Jimma University

Jimma Institute of Technology

Faculty of Mechanical Engineering

Graduate studies in Sustainable Energy Engineering

Production of charcoal briquette to be used as cooking fuel by pyrolysis of non-woody biomass and recovery of smoke for vinegar production

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Executive summary

The depleting oil reserves impose a threat to ever-increasing energy requirements all over the world. This necessitates research and development on alternative energy sources such as energy from biomass. The main concern of this research work was production of charcoal briquette from non woody biomass such as coffee husk, saw dust and Chat Geraba using pyrolysis process and recovery of pyrolysis co-product (smoke) for vinegar production. The charcoal briquette was produced from the char with the help binder using PVC molding tools. It has greater advantage for recovery of clean renewable energy sources and reduction of deforestation of indigenous trees.

The raw material i.e. particular biomass used as raw material should be characterized i.e. its fixed carbon content, volatile mater, moisture content and ash content should be known since these components have an impact on the calorific value of final briquette. Then the characterized biomass (coffee husk, saw dust and chat Geraba) is pyrolysed using carbonizing kiln to produce char which is used as raw material for production of briquette. The optimum temperature and heating time of the carbonizer are found to be 500^0C and 3 hours respectively. The char is then grinded into appropriate particle size using grinding machine to have uniform particle size which helps to have good quality charcoal briquette. This char is then mixed with appropriate binders (molasses, starch and clay) with standardized mixing ratio and briquetted using manual operated hand press briquetting technique. Finally, the briquette has been characterized in terms of its calorific value, volatile matter, moisture content, ash content and fixed carbon content and it has the values of 24.098 MJ/kg, 20%, 7.6%, 7.4% and 65% respectively. These are the characteristics of charcoal briquette produced from Chat Geraba (which is best raw material out of the others) with molasses which is the best binder from others. Each kilogram of charcoal briquette (the product) can substitute 1.72 kg of wood and it can protect 2.97 kg of CO_2 from emission to the environment.

The other product of slow pyrolysis is wood vinegar which is produced by condensation of synthesis gas or smoke emitted during pyrolysis of coffee husk, saw dust and Chat Geraba by using condensation technology. The liquid condensate is separated to its component (Bio oil, wood vinegar and coal tar) using sedimentation or centrifugation process. Wood vinegar is used as pesticide, fungicide, insecticide and herbicide while the bio oil can be upgraded to transport fuel but the economic feasibility need to be assessed. The Coal tar is used as a binder for briquetting process. The wood vinegar produced has the characteristics of specific gravity 1.020 and pH = 3.857 which has acidic characteristics.

Key words: Biomass, Pyrolysis, Binder, hand press briquetting machine, Charcoal briquette, vinegar, carbonization.

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Table of Contents

List of Table

List of figure

Acronyms

MJ/kg	Mega joule per Kilogram
ASTM	American Society for Testing and Materials
CFC	Chloro Floro Carbon
CO	Carbon monoxide
CO_2	Carbon dioxide
MWE	Ministry of water and energy
SNNP	Southern Nation Nationality of People
mm	millimeter
YFC	fixed carbon yield
^0C	degree centigrade
VM	Volatile matter
AC	ash content
MC	Moisture content
PVC	poly vinyl Chloride
cm	Centimeter
ml	milliliter
µm	micrometer
pH	Potential of hydrogen

1. Introduction

1.1. Back ground of the study

The three basic requirements for survival of man are food, shelter and clothing. However, with rapid industrialization, all these three requirements need energy for their synthesis, production or manufacture. It will not be a mistake to say that man has only one requirement and that is ‘energy’. And a country’s power is judged by its self-sufficiency and independence in terms of energy production and its utilization. Talking about energy, the most obvious thing that comes to our mind is the energy derived from fossil fuel. The three major sources of energy are Crude oil, Coal and Natural gas. While crude oil has an animal origin and has been formed from the remains of dead animals buried under the earth crust thousands of years ago, coal and natural gas have a vegetable matter origin and have been formed by a process similar to crude oil where remains of dead plants were subjected to the extreme conditions of the earth’s crust for thousands of years.

As is suggestive from the origin of these sources, they are all non-renewable and once used, they can never be reused. This non-renewability of the fossil fuel introduces us to the problem of depletion of these sources. And owing to the rapid population increase and urbanization, the demand for energy has reached a level where we find ourselves at the brink of an acute energy crisis. Fossil fuel, though a very good source of energy, are on the verge of extinction. Currently available reserves of these fossil fuels may serve us comfortably for another century but once that is depleted, there is no means we can get it back. It is thus immensely important at this point to look for alternative methods of production or sources of energy. Failure to do this will send us back to pre-industrialization era. To face these challenges scientists and researchers have come up with several alternatives which are renewable sources of energy. Some of which are wind energy, solar energy, geothermal energy, energy derived from biomass, etc. These sources though serve as an alternative, have not been exploited to the extent where they have proved themselves to be economically viable. And most, except the energy derived from biomass, have been used with very little use on a commercial scale.

Biomass is a promising eco-friendly alternative source of renewable energy in the context of current energy scenarios. It has been found to be a source of a variety of useful chemicals and fuels. Historically, biomass has been a major source of household’s energy in Ethiopian. It meets the cooking energy needs of most rural households and half of the urban household’s demands.

Despite significant penetration of commercial energy in Ethiopia during last few decades, biomass continues to dominate energy supply in rural and traditional sectors. [7]

Table 1. Share of Ethiopia Energy supply 2008 E.C

Energy type	Percentage (%)
1. Biomass	92
2. Oil	7
3. Electricity	1

This dependence on biomass (woody biomass) resources has been detrimental to their sustainability and adverse to the environment. The overall dependency of majority of the population on the charcoal and fuels wood as energy source has brought in its wake the threat of deforestation and this leads to decrease the soil fertility. This impasse can be sustainably resolved through the introduction and wide dissemination of new and renewable energy technologies.

Such as:

1. Use of densified agricultural residues for fuel;
2. Demonstration projects on biogas, solar energy and thermal;
3. Improved stoves;
4. Improved charcoal production technologies and
5. Trials on fast growing tree species for fuel.

Processing of agricultural residue to produce good quality house hold cooking fuels had started in the early 1990 after the investigation of the opportunities to use biomass residue at state farms and agro industries as the substitute for the fuel used in households and industries. And a pilot plant had erected in different governmental farms such as Diksis (wheat straw), Amibra (cotton stalk) and Shoa (bagasse) and so on. But these plants were not successful while operation due to the instability of the country in the civil war in 1980’s and some technical failure such wear of the pressing machine and lack of skilled man power to operate the plants. [5]

Thermal pyrolysis of biomass produces solid, liquid and gaseous products. Charcoal is the solid residue remaining when wood species, agro-industrial wastes and other forms of biomass are carbonized or burned under controlled conditions in a confined space such as a kiln.

Charcoal-making is the transformation of biomass through the process of slow pyrolysis. The process takes place in four main stages governed by the temperature required in each stage.

Stage 1: drying (110-200°C)

Air-dry biomass contains 12-15% of adsorbed water; after the first stage all the water is removed. This stage requires heat input, which is provided by burning a fraction of the biomass that would otherwise have been converted into charcoal.

Stage 2: pre-carbonization stage (170-300°C)

During the pre-carbonization stage endothermic reactions take place resulting in the production of some pyroligneous liquids such as methanol and acetic acid, and a small amount of non-condensable gases such as carbon monoxide and carbon dioxide.

Stage 3: carbonization (250-300°C)

In this stage, exothermic reactions take place and the bulk of the light tars and pyroligneous acids produced in the pyrolysis process are released from the biomass.

Stage 4: carbonization (>300°C); during this stage, the biomass is transformed into charcoal, characterized by an increase in the fixed carbon content of the charcoal.

The charcoal does, however, still contain appreciable amounts of tarry residue, together with the ash of the original biomass. The above process takes under pyrolysis conversion which is a thermal conversion process where the material is treated in an inert atmosphere in the absence of air or oxygen with final temperatures of about 500 ºC.

The order of pyrolysis is Hemicellulose $\Longrightarrow$ Cellulose $\Longrightarrow$ Lignin

The solid product charcoal is used as energy sources for house hold application for cooking and other domestic application. In addition to that charcoal from non woody biomass is grinded and mixed with binder such as molasses, Clay and briquetted using compaction process to form a product of higher bulk density, lower moisture content, and uniform size shape, and material properties. [3]

Hand press briquetting is manual briquetting process used to form small quantities of briquettes. This is a low pressure compaction used to produce households cooking fuels from any available waste biomass and binding agents. It was expected that this manually operated briquetting machine will be useful to small and medium scale briquette manufacturers. Some of the advantages of briquettes are; it is one of the alternative methods to save the consumption and dependency on fuel wood and animal dung cake, easy to handle, transport, store and they are uniform in size and quality, assists the reduction of fuel wood and deforestation, minimizes indoor air pollution, high burning efficiency, and are ideally sized for complete combustion, are usually produced near the consumption centers and not transported from long distances and the technology is pollution free and Eco-friendly. [6].

The other coproduct that needs great attention is wood vinegar. It is an organic liquid mixture produced through condensing the smoke produced during the carbonization or pyrolysis of non woody biomass. The major composition of wood vinegar is acetic acid, and it also contains acids, alcohols, phenols, esters, carbonyl and furans and other organic ingredients. In the last century, a number of countries, such as Japan, have used wood vinegar in a wide range of applications, such as crop pest control, crop growth promotion, deodorizing and feed additives. [9]

1.2. Statement of problem

Before 40 or 50 years the majority of land of Ethiopia was covered by forests but now a day the forest is removed for construction purpose, consumption of wood for fuel purpose and expansion of farm lands due to population growth. Because of this one can observe catastrophic events like famine, drought and desertification which is an indication of climate change due to deforestation. Charcoal briquette which is produced by pyrolysis of non-woody biomass such as agricultural residue, coffee husk, Chat Geraba, saw dust and other biomass resources to be used as cooking fuel instead of wood minimizes this deforestation and environmental pollution.

In addition to this wood vinegar that is produced by recovering the smoke which is emitted during pyrolysis process minimizes emission of pollutant to the surrounding environment which helps to protect environmental pollution.

This vinegar is used as pesticide, insecticide and herbicide which helps to avoid dependency on synthetically produced pesticide, insecticide and herbicide and this is used to avoid water and soil pollution which is the result of the use of this synthetic chemicals.

1.3. Significant of the study

In the near future the world and our country will face energy crisis due to the depletion of fossil fuel such as coal, petroleum and natural gas and emphasis should be given to solve this problem. And it is better to substitute these non-renewable energy source with renewable sources such as biomass resources. In addition to this combustion of these fossil fuels emits CO_2, CO, CFC and other pollutants which are harmful to the environment. Wood charcoal which is produced from wood biomass has been the primary fuel for cooking in Ethiopia because it is cheap and easily available. However, using wood charcoal has consequences on health and pollution because of smoking. In addition, cutting wood trees for the purpose of charcoal production and use it as fuel cause deforestation and using wood biomass as energy source may cause many problems such as increase in CO_2 emission and global warming. So using non woody biomass in the form of charcoal briquette as energy fuel will solve these environmental related problems and it is a good alternative energy resource.

The condensate that is commonly called wood vinegar has wide application in agricultural sector. It is a promising solution in plant protection, showing good potential for inhibition of pathogenic-fungi and bacterial growth. As we know Agriculture is the main sector of economy for Ethiopia. About 85% of the population depends on agriculture. But there are a lot of obstacles such as plant fungi, pests, herbs etc. Traditionally this issue has been solved by using chemical pesticide and fungicide. However, these chemical pesticide and insecticide are costly and harm full to the environment and wood vinegar is a low cost and environmentally friendly to replace these chemicals.

1.4. Scope and limitation of the research

This research focuses on production of charcoal briquette and vinegar from non-wood biomass such as saw dust, coffee husk and Chat Geraba by pyrolysis process and briquetting it using hand pressing briquetting machine and test the quality of this product by characterizing it in terms of its calorific value, moisture content, volatile matter, ash content and fixed carbon content.

The optimum operating parameters such as optimum carbonizing temperature, heating time, appropriate type of binder and other operating parameter is analyzed. It also tried to solve the problem of improper management of biomass like coffee husk, sawdust and chat Geraba. The efficiency of the condenser was very low and it is difficult to collect enough amount of vinegar as much as it was expected.

1.5. Objectives of the study

1.5.1 General objective

To produce environmentally friendly and high quality charcoal briquette from non woody biomass such as saw dust, coffee husk and Chat Geraba by pyrolysis process which is used as sustainable energy fuel and recovering the smoke for vinegar production.

1.5.2 Specific objectives

1. Characterization of raw materials specifically coffee husk, sawdust and chat Geraba.
2. Study the effect of temperature and heating time on the quality and yield of char
3. Study the effect different types of binder on calorific value of charcoal briquette and select the best binder.
4. Characterization of charcoal briquette
5. Physical characterization of wood vinegar.

2. Literature Review

2.1. Over view of energy resources

The energy resources can be divided into three types: fossil fuels, nuclear resources and renewable resources. Among these three, fossil fuels are vastly used in each sector of life. The demand for fossil fuels has increased rapidly due to increased industrialization and increased world population. This increased demand has put added load on the fossil fuel reserves, which are limited. It has also affected the environment adversely and increased threat to global climate change and health risks. Global warming or global climate change is a major problem of 21st century. It has various adverse effects on health and socio-economic issues, for example, increased global temperature, increase in average sea level, increased droughts and floods, and effects on the risk of calamities and malnourishment. [5]

This has aroused great interest in encouraging research on alternative fuels such as solar, wind, hydropower, biomass and other renewable resources which would be capable enough to meet world's ever increasing energy requirements. These energy sources are the primary, domestic and clean or inexhaustible energy resources also known as non-conventional or alternative energy sources. As opposed to non-renewable energy sources, the renewable sources are clean sources of energy and careful use of such resources reduces the hazardous impacts on the environment, produce less wastes and can be sustainable models of energy generation based on current socio-economic situations. Currently, 14% of world's total energy demand is fulfilled by renewable energy sources. [4]

Table 2. Main resource of renewable energy and their usage form

Sr.No.	Energy sources	Application and conversion
1	Solar	Solar cookers, solar home system ,solar dryers
2	Wind	Power generation, windmills, wind generators, water pumps
3	Geothermal	Power generation, urban heating, hydrothermal, hot dry rock
4	Hydropower	Generation of power
5	Direct solar	Thermal power, photovoltaic, water heaters
6	Modern biomass	Digestion, pyrolysis, heat generation, power generation, gasification

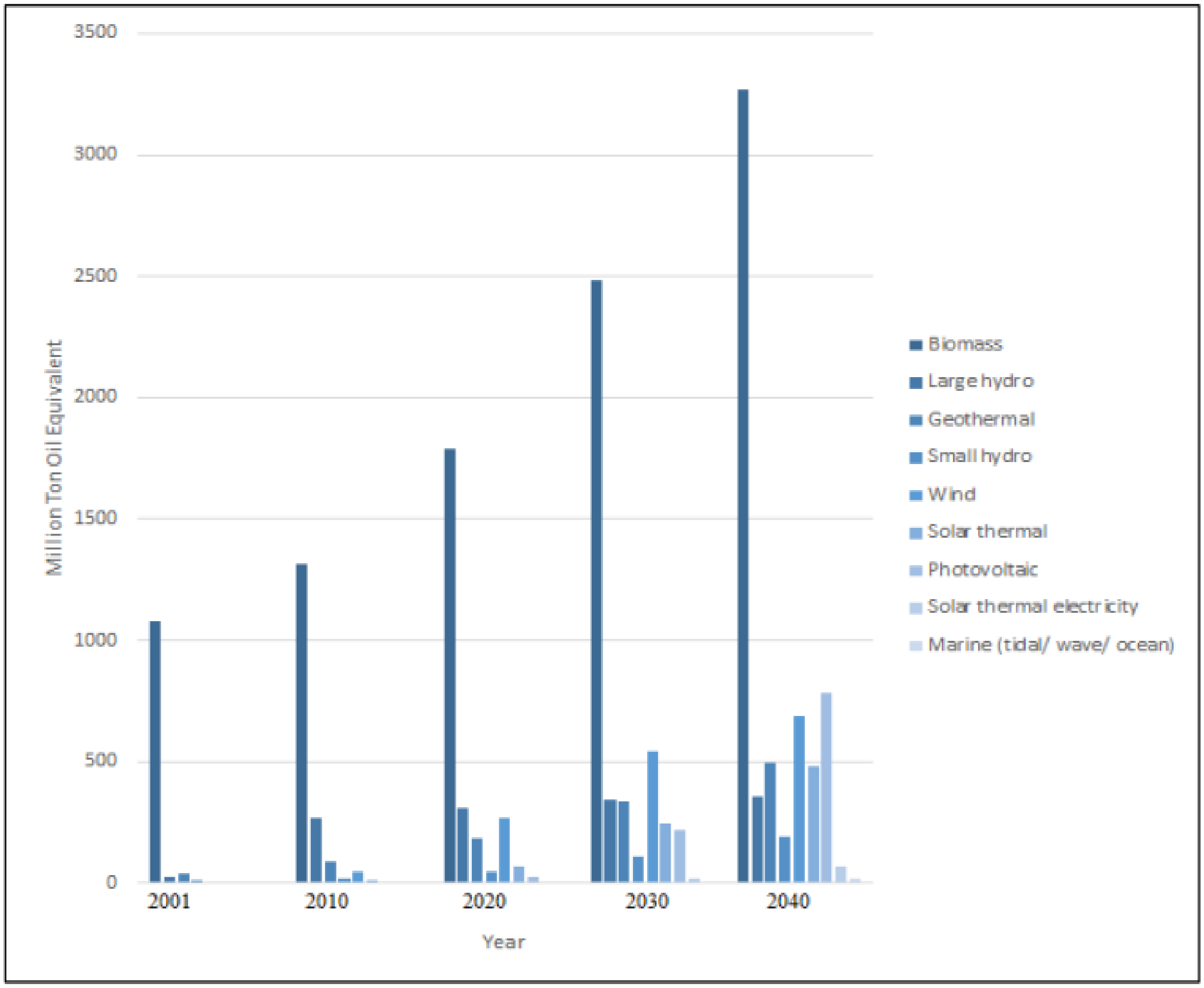


Figure 1. Global renewable energy scenario by 2040 (Estimated)

Here are some previously undertaken studies on charcoal briquette production from different non woody biomass energy resources.

Olorunnisola undertook a study to investigate the properties of fuel briquettes produced from a mixture of a municipal solid waste and an agricultural residue, i.e., carbonized shredded waste paper and hammer milled coconut husk particles. Briquettes were manufactured using a manually-operated closed – end die piston press at an average pressure of 1.2 x 10^3 N/m^2 using four coconut husk to waste paper mixing ratios (by weight), i.e., 0:100; 5: 95; 15: 85; and 25: 75. Results obtained showed that briquettes produced using 100% waste paper and 5:95 coconut husk - waste paper ratios respectively exhibited the largest (though minimal) linear expansion on drying. While the equilibrium moisture content of the briquettes ranged between 5.4 % and 13.3%, there was no clearly discernible pattern in equilibrium moisture content variation with increase in coconut husk content. It was concluded that stable briquettes could be formed from waste paper mixed with coconut husk particles. [20]

Olle and Olof stated that lot of different materials can be used for charcoal briquette making, for example agricultural residues like ground nut shells, straw, tree leaves, grass, rice and maize husks and banana leaves. It is also possible to use already processed materials such as paper, saw dust and charcoal fines. Although some materials burn better than others, the selection of raw material is usually most dependent on what is easily available in the surrounding areas of where the charcoal briquettes are made. They further stated that, briquette can consist of a blend between many different raw materials. The inflammability is not the only thing that matters when the raw material is being selected. Another important characteristic is its ability to bond together, with a suitable binder when compressed. [12]

Larry reported that the U.S. Forest Service estimates national forest wastes at, one billion dry tons. In Minnesota alone, 7.2 million tons of wood residues are available every year for fuel. Hennepin County in Minnesota (part of the seven-county metropolitan Twin Cities area) produces almost 5,000 tons per day of burnable paper garbage. This waste could be effectively converted to briquette fuel that would provide 80 billion Btus of heat energy daily. This 80 billion Btus of daily untapped heat energy is equivalent to that produced by 500,000 gallons of fuel oil, which, at $.90 per gallon, would cost $450,000 per day, or $3.15 million per week. [9]

A Study by Wanamukonya and Jenkins highlighted the potential of briquette biomass as a potential fuel to be utilized in Kenya.

Biomass burning accounts for 85% of Kenya's energy consumption, growing demand and lack of resources have created the need for alternative energy resources. This study found the utilization of waste from over 400 sawmills through the briquetting process could supply about 63,000 tons of combustible material to help toward growing energy demands. [10]

Eriksson and Prior stated that binding agent is necessary to prevent the compressed material from springing back and eventually returning to its original form. This agent can either be added to the process or, when compressing ligneous material, be part of the material itself in the form of lignin.

Lignin, or sulphuric lignin, is a constituent in most agricultural residues. It can be defined as a thermo plastic polymer, which begins to soften at temperatures above 100°C and is flowing at higher temperatures. The softening of lignin and its subsequent cooling while the material is still under pressure is the key factor in high pressure briquetting. It is a physico-chemical process related largely to the temperature reached in the briquetting process and the amount of lignin in the original material. [6]

Lardinois and Klundert suggested that the raw material of a briquette must bind during compression; otherwise, when the briquette is removed from the mould, it will crumble. Improved cohesion can be obtained with a binder but also without, since under high temperature and pressure, some materials such as wood bind naturally. A binder must not cause smoke or gummy deposits, while the creation of excess dust must also be avoided. Two different sorts of binders may be employed. Combustible binders are prepared from natural or synthetic resins, animal manure or treated, dewatered sewage sludge. Non-combustible binders include clay, cement and other adhesive minerals. Although combustible binders are preferable, non-combustible binders may be suitable if used in sufficiently low concentrations. For example, if organic waste is mixed with too much clay, the briquettes will not easily ignite or burn uniformly. Suitable binders include starch (5 to 10%) or molasses (15 to 25%) although their use can prove expensive. [13]

Eriksson and prior acknowledged that of the most important characteristics of a fuel is its calorific value, that is the amount of energy per kg it gives off when burned. Although briquettes, as with most solid fuels, are priced by weight or volume, market forces will eventually set the price of each fuel according to its energy content. However, the production cost of briquettes is independent of their calorific value as are the transportation and handling costs.

They went further stating that the calorific value can thus be used to calculate the competitiveness of a processed fuel in a given market situation. There is a range of other factors, such as ease of handling, burning characteristics etc. which also influence the market value but calorific value is probably the most important factor. [15].

To summarize charcoal briquette production is ancient practice. It is practiced all over the world including Ethiopia as the above literatures stated. But most of the researchers focused on raw materials like crop residue, forest products, waste paper, waste charcoal and others. No researchers use chat Geraba as raw material which is the most abundant waste especially in Ethiopia.

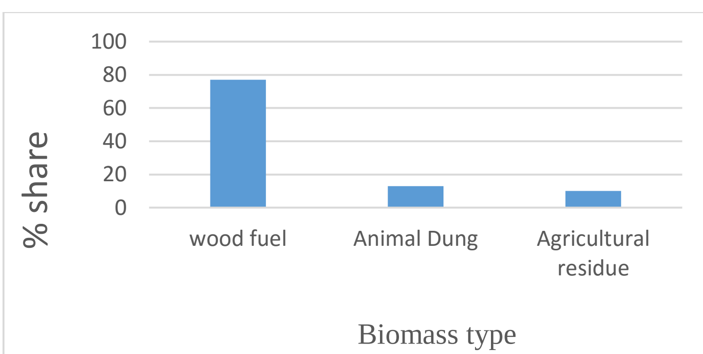
In addition, every researcher didn't consider about the smoke that is evolved during pyrolysis. This smoke is one of the air pollutant and it is better to recover it to produce useful products like wood vinegar rather than venting it to the environment. And it is good to integrate charcoal briquette production with wood vinegar instead of making them individually.

2.2. Biomass assessment in Ethiopia

Historically, biomass has been a major source of household's energy in Ethiopian. It meets the cooking energy needs of most rural households and half of the urban household's demands. The rural population of Ethiopia entirely depends on biomass for everyday energy needs except for light in a traditional way which causes many problems such as pollution arising due to burning of biomass. As cooking is done within the confines house, the pollution cause death of million people in the world including Ethiopia. The option to solve such problem could be the densification or briquetting by carbonizing it.

Ethiopian has an agricultural based economy where all kind of tropical crops are in cultivation and residues such as coffee husk, cotton stalks, wheat straw, bagasse, shells and nuts are major fuels used in many part of the country. [6].

Biomass constitutes about 92% of total potential supply of energy in our country and about 77% of annual biomass consumption in Ethiopia is met from fuel wood followed by animal dung 13% and crop residue 10% respectively [9]. Ethiopia has one of the lowest rates of access to modern energy services, its energy supply is primarily based on biomass followed by oil (6.7%) and hydropower (1.3%).



Source: MWE (ministry of water and Energy)

Figure 2. Percent share of Energy resource in Ethiopia

Table 3. Annual biomass energy consumption of Ethiopia in Tera calorie

Region	Fuel wood	Charcoal	Residue	Dung	Total	Share
Tigray	6,865	249	435	2,260	9,809	0.044
Amhara	49,033	220	10,530	15,917	75,699	0.339
Oromiya	58,281	577	3,150	9,762	71,771	0.322
SNNP	44,138	75	4,971	677	49,862	0.223
Afare	1,813	18	0	2	1,833	0.008
Benshangul	2,472	27	328	10	2,837	0.013
Gambela	771	1	3	0	775	0.003
Dire-Dawa	196	22	24	0	242	0.001
Harari	128	6	30	0	164	0.001
Addis Ababa	5,617	429	78	392	6,517	0.029
Total	172,608	1,742	19,667	29,152	223,169	1
Share	77%	1%	9%	13%	100%	

Source: MWE (ministry of water and Energy)

In Ethiopia, enormous amounts of coffee husk and pulp are generated from coffee processing industries annually. Even in jimma zone there are around 22 coffee processing factories and they generate enormous amount of coffee husk. Nevertheless, these materials have been poorly utilized and managed or are left to decompose or burned in open fields or dumped in the environment including water bodies. Yet, these activities cause and aggravate pollution of air, the environment, and water potentially undermining coffee certification since environmental considerations and sound coffee production systems are among the criteria and code of conduct required for the certification. [7]

On the other hand, utilization of coffee husk and pulp is an option to alleviate the problems. For example, in different regions of Ethiopia, this biomass has been consumed by households in place of firewood with inefficient open fire stoves. However, direct utilization of this type of biomass as a source of energy is not suitable because it has low density, high smoke, and low energy intensity. Moreover, smoke released from the biomass causes acute respiratory infections. Alternatively, converting such agricultural residues into briquettes addresses these problems because briquette production is environmentally friendly, socially acceptable, and provides a smokeless source of fuel. Besides, briquette production requires low cost, offers a significant advantage over firewood in that it has greater heat intensity.

It also realizes zero waste production and improves the calorific value of the biomass. Despite ample availability, coffee husk and pulp have never been used in Ethiopia as an effective source of energy, but have been dumped into nearby rivers.

Especially in Jimma zone now a day there is no governmental or private company operational that utilize this resource in commercial scale. There is one private company which is around 20 Km away from jimma town that produce briquette from coffee husk. So there is no doubt on the availability of raw material.i.e. coffee husk. For the case of sawdust there are so many wood work industries that produce enormous amount of sawdust and again some of these sawdust used by nearby community in a traditional way as source of fuel. And the majority of the sawdust is dumped into the river which causes pollution of water body. So it is better to utilize these resources in the form of charcoal briquette.

Chat is an evergreen plant cultivated in Ethiopia for its stimulant leaves. The young leaves are chewed as a part of social recreation and the older leaves along with the twigs called chat Geraba is discarded.

Chat Geraba which is the other raw material is highly available in jimma. Above half of the population of jimma especially men chew chat that results in large amount chat Geraba presence which is now a day it becomes a major problem in the cleanness of the city. So converting these waste to valuable product that is charcoal briquette has advantage not only energy perspective but also it has advantage on environmental perspective and it helps to keep the beauty of the city. [18]

2.3. Carbonization

Carbonization is defined as the process by which high carbon content solid residues are formed from organic material usually by pyrolysis in an inert atmosphere. During this thermal decomposition process, moisture and volatiles are driven off, leaving a solid residue (char), liquids (condensable vapor) and permanent gases. [22]. Pyrolysis is one possible path by which we can transform biomass to higher value product. It is a thermal conversion process where the material is treated in an inert atmosphere in the absence of air or oxygen with final temperatures of about 500ºC. The process yields solid char (charcoal, biochar), volatile condensable compounds (distillates) and non-condensable gases. The first step in carbonization in the kiln is drying out of the biomass at 100°C or below to zero moisture content. The temperature of the oven dry biomass is then raised to about 280°C. The energy for these steps comes from partial combustion of some of the biomass charged to the kiln or pit and it is an energy absorbing or endothermic reaction. When the biomass is dry and heated to around 280°C, it begins to spontaneously break down to produce charcoal plus water vapor, methanol, acetic acid and more complex chemicals, chiefly in the form of tars and non-condensable gas consisting mainly of hydrogen, carbon monoxide and carbon dioxide. The spontaneous breakdown or carbonization of the biomass above a temperature of 280°C liberates energy and hence this reaction is said to be exothermic. This process of spontaneous breakdown or carbonization continues until only the carbonized residue called charcoal remains. Unless further external heat is provided, the process stops and the temperature reach a maximum of about 400°C. This charcoal, however, will still contain appreciable amounts of tarry residue, together with the ash of the original biomass.

The ash content of the charcoal is about 3-5%; the tarry residue may amount to about 30% by weight and the balance is fixed carbon about 65-70%. Further heating increases the fixed carbon content by driving off and decomposing more of the tars. A temperature of 500°C gives a typical fixed carbon content of about 85% and a volatile content of about 10%. [15]

2.3.1 Types of pyrolysis system

The pyrolysis process greatly affects the characteristics of char and its potential worth to agriculture in terms of agronomic performance and in carbon sequestration and its energy value. The process and process parameters, principally temperature and furnace residence time, are particularly significant; nevertheless, the process and process conditions also interact with feedstock type in establishing the nature of the product.

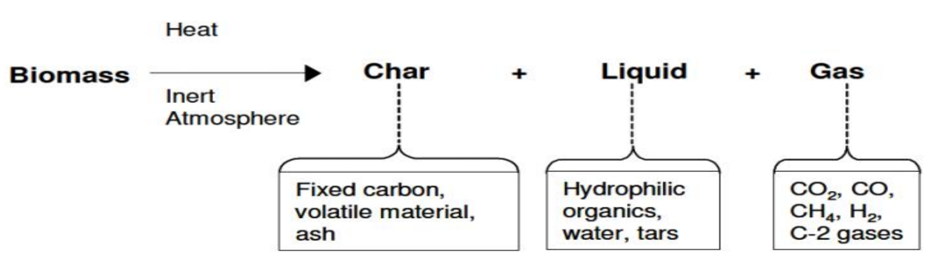


Figure 3. Biomass decomposition by pyrolysis system.

These variables together impact chemical, biological and physical properties, which unfortunately confine the potential usage for biochar products. Each and every category of pyrolysis process is characterized by a contrasting equilibrium between biochar, bio-oil and syngas.

2.3.1.1 Slow pyrolysis

Slow pyrolysis is the thermal conversion of biomass by slow heating at low to medium temperatures (450 to 650°C) in the absence of oxygen, with the simultaneous capture of syngas. Feed stocks in the form of dried biomass pellets or chips of various particle sizes are fed into a heated furnace and exposed to uniform heating, generally through the use of internal or external heating as retort furnace or kilns. It is characterized by: -

- ♣. Relatively low reactor temperatures (450-650°C)
- ♣. Reactor operating at atmospheric pressure
- ♣. Very low heating rates, ranging from 5–80 °C/minute
- ♣. Very short thermal quenching rate for pyrolysis products: minutes to hours.

Several commercial facilities generate syngas and biochar using a continuous flow system in which feedstock passes slowly through a kiln in an auger feed, with combustible syngas continuously drawn away. Biochar, wood vinegar and syngas are formed in approximately equal proportions due to the slow speed of the combustion process, which promotes extensive secondary reactions within biochar particles and in the gas and vapor phases, leading to condensation. The pyrolysis reaction itself is mildly endothermic, with the bulk of energy capture being in the form of the syngas and bio-oil condensates. The biochar has a residual energy content of about 20–30 MJ /kg. The syngas product may be combusted on site to generate heat or electricity (via gas or steam turbine), or both. Adding steam to the pyrolysis reaction liberates additional syngas from the biochar product, mainly in the form of hydrogen. The biochar that remains after this secondary pyrolysis displays rather different properties from the primary product, differing in pore size and carbon to oxygen ratio. [22]

2.3.1.2 Fast pyrolysis

Very rapid feedstock heating (between 200 to 100,000^{0}C per second) leads to a much greater proportion of bio-oil and less biochar. The time taken to reach peak temperature of the endothermic process is approximately one or two seconds, rather than minutes or hours as are the case with slow pyrolysis. Maintaining a low feedstock moisture content of around 10% and using a fine particle size of < 2mm permit rapid transference of energy. In many systems the transfer is further increased by mechanically enhancing feedstock contact with the heat source or maximizing heat source surface area. Surface charring must be continuously removed during reaction to prevent pyrolysis of particle interiors being inhibited by its insulating effect. Bio-oil is condensed from the syngas stream under rapid cooling, with the combustion of syngas providing the pyrolysis process heat. [22]

2.3.1.3 Intermediate pyrolysis

Intermediate Pyrolysis is characterized by moderate temperatures exist (400-600^{0}C) and rapid heating rates less than 2°C/s. Vapor residence times are usually less than two seconds. Compared to slow Pyrolysis, considerably less tar and gas are produced. [23]

2.3.2 Mechanism of Pyrolysis

The mechanism of Pyrolysis system has three main stage such as dehydration, fragmentation and formation of product. The biomass is directly and visibly affected as the Pyrolysis process proceeds. For example, the change of color of biomass from white to brown and finally the color change to the black. Size and weight are reduced while flexibility and mechanical strength are lost.

2.3.2.1 Dehydration

Dehydration, which is dominant at low temperature, is the primary of the two reactions during slow Pyrolysis. Normally the reaction take place below 300^{0}C and result in the reduction of the biomass molecular weight, the evaluation of water, Carbon Monoxides (CO), Carbon Dioxides (CO_2) and char.

2.3.2.2 Fragmentation

Fragmentation dominates at temperature above 300^{0}C. It involves the deploymerization of the biomass to hydro glucose compound and other light combustible volatiles. Because of the temperature range involve, fragmentation is of greater interest in fast Pyrolysis.

2.3.2.3 Formation of Product

Biomass is complex and information known about it is often limited it is specimen used, the stable end product and how some of these product depend on the pyrolytic treatment. Normally the final product can be divided into three categories. The first category is volatile product of molecular weight (M) below than 105 such as Carbon Monoxides (CO), Carbon Dioxides (CO_2), Acetol and unsaturated Aldehydes. The second product is tars with higher molecular weight and the last product is chars. [23]

2.4. Briquetting technologies

Depending on the type of biomass that has been carbonized, subsequent sizing (milling) and briquetting may be needed to produce charcoal briquettes. The main briquetting technologies suitable for producing charcoal briquettes, varying from very small to medium capacity, are introduced below.

2.4.1 Hand presses

Briquetting can be done by hand, using a simple mould and hammering the charcoal dust together. There are a considerable number of designs that have been disseminated across rural areas in developing countries lacking electricity supply. Hand briquetting requires only a low investment but is very labor intensive.

2.4.2 Screw extruders

A simple screw extruder, like the one used to mincemeat, can be applied to produce charcoal briquettes. When or where no electric power is available the technology may be operated manually. Especially when hand operated the technology is still rather labor intensive.

Figure 4. Screw extruders

2.4.3 Agglomerators

Another small-scale briquetting processes applied in several developing countries is the agglomeration technology. The charcoal is milled to powder, binders are added, the components are mixed together, and the mix is then agglomerated. Agglomeration technology involves size enlargement of a nucleus/balls of charcoal formed within a rotating cylinder.

2.5. Binders

Charcoal is a material totally lacking plasticity and hence needs addition of a sticking or agglomerating material to enable a briquette to be formed. The binder should preferably be combustible, though a non-combustible binder effective at low concentrations can be suitable.

Clay

Clay has the advantage that in many areas it is widely available at practically no cost. Main disadvantage is that clay does not add to the heating value of the briquette; if a large amount of clay is used for briquetting the briquette will ignite and burn poorly or not at all.

Molasses

Molasses is a by-product from the sugar cane industry. For each tone of briquettes about 20-25% molasses is needed. Each unit of pure molasses is diluted with 2-3 units of water before entering the briquetting process. Briquettes made by molasses burn well, however the briquettes have an unpleasant smell during the initial phases of burning. To avoid this smell, the briquettes can be thermally treated before use, also called "curing", which is in fact a light torrefaction step.

Starch

The most common binder is starch. About 4-8% (usually 5%) of starch made into paste with hot water. The binder is mixed with water and heated for some time after which it is ready for mixing with the charcoal powder.

Wood tar

Wood tars that arise during the carbonization process could be recovered and used as a binder for briquetting. The recovery of tars helps to reduce the emissions to the air, but tar recovery technologies are only applied in stationary kilns and retorts. Briquettes made with wood tar require a full carbonization step to avoid the emission of heavy smoke.

In this part the effect of these binder on calorific value was examined and the appropriate binder was selected. At the end the final product or briquette will be characterized by the same way as characterizing the raw material. [4]

Carbonization of biomass residues almost doubles the energy value per unit of weight – with bio-char having a calorific value of 20–30 MJ/kg, compared to around 15 MJ/kg for unprocessed biomass and gives briquettes a charcoal-like appearance, hence the terms 'charcoal briquettes' or 'biocoal'. [25]

Table 4. Similarities and differences between wood charcoal and charcoal briquettes

Characteristic	Wood charcoal	Charcoal briquettes
Raw material	Wood	Sawdust, coffee husk, nut shells, bagasse, crop residues, dust and fines of coal or charcoal (char-dust)
Source of raw material	Tree plantations or natural forests/woodlands	Agri-businesses, crop processing industries, smallholdings, urban charcoal traders, coal mines
Location of production process	Almost exclusively rural	Largely rural or pri-urban although charcoal dust usually salvaged from urban traders; urban when raw material obtained from urban biomass waste (e.g. saw dust from carpentry centers)
Production process	Ranges from traditional earth mounds and pits, to metal and brick batch kilns, to continuous rotary kilns and microwave systems.	Ranges from small scale production using steel drums as kilns and modified meat mincers as extruders to large scale factory set up with densify-first or carbonize-first options
Efficiency of production	Traditional earth mounds and pits: 15–25% metal and brick kilns: 25–25%; continuous rotary kilns and microwave systems: up to 40%	15–25% if carbonization is required. >90% if material is already carbonized.
Energy value	31–33 MJ/kg	20–30 MJ/kg
Ash content	< 5%	10–30%
Ease of lighting	Easy to light	Harder to light, due to higher ash content
Length of burn	Fast burning due to high energy and low ash	Slow burning, due to lower energy and higher ash
Extinguish ability	Can be put out for later re-use	Generally crumbles if put out, and cannot be re-used
Principal applications	Limited use, usually cooking and barbequing	Variable uses including space heating, water heating, slow cooking

2.6. Wood Vinegar, Pyroligneous Acid

Pyroligneous acid, also called wood vinegar or mokusaku, is an aqueous liquid produced from slow pyrolysis of hard wood. When wood is burnt in the open air, it is reduced to ash. However, if it is heated in a closed vessel or air-tight environment, it is pyrolysed, or transformed through the action of the heat, leaving behind charcoal. During this process of carbonization, smoke is emitted. If this smoke is cooled, a liquid can be collected. This liquid, if left to sit, will separate into three distinct layers as shown in Figures 5. An oily liquid occupies the top layer which is called bio-oil while thick wood tar settles on the bottom. The middle layer consists of a transparent, yellowish-brown liquid which is commonly called raw wood vinegar. Wood vinegar has been used in a variety of ways, including as an ingredient in medicines, an additive to animal feeds, a deodorizer, a mordant in the dyeing process, a facilitator in the fermentation process, a filter in sewage treatment and a raw material in various other industries. [17]

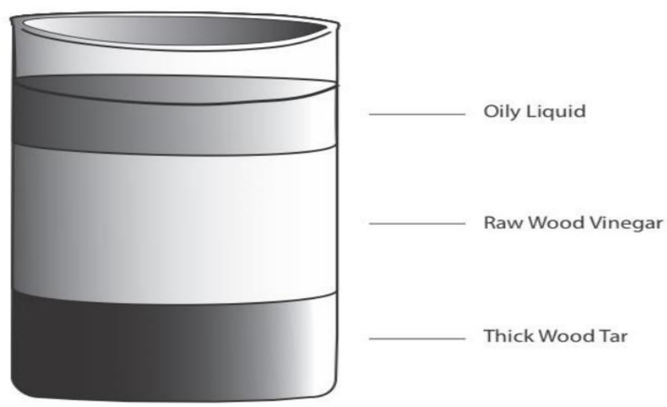


Figure 5. *Component of distillate from bio mass (wood) pyrolysis*

The most common component in wood vinegar, except for water, is acetic acid, which accounts for 3 to 7% of the total ingredients and 50-70% of the organic matter. In addition to acetic acid and other organic vinegars, raw wood vinegar also consists of roughly 5% phenols and several percent of various types of alcohol including methanol and ethanol. [20] Biomass constituent destructive depends on temperature such that hemicellulose was started at temperature of 100-260^{o}C, then followed by the destructive of cellulose at temperature of 240-350^{o}C. Finally, lignin was changed at temperature of 280-500^{o}C. Fenkel and Wegener (1984) reported that hemicellulose thermal degradation provides acetic acid, methanol, furfural, aldehyde and ketones which are some of the constituent of wood vinegar. [29].

Wood vinegar is generally dark brown, viscous and composed of a very complex mixture of oxygenated hydrocarbons. It is useful for soil improvement, break seed dormancy, germination and especially in biological activity of fungal and termite attack. Wood vinegar compositions and yields depend on process conditions and compositions of starting material. [28]

Researchers have found that the beneficial effects of wood vinegar in agricultural applications include:

1. Spraying diluted wood vinegar on plant leaves increases their vitality and improves crop quality.
2. Spraying also helps control harmful insects and some kinds of plant diseases.
3. Wood vinegar and agricultural chemicals are complementary. The efficiency of using them together is greater than using either one alone.
4. If wood vinegar is applied to the soil or mixed into it in high concentrations, it inhibits eelworms and soil diseases.
5. Wood vinegar helps plants develop stronger roots.
6. Mixing wood vinegar with manure reduces odours and facilitates composting. [21]

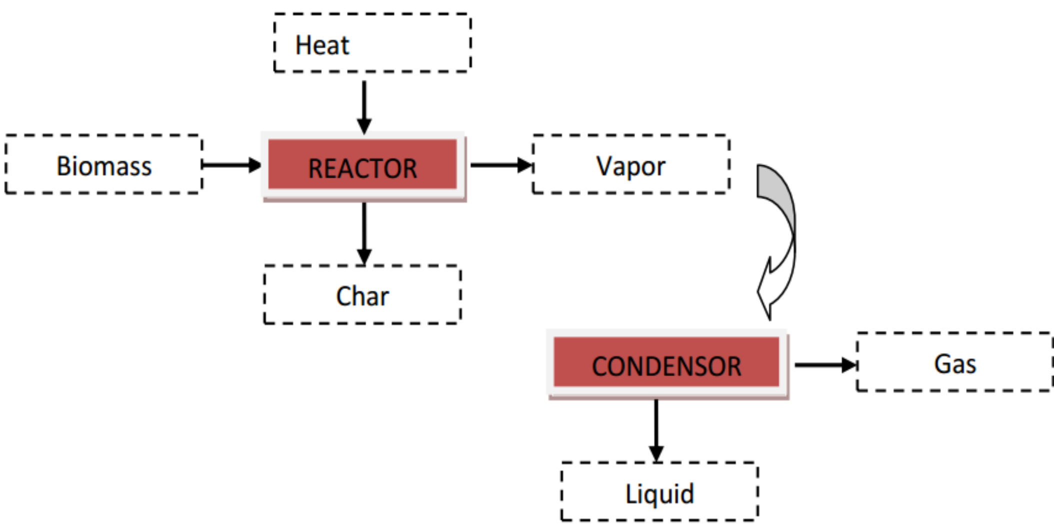


Figure 6. Reaction pathway of Pyrolysis process

3. Materials and methods

3.1. Description of the Study Area

Some part of the experiment of this work was conducted at Jimma institute of technology (JIT) and some of the other experiments were done in jimma university college of agriculture post harvesting department. Determination of calorific value of fuel charcoal briquette was carried out in the Laboratory at Geological survey of Ethiopia in Addis Ababa. List of material used during experimentation includes Furnace, oven, balance, jaw crusher, pH meter, densitometer, PVC pipes with different diameter Balance, Sieve and others.

3.2. Raw material collection and production process

The raw materials are coffee husk from coffee processing or coffee hulling industry, sawdust from wood processing factory, Chat Geraba and other agricultural wastes. The production process for the products is given below using schematic block diagram: -

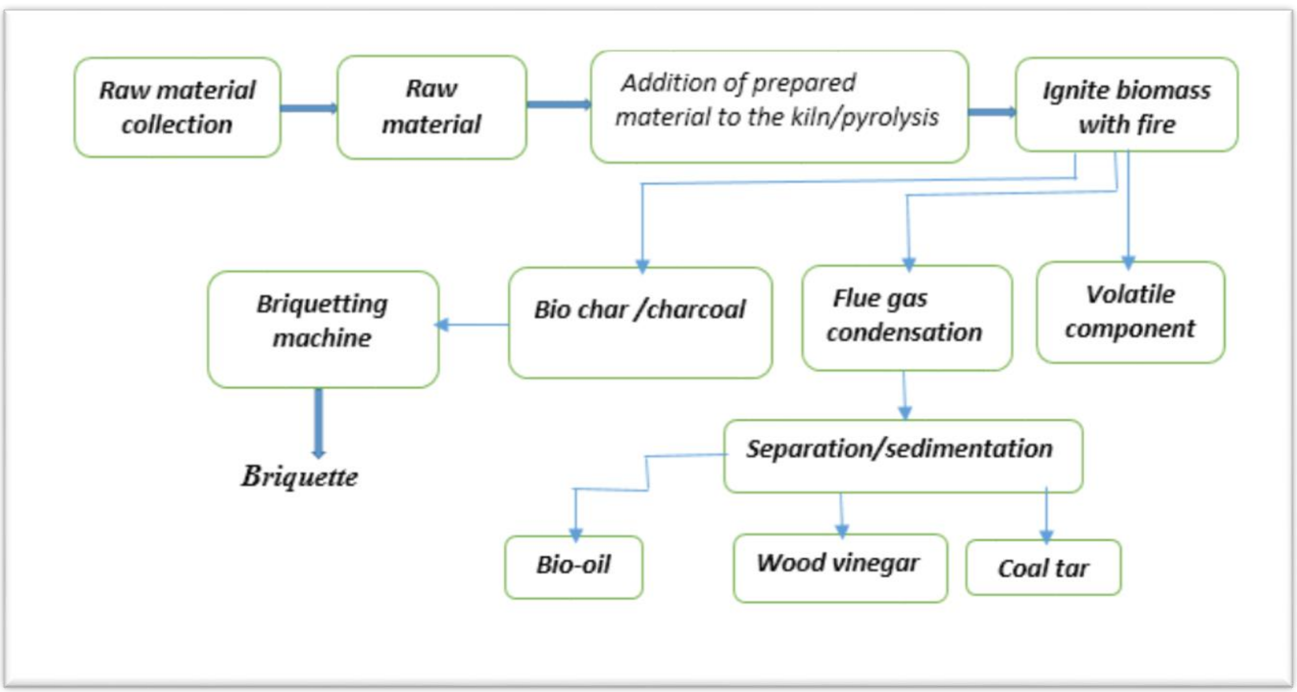


Figure 7. Process block diagram for charcoal briquette and vinegar production

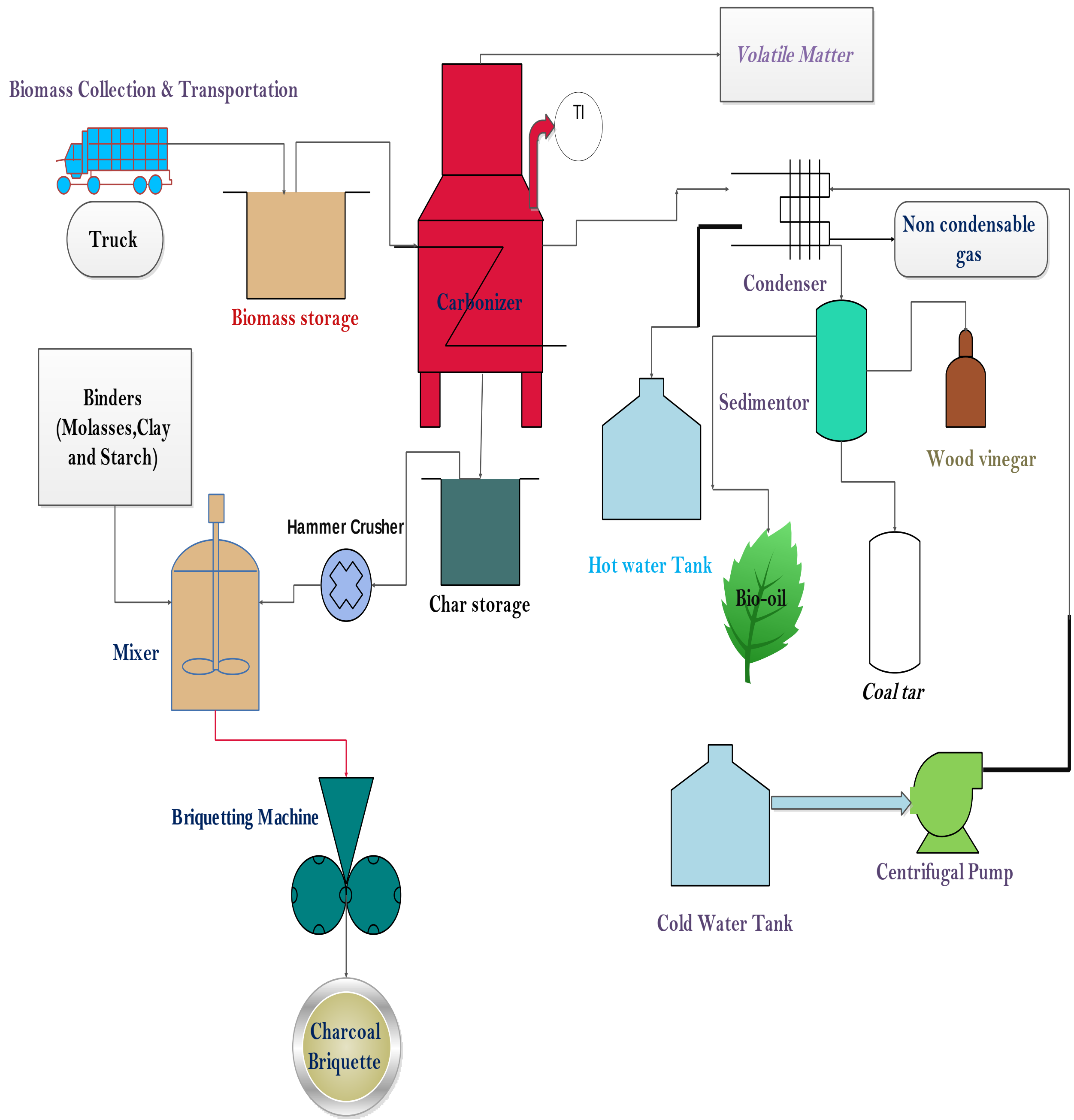


Figure 8. Process flow diagram for charcoal briquette and vinegar production

3.3. Raw material characterization

The raw materials are characterized in terms of its fixed carbon content, moisture content, volatile matter and ash content that is its proximate analysis. These components are typically among the primary parameters used for assessing the quality of a solid fuel material.

The moisture result is utilized for calculating the dry basis results of other analytical results. The ash result is utilized in the ultimate analysis calculation of oxygen and for calculating material balance and ash load purposes in industrial boiler systems. The volatile matter result indicates the coke yield on the carbonization process providing additional information on combustion characteristics of the materials, and establishes a basis for purchasing and selling the solid fuel materials. Fixed carbon is a calculated value of the difference between 100 and the sum of the moisture, ash, and volatile matter where all values are on the same moisture reference base and directly related with the energy value of charcoal. The procedures of the ASTM D-3175(2007) standard were adopted to obtain the above parameters.

3.3.1 Moisture content

The moisture content of the biomass is determined by heating fixed mass sample of biomass to 110 ^{o}C using oven to a constant mass and the moisture was computed on weight basis according to the following equation:

$$\text{Moisture content}(\%) = \frac{\text{Weight of sample} - \text{Weight of oven dried sample}}{\text{Weight of sample}} * 100$$

For this work two (for the case of coffee husk and chat Geraba) and three (for the case of saw dust) samples are taken and put into oven using Petri dish as holding container at about 110^{o}C.

Coffee husk Chat Geraba Saw dust

Figure 9. Coffee husk, saw dust and Chat Geraba

3.3.2 Volatile matter

The volatile matter was determined by heating an oven-dried sample in absence of oxygen at 925°C for seven minutes. It was computed as the ratio of difference between the initial weight and final weight of the sample to the initial weight of the biomass sample as follows.

$$\text{Volatile Matter (\%)} = \frac{\text{Weight sample@11o ℃} - \text{Weight of sample @ 925 ℃}}{\text{Weight of sample@ 11o ℃}} * 100$$

The dried samples after moisture removal was then taken in a crucible and placed in an electrically heated furnace at a temperature of 925°C for seven minutes and then cooled.

Figure 10. Electrical furnace used to determine volatile matter

3.3.3 Ash content

Ash content was determined by heating the sample in a crucible at 725°C for one and half hours in the Furnace. The ash content was calculated as the proportion of the weight of the ash in the sample to the weight of sample as follows:

$$\text{Ash content (\%)} = \frac{\text{Weight of sample at 925 ℃} - \text{Weight of sample at 725 ℃}}{\text{Weight of sample 925 ℃}}$$

The remaining samples after determination of volatile matter of coffee husk, saw dust and chat Geraba was kept in furnace at a temperature of 725°C for one and half hours.

3.3.4 Fixed carbon

The percentage of fixed carbon content of the briquettes was computed by subtracting the sum of volatile matter (VM), ash content (AC), and MC (moisture content) from 100.

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

3.4. Procedure for Char and wood vinegar making process

After characterizing the biomass, it should be carbonized to produce char using carbonizing kiln and the effect of parameters like temperature and heating time on carbonizer is examined.

1. Get ready both the pyrolysis system (carbonizer) and condenser

Figure 11. Diagrammatic representation of carbonizer (pyrolizer)

2. Prepare samples of Saw dust, coffee husk or Chat Geraba turn by turn by using balance
3. Put the prepared sample to the carbonizer (pyrolizer) which works under air tight condition (in the absence of air) and cover the pyrolizer with it Owen cover lid (both the internal and

external cover) try to minimize leakage of smokes and syngas from this carbonizer as much as possible.

Figure 12. Horizontal carbonizer with samples

4. Start the burning process by turning on the electric power gage and setting both temperature (350^0C-550^0C) based on our interest and residence time 4:40 (1 hour to heat the machine 3 hours for carbonization process and 40 minutes for cooling the machine (Quenching).
5. Start the condensation process when the temperature reaches around 280^0C or start the condensation when the color of the smoke changes from white to brown and condense until the color of smoke becomes black. [28]

Figure 13. Integrated diagram of carbonization and condensation process

6. After that dismantle the condensation setup and measure how much raw wood vinegar is produced from the given amount of raw material (saw dust or coffee husk)
7. After carbonization is completed, supply water to the system by turning on the water supply valve to the metal tube which enwrapped around the horizontal bed reactor and cool the system for around 40 minutes.
8. After sufficient cooling, collect the char that is produced in the carbonization process. Here are some of the diagrams that illustrate the work.

Figure 14. Char and wood vinegar from coffee husk

Figure 15. Char from saw dust

Figure 16. Chat Geraba and char

3.5. Kiln conversion efficiency (Carbonization efficiency)

The conversion of biomass to char plays a small but crucial role in the biomass/bio waste-to-charcoal value chain. The success of the carbonization process is the efficiency of the kiln, defined as the mass yield of char, expressed as a percentage of the dry mass of feedstock substrate initially placed in the kiln. Kiln or retort efficiency is also referred to as carbonization efficiency, conversion efficiency or char yield.

$$Ycha = \frac{M\ cha}{M\ bio} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where M_{cha} is the dry mass of charcoal produced in the kiln and M_{bio} is the initial dry mass of the biomass feedstock loaded into the kiln [16].

Energy input to the kiln is provided via biomass either burned inside the kiln (to provide direct heating) or externally outside (indirect heating). Biomass, which is burned to provide direct heating, needs to be included in efficiency calculations. Thus, in comparing net yields, the output weight of the char should be compared with the weight of all dry feedstock consumed in the process, including feedstock consumed to drive pyrolysis. But this representation of the efficiency of the carbonization process is intrinsically vague because it does not reflect the fixed-carbon content of char product, which widely varies. [11]

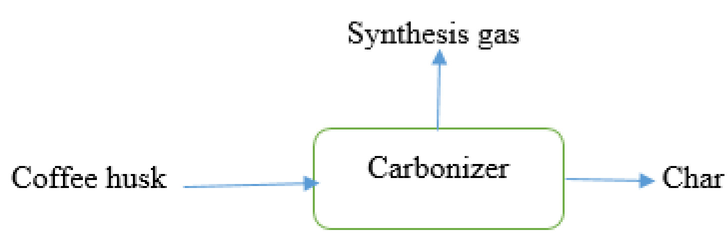
It is relevant to know that the conversion efficiency decreases when peak temperature increases, because the tar fraction is lost, but that the quality of the product improves. [10]. A more meaningful measure of the carbonization efficiency is given by the fixed-carbon yield (Y_{fc}) in equation 2:

$$Y_{fc} = Y_{char} * \frac{\% FC}{(100 - \% Fc)} \quad \ldots\ldots \quad 2$$

Where Y_{char}(%) is yield of char and FC(%) is fixed carbon content

3.6. Mass and Energy Balance calculation for carbonizer and condenser

Mass of coffee husk and char at optimum temperature and heating time (t = 3hr) are 5 and 1.55 kg respectively.



Mass of synthesis gas = Mass of coffee husk- mass of char

Mass of synthesis gas = (5 – 1.55) kg

Mass of synthesis gas = 3.45 kg

Mass flow rate of synthesis gas = mass of synthesis gas /heating time = 1.15kg/hr. (0.00032kg/s)

Input power for the carbonizer can be calculated from its specification i.e. current (I=100A) and voltage (V=220 volt).

$$P = I * V$$

P = 100A * 220V = 22 KW

<u>Energy balance for the condenser</u>: - synthesis gas is a mixture of different component such as

- CO_2 (carbon dioxide) – 9 to 55 volume-%
- CO (carbon monoxide) – 16 to 51 volume-%
- H_2 (hydrogen gas) – 2 to 43 volume-%
- CH_4 (methane) – 4 to 11 volume-%
- Low amount of N_2 (Nitrous gas)
- Low amount of other hydrocarbons [31].

To calculate the heat contained in the synthesis gas some assumption should be made. Such as

*** No heat loss from the pipe (that takes synthesis gas from carbonizer to condenser) to the surrounding. So the inlet temperature of the synthesis gas is 500^{o}C.

*** Heat capacity of synthesis gas is the summation of heat capacity of its component.

$$C_p = x\ CO_2 * C_p\ CO_2 + x\ CO * C_p\ CO + x\ CH_4 * C_p\ CH_4 + x\ H_2 * C_p\ H_2$$

By taking the average volume fraction of each component and heat capacity of each component except CH_4 can be red from thermodynamic table. [30] Heat capacity of CH_4 can be red from Engineering tool box and it is 3.823 KJ/kg. k.

$$C_p = 0.32 * 1.157 + 0.335 * 1.133 + 0.11 * 3.823 + 0.225 * 14.67$$

$$C_p = 4.471 \text{ KJ/kg. k.}$$

*** The vapors produced were condensed using a water-cooled condenser at an outlet temperature of 80–150°C and the average is taken as the exit temperature of the condensate which is 115^{o}C and the condensation starts at this point. [32]

*** From 5 kg of coffee husk 3.45 kg of synthesis gas was obtained and from this 0.6 litter of raw wood vinegar was found. And density of wood vinegar is 1020Kg/m^3. [34]

So efficiency of condenser can be calculated as;

$$\text{Efficiency}(\eta) = \frac{out\ put}{input} = \frac{0.612}{3.45} = 18\%$$

***Latent heat of condensation of synthesis gas is the summation of latent heat of condensation of the major component.

$$\lambda_{Mix} = x * \lambda_{Co2} + x\lambda_{CO} + x\lambda_{H2} + x\lambda_{CH4}$$

$$\lambda_{Mix} = 0.32*574\text{KJ/kg} + 0.335*216\text{KJ/kg} + 0.225*461\text{KJ/kg} + 0.11*510\text{KJ/kg}$$

$$\underline{\lambda_{Mix} = 415\text{KJ/kg}}$$

And the heat transfer rate for the hot fluid can be calculated as;

$$Q = m * \text{Cp} * \Delta\text{T} + 18\% * m * \lambda_{Mix}\ (latent\ heat\ of\ condensation)$$

$$Q = \left[\frac{0.00032\text{kg}}{\text{s}} * 4.471\frac{\text{KJ}}{\text{kg}}.\text{k}.* (500 - 115)\text{k}\right] + (0.18 * 0.00032\text{kg/s} * 415\text{KJ/kg})$$

$$\underline{Q = 0.575kJ/s = 575\text{J/s}}$$

The general equation for heat transfer across a surface is:

$$Q = UA\Delta T_m$$

where Q = heat transferred per unit time, W,
U = the overall heat transfer coefficient, $W/m^2\,°C$,
A = heat-transfer area, m^2,
ΔT_m = the mean temperature difference, the temperature driving force, °C.

***The inlet and outlet temperature of the water are 25 and 50°C measured using thermometer and log mean temperature can be calculated as

$$\Delta T_{\text{lm}} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \dfrac{(T_1 - t_2)}{(T_2 - t_1)}}$$

where ΔT_{lm} = log mean temperature difference,
T_1 = hot fluid temperature, inlet,
T_2 = hot fluid temperature, outlet,
t_1 = cold fluid temperature, inlet,
t_2 = cold fluid temperature, outlet.

$$\Delta T_{lm} = \frac{(500-50)-(115-25)}{\ln((500-50)-(115-25))} = 180^{o}C$$

*** To calculate heat transfer area overall heat transfer cofficient was assumed and red from Table 12.1 of [33]. And it is 500 $w/m^{2o}C$ by assuming synthesis gas as organic(some noncondensable) hot fluid and water as cold fluid.

$$Q = UA\Delta T_m$$

from the equetion above heat transfer area A;

$A = \frac{Q}{U*\Delta Tlm} = \frac{575}{500*180} = 6.4*10^{-2}\ m^2$. The heat transfer area is low. So it is better to increase number of tube since in this work only one tube was used to increase the heat transfer area.

*** Mass flow rate of cold fluid (water) can be calculated from the equetion

$$Q = m * Cp * \Delta T$$

The heat lost by hot fluid is absorbed by cold fluid and heat capacity of water is 4.2 KJ/kg.k.

$$m = \frac{Q}{Cp*\Delta T} = (\frac{575J}{s})/(\frac{4.2kJ}{kg.k} * (50-25)k) = \underline{5.5*10^{-3}\ kg/s}$$

3.7. Procedures for charcoal briquette production

The produced char is crushed to appropriate particle size and mixed with binders to produce briquette. Here are the procedures for briquette production:

1. Cutting the PVC which have diameters 5cm, 7cm and 10cm at different size (height).
2. Erect the prepared PVC (cut at different size) at the wood plank by using nail to support it. It can be made with different shapes like cylindrical or hollow tube.

Figure 17. Molding tool with different shape

3. After preparing the molder/casting tool, measure the char produced from different biomass (coffee husk, sawdust, chat Geraba) using measuring balance.
4. Mix the measured char with different binders (molasses, clay and starch) separately with their own given specification.

For instance, for the case of coffee husk char and molasses binder the specification is that;

- Coffee husk char = 75 – 80% and the average is 77.5%
- Molasses = 20 - 25% average = 22.5% and each unit of molasses should be diluted with 2- 3 units of water before mixing with char. For my case 1kg of char was taken and mixed with 0.29 kg of molasses but before that this molasses is diluted with 0.58 litter of water. [4]

For the case of saw dust and molasses,

- Mass of saw dust = 0.6 kg which is 77.5%
- Mass of molasses =0.17 kg (22.5%) and this molasses should be diluted with 0.34kg (340 ml) of water before mixing with char.

For the case of Chat Geraba and molasses

- Mass of Chat Geraba = 0.488 kg which is 77.5% of the mixture
- Mass of molasses = 0.14 kg (22.5%) and it is diluted with 0.28 kg (280ml) of water

For clay binder the specification is as follow,

- Char (coffee husk, saw dust, chat Geraba) =62%
- Clay =10%
- Water =28%

Based on this specification different samples of mixture were made for each raw material (coffee husk, saw dust and chat Geraba) and get ready for briquetting.

That is for coffee husk and clay,

- Mass of coffee husk = 0.372 kg
- Mass of clay = 0.06 kg
- Mass of water = 0.168 kg (168 ml)

For saw dust and clay,

- Mass of saw dust = 0.6 kg
- Mass of clay = 0.096 kg
- Mass of water = 0.27 kg (270ml) of water

For chat Geraba

- Mass of chat Geraba = 0.364kg
- Mass of clay = 0.0587 kg
- Mass of water = 0.164 kg

For starch binder the specification is as follow,

About 4-8% (usually 5%) of starch made into paste with hot water. The binder is mixed with water and heated for some time after which it is ready for mixing with the char powder.
For starch and chat Geraba,

- Mass of chat Geraba char = 0.394kg
- Mass of starch = 0.02 kg

And the coffee husk and saw dust char are mixed with starch binder as the same way with chat Geraba char.

5. Fill the molding PVC (casting tools) with the prepared mixture of char and binder and make it compact by hand pressing.

Figure 18. Molded PVC with mixture of char and binder

6. Drying the charcoal briquette naturally using sun light.
7. Cutting the PVC out using cutter to separate it from the charcoal briquette and the final briquette is shown below.

Figure 19. Charcoal briquettes

3.8. Determination of calorific value of charcoal briquette

Determination of calorific value of fuel charcoal briquette was carried out in the Laboratory at Geological survey of Ethiopia in Addis Ababa. The determination of calorific value or heating value include the following steps. These are sample preparation and working with 1241 Parr adiabatic oxygen bomb calorimeter for heating value determination.

Sample preparation uses the following tools;

1. Oven: - this is used to remove the moisture content of the charcoal briquette since moisture content has a negative effect on calorific value.
2. Jaw crusher: - this is a type crusher which is used to crush the charcoal briquette to powder.
3. Sieve: - it is a 60mesh (250µm) size mesh which is used to separate briquette powder which has a particle size of 250µm and below.
4. Balance: - this is mass measuring instrument which is used to measure 1gram powder briquette which is an input for 1241 Parr adiabatic oxygen bomb calorimeter.

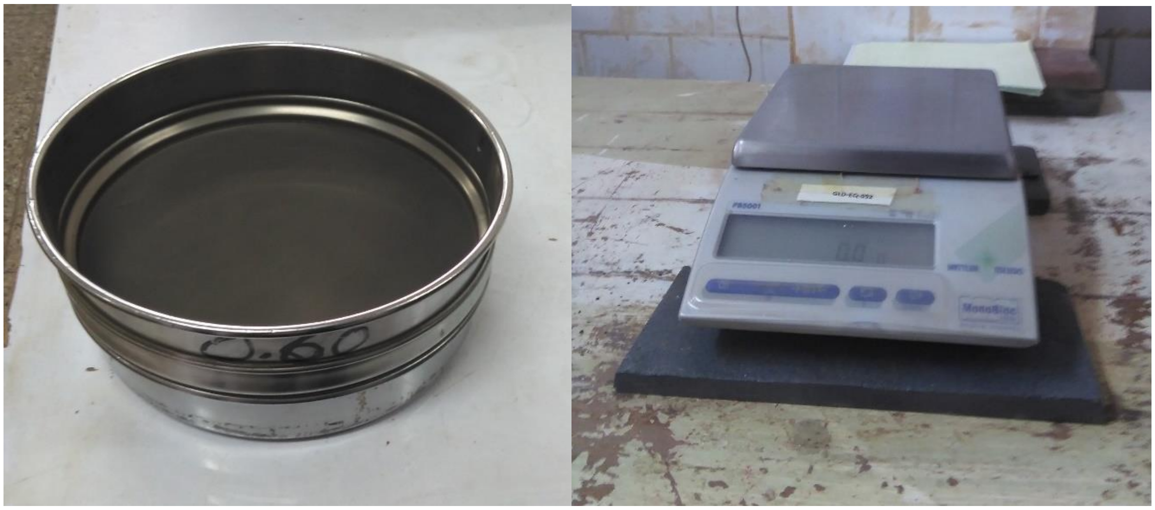


Figure 20. Sieve and Balance

5. Making pellets of 1 gram of solid fuel using mechanical pellet press which is fitted with combustion cup.
6. Preparing water jacket; fill the calorimeter bucket with distilled water and put it into the adiabatic bomb calorimeter.
7. Charging the bomb; put the solid fuel pellet into the combustion cup which intern sits on the electrodes. And the other end of the electrode is connected to the firing source. The bomb electrically fired using the fuse wire. This wire should be measured before because the fuse will burn and we know how much energy comes from burning of the fuse per centimeter. Wrap up the fuse wire around the electrode which actually provide electrical charges to ignite the fuse and the wire is twisted around and is physically touching the pellet and put it into the bomb. When fuse wire is ignited it ignite the pellet of the solid fuel.
8. Adding oxygen into the bomb from the cylinder using tubes which is inserted into the threaded gas inlet of the bomb.
9. After that put the bomb inside the calorimeter water jacket.
10. Completing calorimeter assembly by connecting the bomb with the firing using electrodes and the calorimeter bucket should be covered with cover led.
11. Measure the initial temperature of the water inside the bucket using thermometer and recording it.

12. Finally start the firing using firing button and record the temperature in every 30 seconds until steady temperature is obtained.
13. At the end make the firing button off and disassembling the bomb calorimeter after that remove the remains of fuse wire from the electrodes and measure it.
14. Note: the company i.e. Geological survey of Ethiopia has its own standard formula or correlation that correlate initial and final temperature, initial and final length of the fuse wire with the heating value per gram of charcoal briquette. [35]

3.9. Characterization of wood vinegar

3.9.1 Physical characteristics

pH of wood vinegar is measured with a pH meter. The pH of wood vinegar lies b/n 2.5-4.5 but it depends on the variety of biomass species, heating rate and other operating conditions. Specific gravity (SG) was measured using a densitometer. [16]

3.9.2 Gas chromatography-mass spectroscopy (GC-MS)

GC/MS-a combination of two different analytical techniques, Gas Chromatography (GC) and Mass Spectrometry (MS), is used to analyze complex organic and biochemical mixtures. The Chemicals that is found in wood vinegar such as carboxylic, alcohol, ketone, aldehyde and other chemicals from lignin destructive; namely, phenol, and phenolic derivatives can be analyzed.

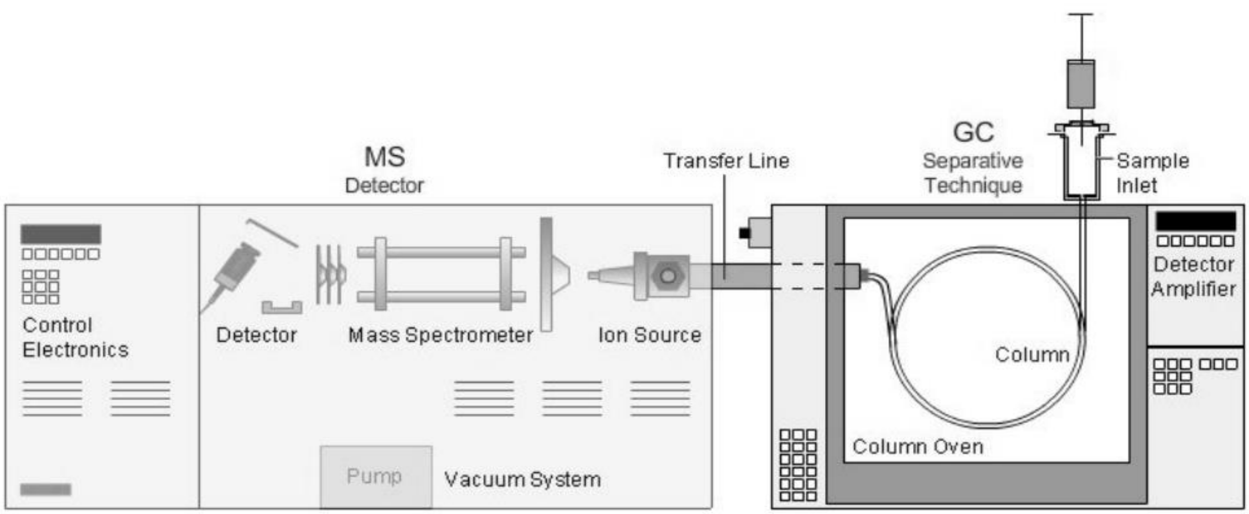


Figure 21. Schematic diagram of GC-MS

4. Result and Discussion

4.1. Proximate analysis of raw materials

The raw materials are characterized in Part (3.3) of this paper and the result obtained are given below

4.1.1 Moisture content

Table 5. Moisture content of saw dust, coffee husk and Chat Geraba

Sr.No.	Raw materials			Moisture content (%)
1.	Saw dust	Initial mass(gr)	Dried biomass (gr)	
	Sample 1	6	5.51	8.2
	Sample 2	7	6.54	6.6
	Sample 3	7	6.50	7.14
Average moisture content of saw dust				7.3
2	Coffee husk 1	20	18.08	9.56
	Coffee husk 2	20	17.95	10.25
Average moisture content of coffee husk				9.905
3	Chat Geraba 1	20	18.73	6.35
	Chat Geraba 2	22.5	20.76	7.7
Average moisture content of chat Geraba				7.025

4.1.2 Volatile matter

Table 6. Volatile matter of saw dust, coffee husk and chat Geraba

Sr.No.	Raw materials			Volatile matter (%)
1.	Saw dust	Initial mass(gr)	Mass after 7 minute (gr)	
	Sample 1	3	0.874	70.1
	Sample 2	3	0.792	73.6
	Sample 3	3	0.831	72.3
Average volatile matter of saw dust				71.9
2	Coffee husk 1	5	1.5	70

	Coffee husk 2	5	1.44	71.2
Average volatile matter of coffee husk				70.6
3	Chat Geraba 1	5	1.35	73
	Chat Geraba 2	5	1.32	73.6
Average volatile matter of chat Geraba				73.3

4.1.3 Ash content

Table 7. Ash content of saw dust, coffee husk and chat Geraba

Sr.No.	Raw materials			Ash Content (%)
	Samples	Initial mass(gr)	Mass after 90 minutes (gr)	
1	Saw dust	1.83	1.71	6.21
2	Coffee husk	2.94	2.85	4.46
3	Chat Geraba	2.67	2.54	4.74

The above result that means moisture content, volatile matter, ash and fixed carbon content are summarized and tabulated below.

Table 8. Summary of proximate analysis of raw material

So.no	Raw materials	Proximate analysis			
		Moisture content	Volatile mater	Ash content	Fixed carbon
1	Saw dust	7.3	71.9	6.21	14.59
2	Coffee husk	9.905	70.6	4.46	15.05
3	Chat Geraba	7.025	73.3	4.74	14.95

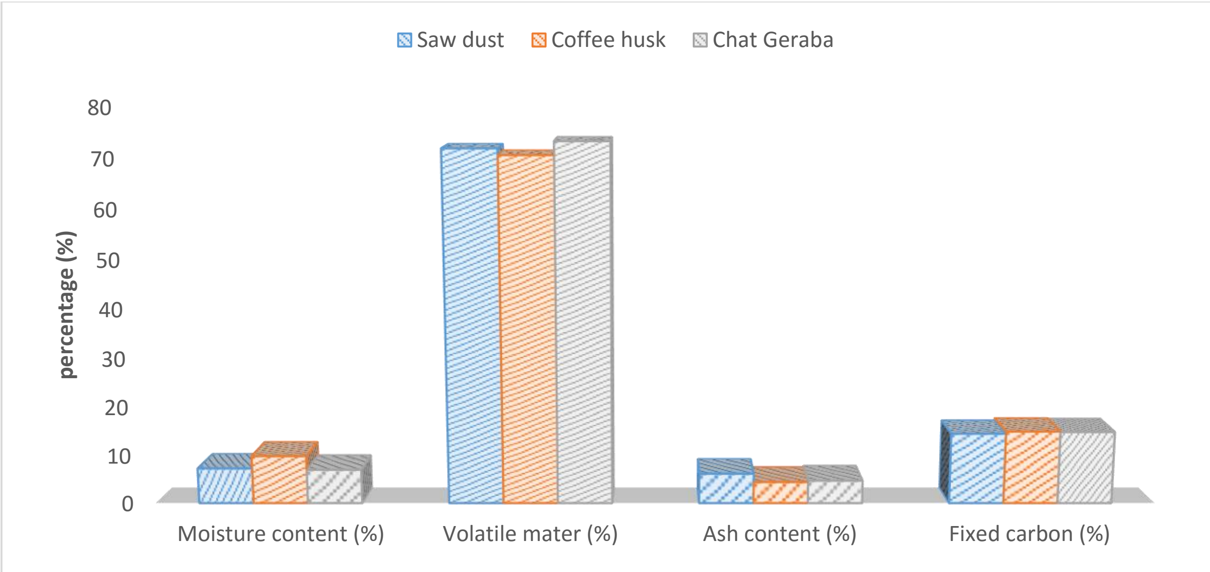


Figure 22. Graphical illustration of characteristics of raw material

As shown in the above figure Chat Geraba has high volatile matter when compared to the others and all Chat Geraba, saw dust and coffee husk has nearly the same fixed carbon content. Coffee husk has high moisture content when compared with the others which will have effect on heating value. Saw dust has the highest ash content out of the rest of raw material and this will have effect on the quality of the final product.

4.2. Production of Char and wood vinegar

Figure 12 shows the carbonizer which is a type of horizontal bed reactor and it has a mixer that is used to homogenize the sample which helps to get uniformly carbonized char. This carbonizer produce good quality of char. The char has fixed carbon content of 65%, volatile mater content of 23% and 9% ash content which is the result of proximate analysis of the product char. As shown above the fixed carbon content is good which is directly related with energy content (calorific value) of the char. But the amount of vinegar produced from this carbonizer is not enough as much as it is expected. The reason for this may be the type of condenser is not good enough to capture and condense all the smoke (flue gas) that comes from the pyrolizer (carbonizer).

4.3. Effect of temperature on yield and quality of char

To show the effect of temperature other parameters such as heating time, heating rate and type of raw materials should be constant.

Table 9. Effect of temperature on yield and quality of char

Temp(^{0}C)	Mass of coffee husk,(kg)	Mass of char, (kg)	Proximate analysis (%)			Yield (%)	Fixed carbon yield (%)
			Ash	Volatile	Fixed carbon		
300	5	2.35	6.7	60	32	47	22
400	5	1.75	7.8	29	62	35	57
500	5	1.55	10	23	66	31	60
600	5	1.4	10.4	14.6	74	28	84

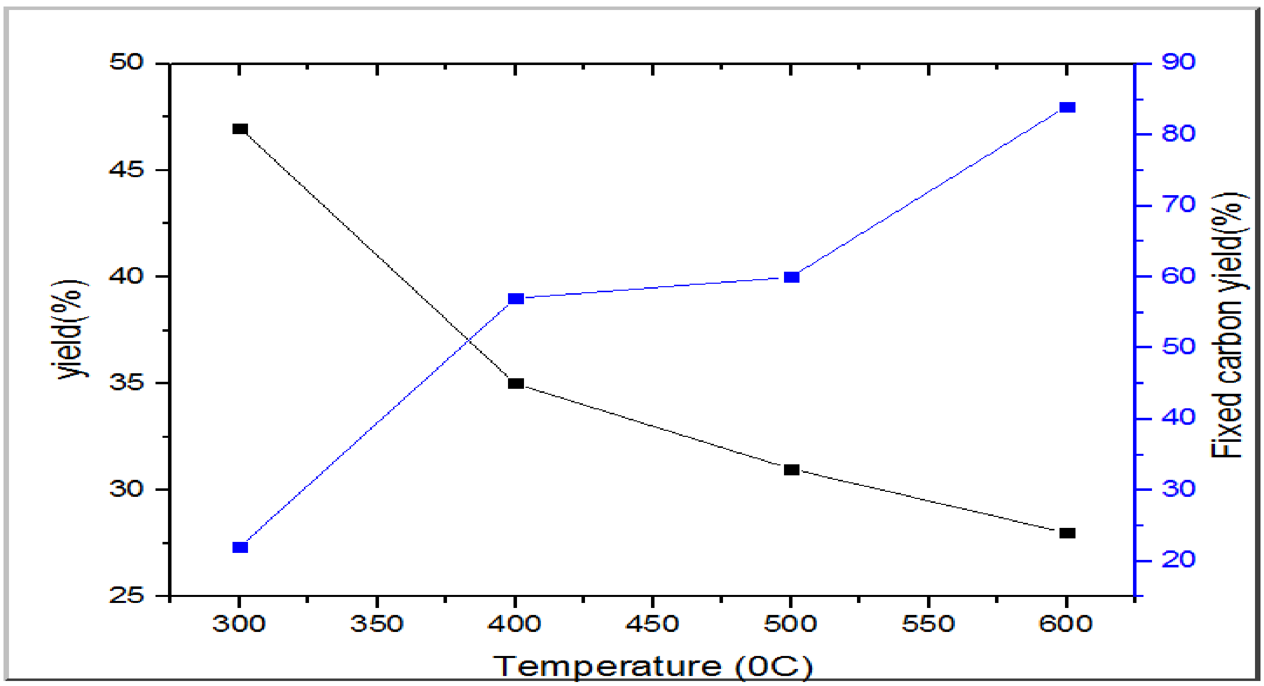


Figure 23. The effect of temperature on yield and quality of char

As shown in the above graph the yield of char decrease as the temperature of the carbonizer increase but the quality of the char increase. The decrease in the biochar yield with increasing temperature could either be due to greater primary decomposition (decomposition of biomass to volatile matter, ash, tar and fixed carbon) or through secondary decomposition (further crack of the volatiles fractions into low molecular weight liquids and gases) of char residues.

The high yield of biochar at low temperatures indicates that the material has been only partially pyrolysed. The quality of char is highly dependent on fixed carbon content and as temperature increase the amount of fixed carbon content increase as well as its quality increase as shown in the above graph. But attention should be given on the quantity (yield) of char and it is better for the temperature of the carbonizer to be around 500^0C because at this temperature the char has good quality but a little bit low yield. This low yield is compromised by recovering low molecular weight liquids and gases (the result of further cracking of volatility) to useful products like bio oil and vinegar. Further increase in temperature increases the quality of char up to a certain point. After that the quality of char becomes constant and then it will decrease. [8]

4.4. Effect of heating time

Table 10. Effect of heating time on yield and quality of char

Time (hr.)	Mass of coffee husk, (kg)	Mass of char, kg	Proximate analysis (%)			Yield (%)	Fixed carbon yield (%)
			Ash	volatile	Fixed carbon		
1	1	0.38	5.71	38.26	56.03	38	48.4
2	1	0.35	6.01	35.43	58.56	35	50
3	1	0.3	10.53	23.9	65.57	30	58

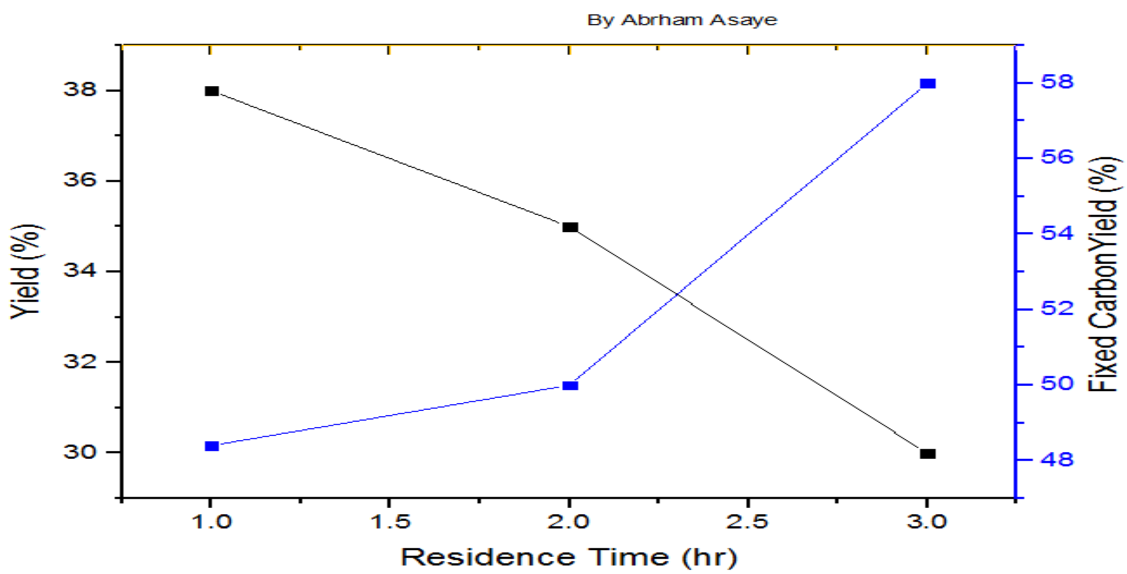


Figure 24. The effect of heating time on the yield and fixed carbon yield of char

Heating time has almost the same effect as temperature. Increase in heating time decreases the yield of char but the quality of char increase with increasing heating time as shown in the above diagram. This might due to the fact that the increasing in heating time at high temperature (500^{o}C) resulted in the further crack of the volatiles fractions into low molecular weight liquids and gases instead of char. In addition to this dehydration of hydroxyl groups of biomass and thermal degradation of cellulose and lignin might also occurred with the increasing of heating time at high temperature. [8]

4.5. Calorific value of charcoal briquette

The calorific value of fuel charcoal briquette was carried out in the Laboratory at Geological survey of Ethiopia in Addis Ababa and the following result Figure 32 of page 57 was obtained. The result shows that charcoal briquette made up of chat Geraba has the highest heating value which is 5737.73 calorie/gram (24.098 MJ/Kg) among the rest of charcoal briquettes made up of other raw materials. And saw dust has a comparable calorific value which is 5723.16 calorie/gram (24.037MJ/Kg). But charcoal briquette made up of Coffee husk has the least calorific value which is around 23.016MJ/Kg.

To show the effect of binder the type of raw material that is chat Geraba (which is the best from the others) is considered and the results are chat Geraba with molasses has calorific value, 24.098MJ/kg, chat Geraba with starch 22MJ/kg and chat Geraba with clay 20.2MJ/kg. From these it can be concluded that molasses is the best binder since the heating value of briquette made from Chat Geraba and molasses is greater than the others. But it has some drawback. For instance, the briquette produced using molasses as a binder has unpleasant smell during the initial phase of burning. To avoid this problem, the briquette should be thermally treated before use which is called curing.

Table 11. Summary of binders

Binders	Cost	Effect on calorific value	Thermal treatment
Molasses	Low	Increase calorific value of briquette	Yes it needs
Starch	High	Contribute to the calorific value	No it doesn’t need
Clay	No or very low	No contribution to calorific value	No

As discussed above chat Geraba is the best raw material and molasses is again the best binder which make a charcoal briquette with calorific value of 24.098MJ/kg. This is good fuel to be used as a substitutive or alternative energy sources. This heating value is within the range of the standards which states that carbonization of biomass residues almost doubles the energy value per unit of weight bio-char having a calorific value of 20–30 MJ/kg, compared to around 10-15 MJ/kg for unprocessed biomass and gives briquettes a charcoal-like appearance, hence the terms 'charcoal briquettes' or 'biocoal'. [25]. Each kilogram of charcoal briquette is used to substitute 1.72 kilogram of wood and prevents 2.97 kg CO_2 from emission to the environment. So this product has versatile uses such as to protect deforestation by substituting wood fuel, prevent emission of CO_2 and other pollutant to the environment and it also used to create clean environment by converting wastes such as Chat Geraba and others to usable products. So great attention should be given to these types of substitutive energy sources since the world including Ethiopia is in struggle with energy crisis and environmental pollution.

4.6. The proximate analysis of charcoal briquette

Proximate analysis, which is a standardized procedure that gives an idea of the bulk components that make up a fuel, was done to determine the average of the percentage volatile matter content, percentage ash content, moisture content and percentage content of fixed carbon of the charcoal briquettes.

The procedures of the ASTM standard D-3175 (2007) was adopted to obtain the above parameters and the following result is tabulated below:

4.6.1 Moisture content

Table 12. Moisture content determination of charcoal briquette

Charcoal briquette	Proximate analysis		
	Initial mass(gr)	Final mass(gr)	Moisture content(%)
Chat Geraba + Molasses	10	9.24	7.6
Saw dust + Molasses	5	4.49	10.2
Coffee Husk + Molasses	5	4.41	11.8

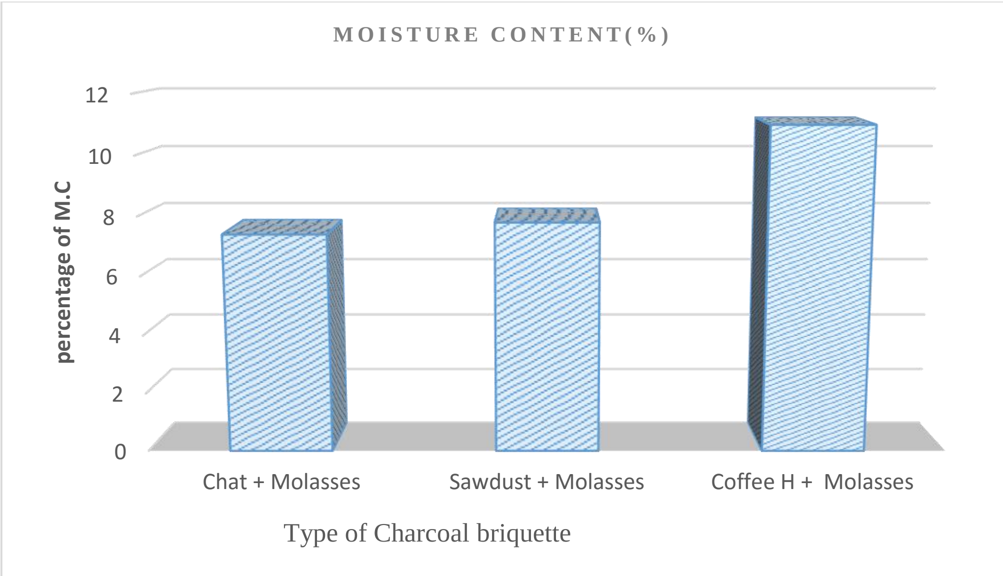


Figure 25. Moisture content of different types of briquette

As shown in the above figure the moisture content of briquette produced from coffee husk has the highest value among the others.

This is the reason why charcoal briquette made from coffee husk has low heating value since moisture content has negative impact on calorific value.

In general, the quality specification of charcoal briquette usually limits the moisture content between 5 to 15% [6]. And the charcoal briquette produced in this research has a moisture content which is in line with the above specification.

4.6.2 Volatile Matter Determination

Table 13. Volatile matter of charcoal briquette

Charcoal briquette	Proximate Analysis		
	Initial mass(gr)	Final mass(gr)	Volatile matter(%)
Chat + Molasses	9.24	7.392	20
Sawdust + Molasses	4.49	3.5022	22
Coffee H + Molasses	4.41	3.52	20.2

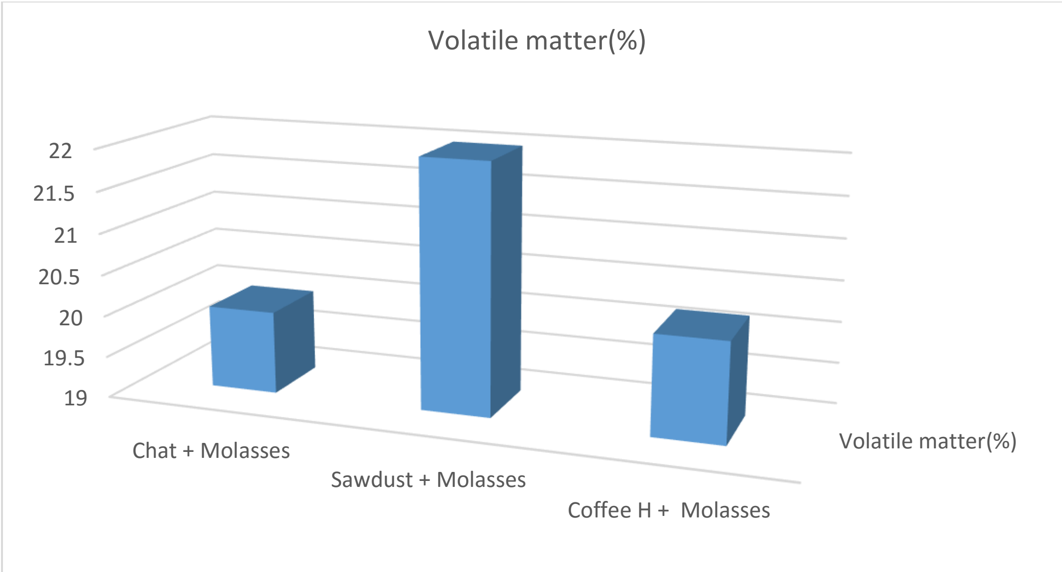


Figure 26. Volatile matter determination of Charcoal briquettes

As shown from the above diagram charcoal briquette made from saw dust and molasses has high volatile matter. And this charcoal briquette has comparable heating value with the charcoal briquette made from chat Geraba and molasses which the best.

The reason for analyzing the volatile matter is that Some part of the energy is originated from combustion of volatile matter of charcoal briquette whereas the majority of energy is originated from combustion of solid carbon or fixed carbon. So volatile matter has positive effect on heating value. Good quality charcoal should have volatile matter range from 20 to 25% [27]. So the produced charcoal briquette can be categorized as good charcoal.

4.6.3 Ash content determination

Table 14. Ash content of different Charcoal briquette

Charcoal briquette	Proximate analysis		
	Initial mass(gr)	Final mass(gr)	Ash content(%)
Chat Geraba + Molasses	7.392	6.845	7.4
Saw Dust + Molasses	3.5022	3.23	7.8
Coffee Husk + Molasses	3.52	3.133	11

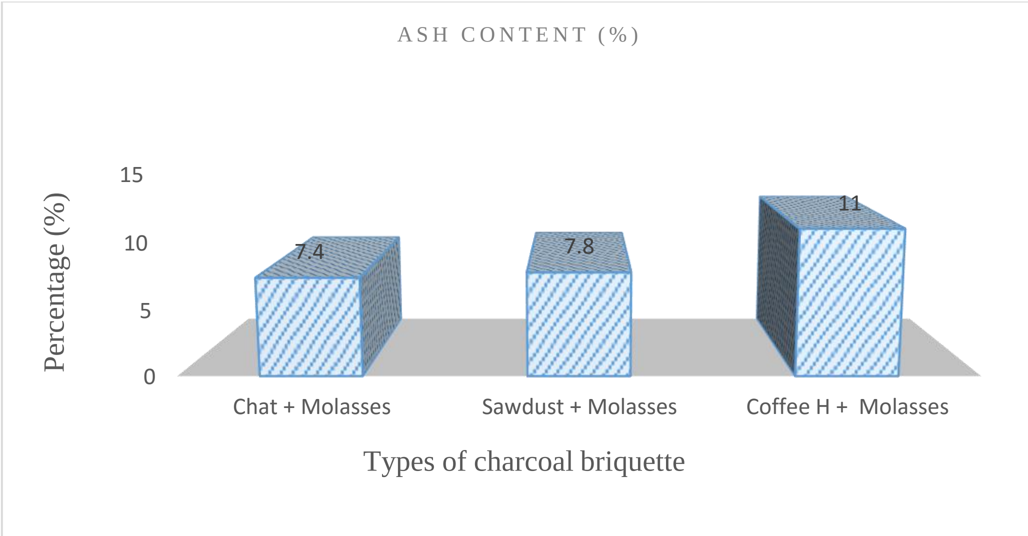


Figure 27. Ash content determination of different charcoal briquette

As it can be shown in the above diagram the ash content of charcoal briquette made from coffee husk and molasses has high ash content than others. And ash content has negative impact on heating value. This is the reason why charcoal briquette made from coffee husk has the lowest calorific value.

4.6.4 Fixed carbon content determination

Table 15. Fixed carbon content of different charcoal briquette

Charcoal briquette	**Fixed carbon content (%)**
Chat Geraba + molasses	65
Saw dust + Molasses	60
Coffee husk + Molasses	57

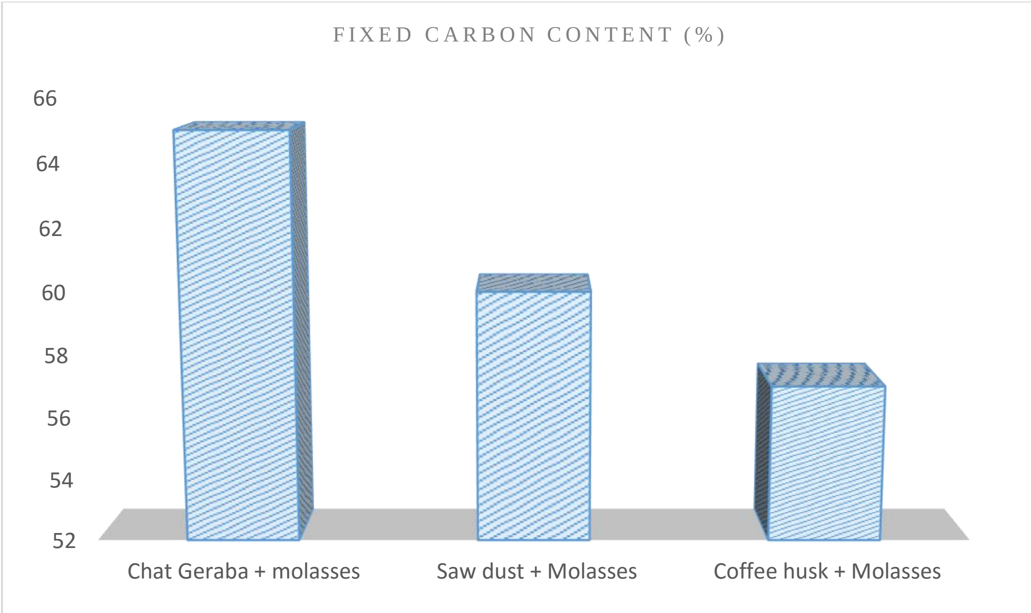


Figure 28. Graphical representation fixed carbon content of different charcoal briquette

As it is observed from the above diagram charcoal briquette which is made up of chat Geraba with molasses has the highest amount of fixed carbon among the others. This is the reason why it has high heating value. Because calorific value has a direct relationship with amount of fixed carbon i.e. increase in fixed carbon content increase in heating value.

4.7. Characterization of wood vinegar

4.7.1 Physical characteristics

pH of wood vinegar is measured using pH meter. Some literature states the pH of wood vinegar lies b/n 2.5-4.5 but it depends on the variety of biomass species, heating rate and other operating conditions. [16] For my case the pH is 3.857 at room temperature.

Figure 29 pH meter for pH measurement of vinegar

From literature specific gravity of vinegar is in the range 1.005-1.05 g/cm^3. [16] And for my case it is 1.020 which is approximately the same with the value obtained from literature. The specific gravity of this vinegar is measured using densitometer.

Figure 30. Specific gravity measurement using densitometer

Table 16 Comparison of physical property of wood vinegar with bench mark

Parameters	Bench mark (literature) result [34]	Result of this work
Yield (%)	23.27-29.01	18
PH	3.6	3.857
Density	1.021 g/ml	1.020g/ml
Color	Yellowish-brown	Yellowish dark-brown

4.7.2 Chemical characterization

Chemical characterization of wood vinegar is not done in this paper because of malfunctioning of Gas chromatography Mass Spectrometer. But most of the literature stated that, the chemical composition of wood vinegar depends on the process condition (temperature, heating rate, heating time) and the type raw material used and the most common components present in wood vinegar except water are acetic acid (3 to 7%), organic matter (50 to 70 %), phenol (5%) and other various types of alcohol like methanol, ethanol etc. [20]

5. Conclusion and Recommendation

5.1. Conclusion

The study undertaken in this paper showed that energy crisis due to the depletion of non-renewable energy resource can be addressed by using alternative energy sources such as biomass and charcoal briquette that is produced from non woody biomass is one of alternative energy fuel. Utilization of non woody biomass such as coffee husk, saw dust and chat Geraba has advantages not only for energy sources but also for waste management.

Similarly, utilization of those non woody biomass in the form of charcoal briquette can deliver clean energy that reduce indoor air pollution and respiratory infectious disease such as Cough, Asthma and lung cancer that is caused due to release smoke and pollutant during cooking through using wood and charcoal. In addition, charcoal briquette production from non woody biomass can be sources of income and create job opportunity for both rural and urban population and it can reduce forest degradation. So this product has many advantages but it has some limitations such as slow burning, low extinguish ability i.e. it crumbles if put out and it can't be reused.

The other product which is covered in this paper is wood vinegar which is an organic liquid mixture produced by condensing smoke that comes from carbonization of non woody biomass. The specific gravity and PH of this vinegar is 1.020 and 3.857 respectively which is nearly the same with previously produced vinegar. This wood vinegar is mostly applicable in agricultural sector as pesticide, insecticide, fruit growth enhancer and it is used as ingredient for medicine like medicated soap and other chemicals. Application of wood vinegar instead of synthetically produced pesticide and insecticide minimizes soil salinity and prevent leaching of chemicals into the water body which affects the water ecosystem. To conclude this paper tried to show how charcoal briquette and wood vinegar can be produced by integrating the two process together rather than producing them individually.

5.2. Recommendation

Based on this research work the following tasks are recommended to be done by other researchers:

1. In this work hand pressed manual operated briquetting method was used which is labor intensive. So it is better to design and manufacture motor driven briquetting machine like screw extruder briquetting machine.
2. Ultimate analysis of charcoal briquette should be done to identify the chemical composition of the briquette.
3. Chemical characterization of wood vinegar should be analyzed since in this paper it was not addressed because of malfunctioning of Mass spectrometer Gas chromatography (GC-MS) for the time being.
4. Economic analysis and feasibility of charcoal briquette production from non woody biomass including the logistic should be evaluated.
5. Design and manufacture of carbonizer and condenser which are compatible with each other since yield of vinegar is highly dependent on the efficiency of the condenser as well as the carbonizer.

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Appendix

Geological Survey of Ethiopia

Geochemical Laboratory Directorate

Hydrocarbon Laboratory analysis report format:Form GD0006

File ID:4150-17PVT

Originator: Abrham Asaye.

Sample type: Charcoal Briquite.

Number of samples:3

Preparation required :60mesh

Element to be determined: (Calorie) .

Method of analysis :(Adiabatic Calorie Meter) .

Customer type:PVT

Date submitted:16/02/2010(10/26/2017)

Date completed: 21/02/2010(10/31/2017)

Field No.	*Lab No.*	*Calorific Value cal/gm*
Coffee Husk + Mol	*4150/17*	5480.00
Saw dust + Mol	*4151/17*	*5723.16*
Chat G + Mol	*4152/17*	5708.74
Chat G + Mol	*4152/17Dup*	*5737.73*

ANALYSTS:
Alemnesh Abate
Haimanot Bayeh

CHECKED BY:
Alemnesh Abate

QUALITY CONTROL:
Awash Yerga

DATE REPORTED:
22/02/2010(11/01/2017)

Page 1 of 1

Figure 31. Result of calorific value of different raw material with the same binder

Geological Survey of Ethiopia
Geochemical Laboratory Directorate
Hydrocarbon Laboratory analysis report format:Form GD0006

Customer type:PVT
Date submitted:20/02/2010(10/30/2017)
Date completed: 05/03/2010(11/14/2017)

File ID:4205-17PVT
Originator: Abrham Asaye.
Sample type: Charcoal Briquite.
Number of samples:2
Preparation required :60mesh
Element to be determined: (Calorie) .
Method of analysis :(Adiabatic Calorie Meter) .

Field No.	*Lab No.*	*Calorific Value cal/gm*
Chat + Starch	*4205/17*	5182.07
Chat + Clay	*4206/17*	*4783.66*
Chat + Clay	*4206/17Dup*	4798.55

ANALYSTS:
Alemnesh Abate
Haimanot Bayeh

CHECKED BY:
Alemnesh Abate

QUALITY CONTROL:
Awash Yerga

DATE REPORTED:
05/03/2010(11/14/2017)

Page 1 of 1

Figure 32. Result of heating value of Chat Geraba with different binders

Figure 33. Saw dust inside the horizontal carbonizer

Figure 34. 1241 Parr adiabatic oxygen bomb calorimeter

Figure 35. Photograph of condensation process