (Table 4.4), was mixed with the same ratio (20%) of the clay soil binder used in this study, the city could possibly produce 921,406 kg of briquettes from a mixture of carbonized branch and leaves (Table 4.4), which would amount to a total energy of about 15.64×10^9 kJ.

Furthermore, the average calorific mean values of the briquette produced from a mixture of carbonized branch with un-carbonized leaves was 1,988 kJ /kg (Table 4.7). If the total amount of carbonized branch and un-carbonized leaves gives a combination of (400,281 kg + 1,316,835 kg) 1,717,116 kg of carbonized branch and un-carbonized Khat leaves (Table 4.4), was mixed with the same ratio (20%) of the clay soil binder used in this study, the city could possibly produce 2,060,539 kg of briquettes from a mixture of carbonized branch and un-carbonized leaves, which would amount to a total energy of approximately 4.10×10^9 kJ.

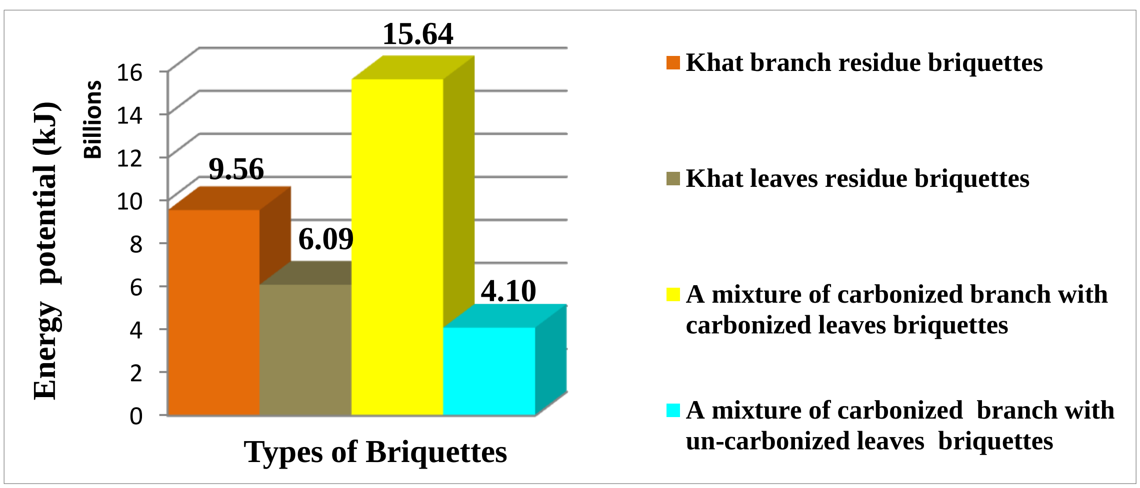


Figure 4.7: Energy potentials with type of briquettes

4.4.1. Evaluation of Charcoal or Fuel Wood Recovery Potential of Fuel Briquettes

One kg of charcoal gives 30.8 MJ of energy which is equal to 30,800 KJ of energy and one ton of charcoal is produced from 6 m^3 of fuel wood (FAO, 1999). Therefore, through production of fuel briquettes from carbonized Khat branch, carbonized Khat leaves, a mixture of carbonized Khat branch with carbonized Khat leaves and a mixture of carbonized branch with un-carbonized leaves, the city could possibly substitute 310, 198, 508, and 133 tonnes of charcoal or using the conversion 1 ton is approximately equivalent to 1000 kg the city could possibly substitute 1,862.34, 1,186.36, 3,046.75 and 798.70 m^3 of fuel wood annually only from taxable Khat supply respectively.

According to Girard (2002), 250 kg of charcoal have 225 kg of carbon and 300 kg of carbon is equivalent to 1.1 tonne of CO_2 which means 250 kg of charcoal is equal to 0.825 tonnes of CO_2. Therefore, through production of fuel briquettes from carbonized Khat branch, carbonized Khat leaves, a mixture of carbonized Khat branch with carbonized Khat leaves and a mixture of carbonized branch with un-carbonized leaves the city could possibly reduce 1,024, 652, 1,676 and 439 tonnes of CO_2 that release to the environment.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary and Conclusions

The heavy dependence on traditional biomass in Ethiopia like Hawassa city is leading to different environmental and socio-economic problems, to reduce such problem the current study which is on the “production and characterization of fuel briquette from Khat (*Catha Edulis Forsk*) residue for diversification of household energy sources” was conducted by taking a sample of 200 kg quantity of wet Khat residue and fuel briquettes were produced using a material, drum kiln, beehive briquette machine and finally the laboratory analyses was done using ASTM D1762-84 procedure.

The result of the study indicated that fuel briquette produced from Khat residue was found a more quality source of energy. The fuel briquette made from Khat branch have higher calorific value and fixed carbon content with values of 19,891 ± 748 kJ and 49.48 ± 2.45% respectively; and lower volatile matter, moisture content and ash content of 23.57 ± 0.90 %, 3.33 ± 0.47% and 23.62 ± 3.10% respectively, compared with the results of briquettes produced in the study. On the other hand, the results of the study indicated that the fuel briquette produced from a mixture of carbonized branch and leaves have higher calorific value and fixed carbon content with a value of 16,985 ± 793 kJ and 43 ± 0.58%, respectively and lower volatile matter, moisture content and ash content with a value of 28.21 ± 1.65%, 3.65 ± 0.16% and 25.06 ± 1.65 % respectively, compared with fuel briquette produced in the study, except the fuel briquette produced from Khat branch. Moreover, from the average wet Khat residue potential taken from the

Hawassa city which was 4,549,595 kg, the study indicated that 920,743 kg of fuel briquette can be produced from a mixture of carbonized Khat branch and leaves, this amount could possibly produce around 15.64 billion kilo Jules of energy and this substitutes nearly 508 ton of fuel charcoal (approximately 1,676 tonnes of CO_2 can be reduced).

Therefore, the study concluded that fuel briquette produced from Khat residue could be used as an alternative source of energy, reduce alarming rate of deforestation and improve waste management. In addition, utilization of fuel briquette obtained from Khat residue can be used as source of clean energy mainly for the household sector which reduce indoor air pollution and improve their health problems that happened during cooking.

5.2. Recommendations

The government should encourage and increase the investment in fuel briquette production to subsidize fuel consumption, and give intensive policies for the investors who invest with fuel briquette production. In addition to this an appropriate assistance of government, non-governmental organization and professional persons has to be performed.

Comprehensive investigation like ultimate analysis would be carrying out to assess the chemical composition of fuel briquette produced from Khat residue.

The produced fuel briquettes ash content of this study is high from the expected, the calorific value and fixed carbon content of the carbonized Khat residue decreased after mixing with the clay soil used as a binder. Therefore, to minimize this effect other binder options (like starch, cassava etc.) are recommended.

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7. ANNEXES

7.1. Letter of Certification

በኢትዮጵያ ፌዴራላዊ ዲሞክራሲያዊ ሪፐብሊክ
የውሃ፣ መስኖና ኤሌክትሪክ ሚኒስቴር
The Federal Democratic Republic of Ethiopia
Ministry of Water, Irrigation & Electricity

ቁጥር
Ref.No MoWIE 260/11/221
08 MAY 2018

To: Hawassa University Wondo Genet College of Forestry and Natural Resources
Hawassa

Subject: Letter of certification and experimental results

As stated in the subject Hawassa University Wondo Genet College of Forestry and Natural Resources asked our ministry with Ref.No 1562/1.23/17 and on date 12 Dec 2017 for Mr. Endale Fekadu Gebreyes to do laboratory work on his thesis research paper, entitled "**Production and Characterization of Fuel Briquette from Khat (*Catha EdulisForsk*) Residue for Diversification of Household Energy Sources**."

Therefore, it is to inform you that the aforementioned M.Sc. student has done properly his experimental work and has obtained his results in Ministry of Water, Irrigation and Electricity in Alternative Energy Development and Promotion Directorate Laboratory and Workshop section, located at Gurd Sholla Addis Ababa, with the coordination of the workshop experts, from January to April 2018 and for assurance a 3 page laboratory results are attached with this paper.

With Regards

Asress Wolde-Giorgis
Alternative Energy Technology
Development & Promotion Directorate
Director

እባክዎን መልሱን በሚጽፉልን ጊዜ የእኛን ደብዳቤ ቁጥር ይጥቀሱልን
Please Quote our Ref. No. When Replying

ስልክ 011-6-61-11-11
Tel. 011-6-63-72-22

ቴሌ ፋክስ 011 - 6-61-08-85
Telefax 011 - 6-61-07-10
011 - 6-62-73-69

ፖ.ሣ.ቁ. 5744
P.O.Box 5673

አዲስ አበባ - ኢትዮጵያ
ADDIS ABABA - ETHIOPIA

7.2. Letter of Khat Supply

በደቡብ ብሔሮች ፣ብሔረሰቦች ሕዝቦች
ክልል መንግስት የሀዋሳ ከተማ አስተዳደር
ገቢዎች ባለስልጣን ዋና ቅ/ጽ/ቤት

south nations natonalities & people regional state
Hawassa City Administraton Revenue Authority
Main Branch Office

ቁጥር 1375/2/7/2010
ቀን 12-04-2010

ለሀዋሳ ዩንቨርስቲ ወንዶ ገነት ደ/የተፈ/ሀብት ኮሌጅ

ወንዶ ገነት፣

ጉዳዩ፡- መረጃን ስለመስጠት ይሆናል፡፡

በርዕሱ እንደተጠቀሰዉ ለጥናት የሚሆን መረጃ ከተቋማችን እንድናመቻች በደብዳቤ በጠየቃችሁን መሠረት የተፈለገውን መረጃ ከዚህ ሸኚ ደብዳቤ ጋር አያይዘን መስጠታችንን እናስታውቃለን፡፡

ከሠላምታ ጋር/

ሙሉጌታ ገ/መድህን አርሳንጎ
Mulgeta G/Medihne Arsango
ስቅድ ልማት ክ/ማ/ግ/መልስ አፈፃ

ግልባጭ

ለሀዋሳ ከተማ ገቢዎች ባለስልጣን

ለአቶ እንዳለ ፍቃዱ

ሀዋሳ፣

ፖስታ 1640 ስልክ 0462210026

ግብር ለስልጣኔ የሚከፈል ዋጋ ነው፡፡ የታክስ ሙስናን መከላከል ሀገርን ከጠላት መከላከል ነው፡፡