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Characterization and evaluation of mush valley Coal for its application as a domestic energy source

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This is to certify that the thesis prepared by *Kitaw Abraham*, entitled: *Characterization and evaluation of mush valley Coal for its application as a domestic energy source* and submitted in partial fulfillment of the requirement for the degree of Master of Science (Chemical and Bio Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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DECLARATION

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ABSTRACT

The main goal of this study is to substitute domestic biomass fuel energy source by the presented mush valley coal. To use it, a number of experiments were conducted before use in household application. During the experimental work the proximate and ultimate analysis where carried out through in different methods. The proximate analysis result shows the coal quality; from the analysis the coal has an average moisture content of 19%, volatile matter of 31.34%, ash content of 11.58, fixed carbon value of 38.02%, and its calorific value of 4117 kcal/kg and also Hard Grove Gridability Index values ranging between 45 and 64.3. Finally the proximate analysis result shows, the Mush Valley coal is fall under the rank of lignite A to sub-bituminous B categories. In the ultimate analysis the amount of Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen were determined by using CHNS/O analyzer. To use coals for domestic application, effective stove was designed, fabricated and tested to evaluate the thermal performance of the stove. The design part of stove focused on, the insulation around the combustion chamber, air inlet to ensure the accessibility of sufficient air for the complete combustion of the fuel coal, and the integration of chimney to convey flue gases away from the place of use. Water boiling tests were carried out in order to produce the required data for evaluating the stove's performance by calculating Specific Fuel Consumption, Fire Power, Percent heat utilized and thermal efficiency. The performance evaluation shows that average fire power of 9.7 KW, average specific fuel consumption of 0.765, average percent heat utilized of 49 % and thermal efficiency of 58.3%. The efficiency of the results of the study, it can be seen that the performance of the designed coal stove is better than the traditional three-stone open fire reported to have efficiency of about 14-25%.

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ACRONYMS

ASTM	American Society of Testing and material
BLT	Branch, Leaf, Twigs
Btu	British thermal unit
Cal	Calorie
CV	Calorific Value
D.m.m.f	Dry mineral matter free
FC	Fixed Carbon
HGI	Hard Grove Gridability Index
IAP	Indoor Air Pollution
IM	Inorganic Matter
M.m.m.f	Moist mineral matter free
M/S	Meter per second
MgO	Magnesium Oxide
MT	Million Tons
MW	Mega Watt
OM	Organic Matter
PHU	Percent Heat Utilized
PICs	Product of Incomplete Combustions
PM	Particulate Matter
SFC	Specific Fuel Consumption
USA	United State of America
VM	Volatile Matter
WBT	Water Boiling Test

1. INTRODUCTION

Energy is one of the basic inputs in economic development and human survival. Energy is needed as inputs in industry, agriculture, cooking, mining, construction, service giving organization etc. The ever-growing of the price of petroleum products affects all the countries of the world. Owing to the present world-wide energy crisis, low-grade fuel (coal, oil shale, etc.) is becoming an alternative resource in many countries of the world. Many countries in the world are beginning the processes of developing various coal fields. For sound economic development and social progress, developing nations like Ethiopia require an adequate supply of energy at affordable prices. To meet the ever-growing need of energy in Ethiopia, successive studies are ongoing in various fields to establish plants of hydroelectric power, geothermal energy, natural hydrocarbon, solar energy, and others.

In Ethiopia energy resource condition has substantial energy resources are consisting mainly of biomass, hydropower, geothermal and fossil fuels such as natural gas and coal (Ethiopian Economics Association, 2007). Other renewable energy sources like wind and solar energy are available in the country. Even if the country’s energy demand is increasing from time to time due to high population growth, industrial development, improved living standards and other factors. More over most of the major economic sectors are dependent on imported petroleum products, while the prices of these products are increasing at alarming rate. However the total of about 297,000,000 Metric tons of coal reserve are registered in the country (Ahmed, 2008). But still the main sources of energy in Ethiopia are wood, oil and hydroelectric power for domestic, industrial and transportation sectors.

The entire rural and a large segment of urban population in the country use wood as domestic fuel. The need of domestic fuel is the major factor for deforestation in Ethiopia, rural population depends on biomass energy sources for cooking and other energy requirements a total of 105.2 Mt wood per year are consumed at national level. From the different biomass energy sources, fuel wood accounts for around 78% of the total energy demand, while animal dung and crop residues account for 12% and 9%, respectively (Damte & Koch, 2011). It creates environmental and health problems, such as soil degradation, desertification, destruction of natural ecosystem and exposed for different diseases due to indoor pollution. Different studies show the main cause of human health problem especially women and child is due to lack of modern stoves, which has no indoor pollution reduction mechanism.

Therefore we have seen different alternative source of energy instead of the biomass fuel energy for domestic energy sources. One of the alternative source of energy is coal, however before using it, should know the chemical composition of the coal in terms of its proximate and ultimate (elemental) analyses. The parameters of proximate analysis are moisture, volatile matter, ash, and fixed carbon(Yi et al., 2017). Elemental or ultimate analysis encompasses the quantitative determination of carbon, hydrogen, nitrogen, sulfur and oxygen within the coal. And also the way of mining methods is another challenge to use it. Coal mining- modern mining methods allow to easily reach most of coal reserves (Museum, 2009). Depending on the amount of ground cover or overburden, the coal can be mined by the two methods surface mining (complete removal of overburden) or the deep (underground mining.) method (Zha et al., 2017).

Surface mining: It also known as opencast or open cut mining is only economic when the coal seam is near the surface. This method recovers a higher proportion of the coal. It is used when a coal seam is relatively close to the surface; this is less expensive than underground mining. In surface mining giant machines remove the top-soil and layers of rock to expose large beds of coal. Once the mining is finished, the dirt and rock are returned to the pit, the topsoil is replaced, and the area is replanted (Conte & Civiliz, 1981).

Underground mining sometimes called deep mining is used when the coal is suppressed several hundred meters below the surface. To take out coal in underground mines, miners ride elevators down deep mine shafts where they run machines that dig out the coal. In underground mining, workers and machinery go down a vertical "shaft" or a slanted tunnel called a "slope" to remove the coal, mine shafts may sink as much as 305 meter deep (Zha et al., 2017).

The Non- renewable energy source coal (fossil fuel) is the primary source for many technological activities of the present day. It provides the major fraction of consumable energy and feedstock to industrial sectors, commercial organizations, as well as household entities all around the world (Osborne & Gupta, 2013).

The largest top five coal producing countries are China, USA, India, Australia and South Africa(Agency et al., 2015). Much of global coal production is used in the country in which it was produced; only around 16% of hard coal production is destined for the international coal market. According to world energy council global coal production is expected to reach 7000 Mt in 2030 with China accounting for around half the increase over this period (“World Energy Resources,” 2016).

Exploration of coal in Ethiopia was started in the year 1935 at Nejo and Wuchale; however, it is not put into commercial application(Wolela, 2007). The present worldwide energy crisis and increase in chemical fertilizer prices initiated the country to explore its own natural resources and promising reserves of coal have been explored in different parts of the country and now the government and many private investors are trying to use indigenous coal for different applications(Ahmed, 2008). The major applications which have got greater attention are the utilization of coal as a raw material for the production of fertilizer as source of energy for power and heat generation, especially in cement industries and other chemical industries. Widespread and concentrated studies have been carried out at various scales from inspection to detailed mapping and preliminary to detailed drilling networks to determine the amount of coal deposit in Ethiopia. Huge knowledge has been acquired about the geological distribution, geological setting, and geochemical characteristics of Ethiopian coals, more than 23 areas or places have been identified. From such identified area Mush valley is one of the significant coal deposit area(Ahmed, 2008).

Mush Valley is situated 159 km northeast of Addis Ababa along Addis Ababa-Dessie road, in Amhara national regional states in north Shewa zone; it is around 30 km far from Debre Birehan city. The area is found between 2600-2800 m above sea level. The Inter coal-bearing lacustrine sediments predominantly composed of sandstones, siltstones, carbonaceous shale's and coal seams. The succession in the Mush Valley lies on the Miocene-Pliocene basaltic substratum(Wolela, 2007). The lower and upper coal seams attain a thickness of 1.75 m and 1.0 m, respectively and the total reserve is estimated to be 1 million tones(Ahmed, 2008). This study mostly focused on the characterization of mush valley coal and to now the chemical composition (proximate analysis) and ultimate analysis, finally investigate it for household application with direct burning in my designed and manufactured stove.

1.1 Statement of the Problem

Energy is one of the scarce resources in Ethiopia. Hydro and Biomass are the dominate energy sources in the country. Currently in different parts of the country there are expansion of industries and growth of population, due to this the demand of energy for industries and domestic purposes are increase at time to time. Due to the limited energy sources and its supply, energy cost is increasing. And also it is not sufficiently available for industry and household consumption. These problem shows in all part of the country, rural, cities and town.

Biomass is currently the leading source of energy; it contributes around 92% of the natural energy supply and consumption. Especially in rural areas people relay on biomass energy, such as fuel-wood, charcoal, agricultural waste and animal dung, to meet their energy needs for cooking. This significant role of biomass energy is the root cause of deforestation in the country. Resources are harvested unsustainably and inefficient uses of other energy resources; there are serious adverse consequences for health and the environment due to inefficiently burning biomass fuel often produce a significant amount of indoor air pollution. Mostly women and children die prematurely every year because of exposure to indoor air pollution from biomass.

The deforestation of the country can increase at alarming rate with the increase of population due to the dominate use of biomass unless other source of energy is available to substitute and supplement the biomass energy. For such situation coal can be one of the substitutes of the domestic biomass energy in different countries for industrial as well as house hold function. In our country there are coal deposit areas in different regions; from such identified area mush valley is one of the significant places. Nevertheless the characteristics of this coal and the way how to utilize it are not investigated or studied properly yet.

A different study was show that coal fires burn hotter than wood fires, and they need a stove designed to burn it. But you can burn coal in an open fireplace, that is not an energy efficient method and most of the heat is lost. Moreover, coal fires are not a particularly attractive sight and can release pollutants into the indoor air when burned in an open fireplace. To reduce indoor pollutants use different fire resistance materials for making stove and chimney pipe rated for burning coal.

1.2 Objective of the Study

1.2.1 General Objective

The general objective of this study was to Characterize and evaluate the mush valley Coal for its application as a domestic energy source

1.2.2 Specific Objectives

The specific objective of this work includes:

- ✓ To determine the proximate analysis (ash, moisture, fixed carbon content, volatility, gridability and calorific value (Kcal/kg) of the mush valley coal;
- ✓ To study the ultimate analysis (composition of carbon, hydrogen, sulfur, nitrogen and oxygen) of the mush valley coal;
- ✓ To design and construct cylindrical type of an effective coal burning stove for domestic application;
- ✓ To evaluate the performance of the constructed stove in terms of, specific fuel consumption, percent heat utilized, fire power and thermal efficiency.

1.3 Significance of the Study

This study has a contribution to the energy sector, for the enhancement of energy security mostly for the rural and urban societies of the country. It is also reduce the pressure of using biomass fuel for house hold cooking, and helps to minimize discharged hard currency for cooking and heating applications (kerosene), and use as a substitution for fire wood and wood-derived charcoals domestic fuel for rural and urban areas and other importance are:

- ✓ Reduce the serious adverse consequences for healths; mostly inefficiently burning biomass fuels often produce a significant amount of indoor air pollution.
- ✓ The designed stove is important to burn the fuel efficiently, completely remove in-door air pollution, as a result which minimize mostly the death of women's and children due to inefficient burning of biomass.
- ✓ It helps to reduce heat loss when it burn in open fire.
- ✓ The most and significant importance is to reduce the amount of biomass fuel consumption, and it will minimize the cause of environmental damage, such as land degradation, soil erosion and regional air pollution.
- ✓ The study is also very much supportive in slowing down the deforestation problem of the country.
- ✓ Besides this study helps to determine the grade or the standards of the coal before going to exploit the coal, to provide important information about the energy value.

1.4 Scope of the study

The thesis work generally covers the proximate analysis (moisture content, ash content, volatility, gridability and amount of fixed carbon) and ultimate analysis of coal, such as amount of carbon, hydrogen, oxygen sulfur and nitrogen will be done by using standard procedure and testing methods. In addition to this designing, manufacturing and testing of stove will done, testing of stove includes fire power, specific fuel consumption, percent heat utilized and thermal efficiency of the stove.

2. LITERATURE REVIEW

2.1 General Overview of Coal

Coal is a fossil fuel created from the remains of plants that lived and died about 100 to 400 million years ago when parts of the earth were covered with huge swampy forests (Demoze, 2007 & Schweinfurth, 2009). Coal forms when dead plant matter is converted into peat, which in turn is converted into lignite, sub-bituminous coal, and into bituminous coal lastly change to anthracite (Miller & Tillman, 2008). This involves biological and geological process that takes place over a long period of time, heat and pressure acts on it to finally convert into coal(Chelgani, 2016). The energy of the coal is derived from the energy stored by the plant that lived hundreds millions of years ago. Living plants can store energy from the sun through photo synthesis, and after the plants died, the energy is out as the plants deterioration.

2.1.1 Coal Formation

Through geological processes apply pressure to peat over time; it is transformed successively into different rank of coal. The phases in coal formation are; peat, lignite, bituminous and anthracite. The phase depends upon the conditions to which the plant remains are subjected after they were hidden – the greater the pressure and heat, the higher the rank of coal. Higher-ranking coal contains less moisture and gases and has a higher heat value than lower-ranking coal(Miller & Tillman, 2008).

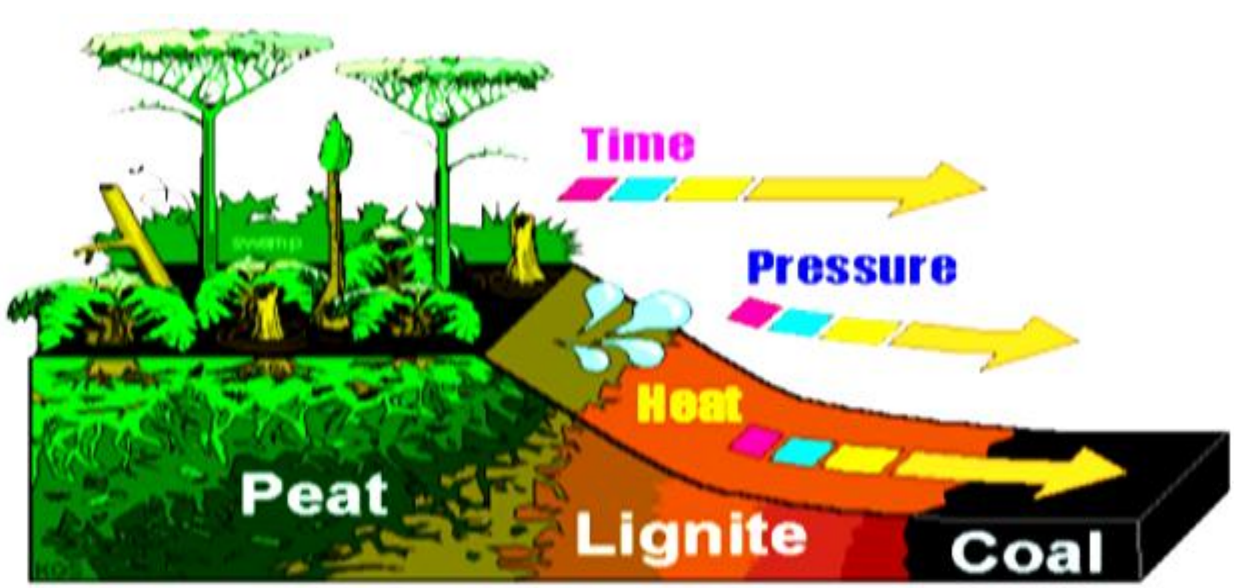


Figure 2.1 Coal formation stages

- ✓ Phase One - Peat

Peat is the first stage in the formation of coal. Normally, vegetable matter is oxidized to water and carbon dioxide. However, if plant material accumulates underwater, oxygen is not present and so only partial decomposition occurs(Breton & Peat, 1998.). This incomplete destruction leads to the accumulation of an organic substance called peat. It is a rubbery, softy substance in which plant remains are easily recognizable. It contains a large amount of water and must be dried before use. Therefore, it is rarely used as a source of heat.

- ✓ Phase Two - Lignite

It is the second stage, which is formed when peat is subjected to increased vertical pressure from accumulating sediments. Lignite is dark brown in colour and, like peat, contains traces of plants. It is found in many places but is used only when more efficient fuel is not available (Rattanakawin & Tara, 2012).

- ✓ Phase Three - Bituminous Coal

Bituminous Coal is the third stage. Added pressure has made it compact and virtually all traces of plant life have disappeared. Also known as "soft coal”, bituminous coal is the type of coal is most abundant fuel (Wickstrom, 2008). It has a higher heating value than either lignite but less than that of anthracite.

- ✓ Phase Four - Anthracite

Anthracite, the fourth stage in coal formation, is also known as "hard coal" because it is hard and has a high luster. It appears to have been formed as a result of combined pressure and high temperature. Anthracite burns with a short flame and little smoke and has the highest energy content of all coals(Tip, 2005).

2.1.2 Classification of Coal

An ASTM procedure to classify coal by rank (low to high) approximates the heating value, fixed carbon, moisture content and volatile matter in coal (Radovic, 1997). Lignite and sub-bituminous are considered low rank coals, characterized by light brown or dull black color, high moisture content, and a low heating value. By comparison, bituminous coal and anthracite are high rank coals, black and reflective in appearance with less moisture and a higher heating value from more fixed carbon. Sub-bituminous and bituminous coals are the most abundant types of reserves worldwide(Logan & Wickstrom, 2008) . ASTM classification by rank; Coals are classified by rank, i.e., according to the degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite. In the ASTM classification, the basic criteria are the fixed carbon and the calorific values calculated on a mineral-matter-free basis. It is necessary, in establishing the rank of coals, to use information showing an appreciable and systematic variation with age. For the older coals, a good criterion is the "dry, mineral-matter-free fixed carbon or volatile." However, this value is not suitable for designating the rank of the younger coals. A dependable means of classifying the latter is the "moist, mineral-matter-free Btu, which varies little for the older coals but appreciably and systematically for younger coals. Proximate analyses and higher heating values are used in making the Parr calculations (Kłosowiak et al., 2005).

Table 2.1 Classification of coal by grades (ASTM) standared

Class	Group	Fixed carbon limit,% (dry mineral matter free basis)		Volatile matter limits, % (dry mineral matter-free basis)		Calorific value limits, Btu/lb (moist mineral matter free basis)	
		Equal (greater than)	Less than	Greater Than	Equal (less than)	Equal (greater than)	Less than
Anthracite	1. Meta-anthracite	98	-	-	2	-	-
	2. Anthracite	92	98	2	8	-	-
	3. Semi-anthracite	86	92	8	14	-	-
Bituminous	1. Low volatile bituminous coal	78	86	14	22	-	-
	2.Medium volatile bituminous coal	69	78	22	31	-	-
	3.High volatile *A* bituminous coal	-	69	31	-	14,000	-
	4.High volatile *B* bituminous coal	-	-	-	-	13,000	14,000
	5.High volatile *C* bituminous coal	-	-	-	-	11,500	13,000
Sub bituminous	1.Subbituminous *A* coal	-	-	-	-	10.500	11,500
	2.Subbituminous *B* coal	-	-	-	-	9,500	10,500
	3.Subbituminous *C* coal	-	-	-	-	8,300	9,500
Lignite	1.Lignite *A*	-	-	-	-	6,300	8,300
	2.Lignite B	-	-	-	-	-	6,300

Source: steam/source of chemical energy

Lignite: The name Lignite is derived from the Latin word “Lignum,” which means, ‘wood’, leftovers of wood fiber are often visible on it. Lignite is the lowest rank of coal with the lowest energy content and relatively a geologically young coal deposits that were not subjected to extreme heat or pressure. It has relatively high moisture content and lowest carbon content, 25- 40 percent, and a heat value ranging between 6,300 and 8,300 BTU/lb (Tip, 2005.).

Figure 2.2 Lignite coal image

- ✓ Sub-bituminous:

The properties of sub-bituminous coal are range between from the level of lignite to those of bituminous coal and which has a higher heating value than lignite. Most sub-bituminous coal is at a minimum of 100 million years old. In grading below bituminous are known as sub-bituminous coal with 35- 45 percent carbon content and a heat value between 8,300 and 11,500 BTU/lb. Although its heat value is greater than lignite, and generally has a lower sulfur content as compared other types, which makes it attractive for use because it is cleaner burning (Radovic, 1997).

- ✓ Bituminous coal:

Bituminous coal is more solid coal contains 45 to 86 percent carbon, and has relatively high heating value as compared with lignite coal which has the range between (11,500 to 15,500 BTU/lb). It was formed through high heat and pressure, and is used to generate electricity and is an important fuel for different industries like steel and iron industries.

Figure 2.3 Bituminous coal image

✓ Anthracite:

Anthracite coal is a form of coal that is almost made entirely of carbon. it is much harder than other forms of coal such as bituminous, and is usually found in areas surrounding mountains or deep valleys. Anthracite burns much cleaner than other forms of coal due to its low pollutant content. In fact, anthracite may contain 86% to 98% pure carbon, leaving only 2% to 14% of other elements. Anthracite coal is difficult to ignite and burns with a blue, smokeless flame. It advantage are produces very little pollution or soot, making it a very clean source of heat, and very efficient because only a small amount needs to be burnt to produce a large amount of energy (In & Metallurgical, 2013).

Figure 2.4 Anthracite coal image

2.1.3 Coal Utilization

There are three major ways for coal utilization. These are illustrated in the following figure 2.5 (*National Energy Strategy*, *Executive Summary*, 1991/1992). The principal process by which coal is used for combustion; it involves burning the coal in air to liberate thermal energy (heat). Carbonization is the heating of coal to high temperatures in the absence of air; it is used in manufacturing coke for the metallurgical industry. Conversion uses various chemical processes to transform coal into gaseous or liquid fuels, called synthetic fuels. Common to all these processes is prior mining of the coal, its preparation (processing) and its transportation to the consumers.

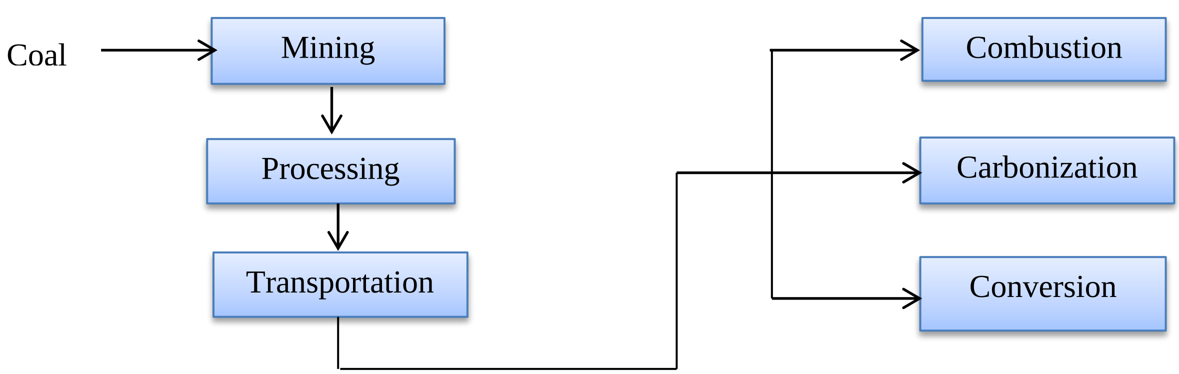


Figure 2.5 Coal utilization path way

2.1.4 Coal Mining

Coal must be mined to get it from the ground to the house holed, factories or electrical power plants where it will be used. Two broad categories of mining techniques are used, such as surface mining and underground mining.

2.1.4.1 Surface Mining

It can be used when the coal is submerged distance is less than 60 m underground. In this activity the topsoil and layers of rock are removed to expose large deposits of coal. The coal is then removed by machines or human power. Once the mining is finished, the mined area is retrieved. The dirt and rock are returned to the ditch, the topsoil is replaced, and the area is planted. The land can then be used for croplands, wildlife habitats, recreation, or other purpose(Colonial, 2016).

2.1.4.2 Underground (or deep) Mining

It is used when the coal is buried deep of 305m within the Earth. To remove coal from underground mines, miners are transported down mine shafts to run machines that dig out the coal(Colonial, 2016).
Coal Preparation (Processing): Once the coal has been mined, it is usually processed to separate the inorganic, ash-forming components and to produce appropriately sized particles. The various operations involved in this processing are collectively known as coal preparation or *coal* beneficiation. The degree of preparation depends on the intended use of the coal.
Coal Transportation: After the coal has been prepared, it will be transported to the point of use. It may then be stored at the plant site for some time before being consumed.

2.1.5 Application of Coal

Coal has many important applications throughout the world; the most significant uses of coal are in (electricity generation, steel production, cement manufacturing and source of energy for household) and uses for different chemical and pharmaceutical industries, paper manufacturing, and also several chemical products can produced from the by-product of coal; such as from refined coal tar can be manufactured different chemicals(phenol, benzene naphthalene etc.) after undergoing through gasification and combustion process(Osborne & Gupta, 2013).
For electric power generation: Now a day's coal has covered about 40 % of the world's electricity consumption. Coal has used as a reliable source of electric city generation for many developed and developing countries. According to the world energy resource report the main coal consumer are china,

India, USA and others are the largest coal user countries in the world. Also electric utility companies, industries and businesses with their own power plants use coal to generate electricity, power plants burn coal to make steam (“World Energy Resources,” 2016).

For steel making: Global steel production dependent on coal, 74% of the steel produced today uses coal as a source of energy. Coal is baked in hot furnaces to make coke, which is used to melt iron ore into wanted iron for making steel(Osborne & Gupta, 2013).

For house hold application: Coal can be utilized as energy source for household and small-scale industries (industrial processes heating and household cooking) is used as direct burning or form of coal briquette. Coal is used as a domestic source of energy by the low income household in South Africa, China, India and other countries. Coal is an affordable fuel source and provides dual utilities- it warms the house and allows cooking to take place in the same appliance utilizing only one fuel.

2.1.6 Coal Production

Coal productions mean the amount of coal mined and taken to market. More than 4970 million tons of hard coal is presently produced, and it provides 25% of overall energy needs and it produces 40 % of the world's electrical energy. The current World coal production declined in 2014 for the first time in this century. This decrease continued through 2015 and also in 2016 to 458 Mt, or 6.3% lower, as combined production of all coal types fell to its lowest level since 2010 (Brook, 2008). According to the international energy agency data book (2017) the worlds coal production in the preceding years are shown in the following table.

Table 2.2 Total world coal production (Mt)

Year	2014	2015	2016
Steam coal	6010.1	5834.6	5407
Coking coal	1108.7	1081.1	1074.3
Lignite	815.4	811.1	783.3
Total coal	7934.1	7726.8	7268.3
Peat	15.2	10.1	-
Oil shale	21.4	20	-

Source: international energy agency -2017

2.1.7 Coal Analysis or Characterization Process

Chemical analyses and testing of a coal sample are generally done off-site in a laboratory. The main purpose of coal sample analysis is to determine the quality or rank of the coal along with its essential characteristics. Furthermore, these data will be used as the fundamental consideration for coal trading and its utilization. General coal analysis and testing include the following(Zhu, 2010)

1. Proximate analysis: moisture content, ash content, volatile matter, fixed carbon;

2. Ultimate analysis: carbon, hydrogen, oxygen, nitrogen, Sulphur;

3. Calorific value (also known as heating value or specific energy).

2.1.7.1. Proximate Analysis

The proximate analysis of a coal determines the moisture content, volatile matter (VM), ash and, by difference, the fixed carbon within the coal sample. It is the simplest and most common form of coal evaluation, and constitutes the basis of many coal purchasing and performance prediction indices used by utility operators (Neavel et al., 1980).

Sample preparation: The samples of coal collected from the field are air dried to remove the free moisture. After drying, the required amount (250 gram) is taken from each sample by coning and quartering method. The portion selected is crushed and passed through 72 mesh (250 micron) sieve. Powdered samples are collected and stored in air tight glass bottles and these samples are used for chemical analyses in the laboratory(Zhu, 2010).

Proximate analysis of moisture determines the residual moisture content of coal(Yi et al., 2017). Residual moisture measures the moisture content of an air dried coal sample. Moisture determination depends on the extent of sample preparation and the condition of the coal sample. The entire procedure for determining the total moisture in coal, after collecting the gross sample, begins with preparing the sample for analysis. If the gross sample is sufficiently dry, it may be reduced immediately and then air dried. If the sample is too wet to reduce in size, it should be weighed and air dried, before size reduction, at ambient temperature. The coal sample must be reduced and divided to the size/mass specified for the test method used in accordance with relevant Standards. The moisture content of coal can be determined by an indirect gravimetric method. This method involves oven-drying a known mass of coal sample to a constant mass at a temperature of 103 to 105°C in an atmosphere of either air. . The moisture content is calculated from the loss in mass of the sample. (Zhu, 2010)

Ash is the residue remaining after the combustion of coal in air and is derived from inorganic complexes present in the original coal substance and from associated mineral matter. Therefore, the result of the determination is 'ash' and not 'ash content' as coal does not contain any ash. The ash yield is commonly used as an indication of the grade or quality of a coal since it provides a measure of the incombustible material (Neavel et al., 1980).

Ash is determined by weighing the residue remaining after burning approximate sample of coal under rigidly controlled conditions of sample weight, temperature, time, atmosphere, and equipment specifications. In the approach described in ISO 1171:2010, a general analysis test sample of coal (ground to pass a sieve of 250 μm apertures), accurately weighed, is heated in air in a furnace from room temperature to 500°C over a period of 60 minutes at a uniform heating rate and is held at this temperature for 30 minutes (60 minutes for brown coals/lignites). The sample is then heated to 815°C ± 10°C and maintained at this temperature for a minimum of 60 minutes until the sample is constant in mass. When the incineration period is complete, the Sample is allowed to cool and then weighed(Yi et al., 2017).

Volatile matter (VM) in coal refers to the thermal decomposition products liberated when coal is heated at high temperature in the absence of air. It is sometimes called volatiles consists mainly of the gases and water and tarry vapour evolved from coal when it is heated at high temperature. To determine it, weight required amount of coal is taken in a silica crucible with a porous silica cover. The cover is used to avoid oxidation. The coal is then heated for 7 minutes at a constant temperature of 950°C inside a furnace. After heating the crucible is cooled and transferred to a desiccator. After few minutes the silica crucible is re-weighed**.** The difference between the weight before and after heat up gives the amount of apparent volatile matter in the coal. The actual volatile matter is obtained after deducting the moisture content of the sample. Volatile matter content is expressed in per cent of coal.(Ash et al., 2013). Fixed carbon in coal is the carbon that remains in the coal sample after volatile matter is driven off. it is not determined directly, it is calculated by subtracting from 100 the resultant summation of moisture, VM and ash, all as a percentage mass fraction on the same moisture reference basis(Zhu, 2010).

The calorific value (CV) as an indicator of the chemically store energy in coal is a very important parameter in the assessment of its value as a fuel (Verma, Singh, & Monjezi, 2010) and potentially could be a basis for the purchase of coal(Mesroghli, Jorjani, & Chelgani, 2009). CV (heating value) is the amount of energy per unit mass released upon complete combustion(Matin & Chelgani, 2016; Taylor et al., 2011). Determination of the calorific value by Bomb Calorimeter; the calorific value of coal is determined in the laboratory with a bomb calorimeter [IS: 1350 (part - II - 1970)]. 250 gram of coal is burnt in an atmosphere of oxygen under a pressure of about 25 atmospheres. The coal inside the bomb is ignited electrically. The bomb is placed in 0.5 cc water. The heat produced is absorbed in the water. The rise in temperature of the water after the combustion is measured with a thermometer(Gravalos et al., 2016).

2.1.7.2 Ultimate Analysis

Ultimate analysis determines the percentage mass fraction of the major constituents of coal such as carbon, hydrogen, Sulphur, nitrogen, and, usually by difference, oxygen, that analysis done by CHNS/O analyzer. The ultimate analysis is used with the calorific value of the coal to perform combustion calculations such as the determination of coal feed rates, boiler performance and Sulphur emissions (Dreier, Högger, & Sorg, 1998). The flat smart CHNS/O configuration is as follows in the figure below:

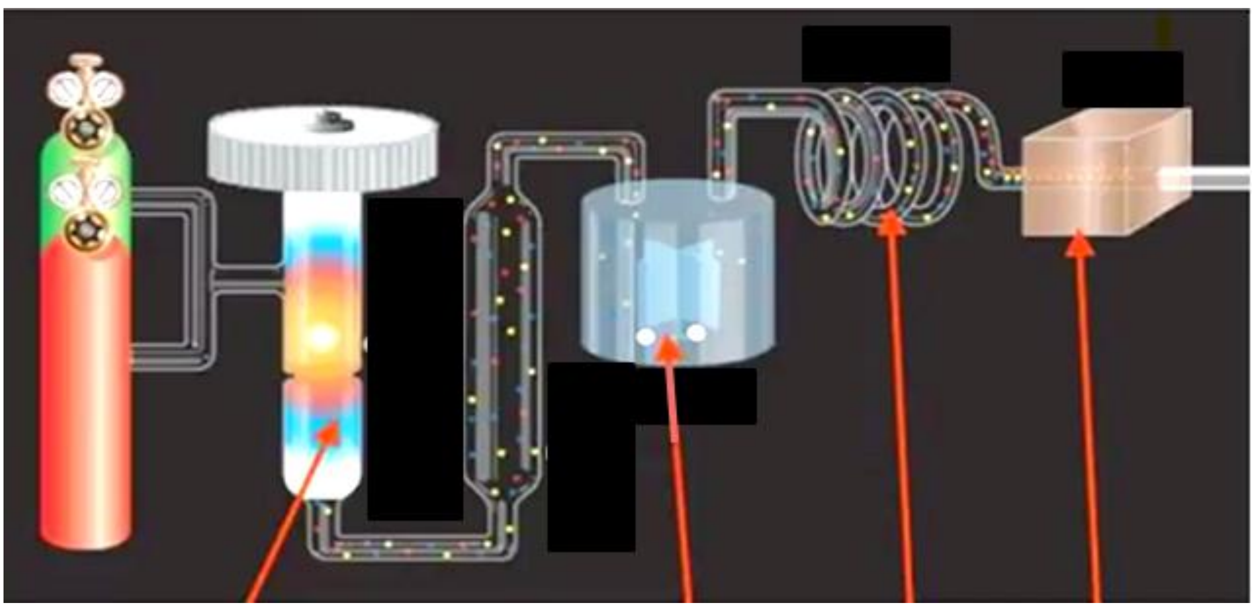


Figure 2.6 Flat smart CHNS/O Configuration

2.1.8 Coal burning and Its Effect on the Environment

The burning of coal, like any other fossil fuel, produces carbon dioxide (CO_2) which is one of the factor that affect the greenhouse gas linked with global warming and nitrogen oxides (NOx) and with different amounts of sulfur dioxide (SO_2) and others, that can pollute the environment, depending on the quality of coal. The other major effect is SO_2 reacts with oxygen to form sulfur trioxide (SO_3), which then reacts with water to form sulfuric acid and which returned to the Earth as form of acid rain (Song, 2010).

2.1.9 Energy Source in Ethiopia

Based on the Ethiopian economic association report, Ethiopia is still at a low level of development of the energy infrastructure and access to energy. The country is by far less than the average for developing countries when one looks at both the installed capacity per person and per capita consumption for electricity. The report shows about 85% of the Ethiopia population lives in rural areas, but electricity supply was addressed mostly on urban areas. However the Electricity coverage of rural population is less than 1% (Ethiopian Economics Association, 2007). Due to these reason there are several challenges face the Ethiopian energy sector.

The available energy sources like hydropower, wind, solar geothermal, wood, natural gas, agricultural wastes and coal are in the country are shown in the table below which is obtained from un published report ministry of mine and energy sector.

Table 2.3 Energy resource in Ethiopia

Resource	Unit	Exploitable reserve	Exploited percent
Hydropower	MW	30,000	< 3%
Solar/day	KMh/m^2	4-6	~ 0%
Wind speed	m/s	3.5-8	~ 0%
Geothermal	MW	1070	~ 0%
Wood	Million ton	1120	50%
Agricultural waste	Million ton	15-20	30%
Natural gas	Billion m^3	113	0%
Coal	Million ton	>300	0%

Source: Ministry of mine and energy sector unpublished report

The Ethiopian energy sector has to see a substantial energy source contains mainly biomass, hydropower, geothermal and fossil fuels (especially natural gas and coal). The remaining is renewable energy sources such as solar and wind energy productions are more suitable in the country. But now the dominate energy resource are traditional biomass consumption, rather than other energy sources.

2.1.9.1 Biomass Energy Consumption in Ethiopia

According to the study of biomass energy strategy in Ethiopia, the yearly amounts of the various biomass fuel energy consumed at national and regional level are indicated in the table below. The main uses of biomass fuels in Ethiopia are for mitad baking (enjera, ambasha, kocho, etc.) and “other cooking” (wot, coffee, tea, etc.). Round wood in some areas its preferred use is for mitad baking and other areas for other cooking. The study shows in rural and urban house hold biomass consumption in all regions of the country.

Figure 2.7 Bio-mass fuel (woods, branches and leafs)

(i) Rural Household Biomass Fuels Consumption

The investigation of the biomass energy strategy in Ethiopia indicates the rural household consumption of wood (i.e. charcoal equivalent of wood) is estimated to be 91.2 million per year with 4.2 million tons per year of charcoal(Geissler et al., 2013). And also in this study the total consumption of residues and dung is expected to be 19.3 million tons per year and 20.7 million tons per year respectively show in the following table below.

Table 2.4 Total rural household consumption of biomass fuels

Fuel source	Round wood	BLT	Charcoal as wood	Total wood	Total wood	Residues	Dung	Charcoal
Unit	Tons/yr	Tons/yr	Tons/yr	Tons/yr	%	Tons/yr	Tons/yr	Tons/yr
Amount	42,239,975	26,206,816	20,565,097	89,115,753	100	18,440,590	19,431,926	4,132,873

Source: Ethiopian ministry of water and energy, 2013

(ii) Total Urban Household Biomass Fuels Consumption

On the same thing the Ethiopian ministry of water and energy study shows the total urban household consumption of wood is estimated to be 11.2 million tons/year with 1.3 million tons of charcoal. Total consumption of residues and dung are 0.4 and 2.1 million tons per year respectively have been shown the following table below (Geissler et al., 2013).

Table 2.5 Total urban household consumption of biomass fuels

Fuel source	Round wood	BLT	Charcoal as wood	Total wood	Total wood	Residues	Dung	Charcoal
Unit	Tons/yr	Tons/yr	Tons/yr	Tons/yr	%	Tons/yr	Tons/yr	Tons/yr
Amount	3,661,564	957,564	6,548,388	11,167,516	100	444,711	1,276,056	1,283,430

Source: Ethiopian ministry of water and energy, 2013

(iii) Total National Biomass Fuels Consumption

Based on the investigation of biomass energy strategy in Ethiopia (Geissler et al., 2013), including the commercial house hold biomass fuel energy as we have seen in the table below, the total national consumption of wood (containing charcoal equivalent of wood) is estimated to be 105.2 million tons/year with 5.7 million tons of charcoal. Total consumption of residues and dung are 19.7 million tons per year and 22.8 million tons per year respectively.

Table 2.6 Total National biomass fuel consumption

Fuel source	Round wood	BLT	Charcoal as wood	Total wood	Total wood	Residues	Dung	Charcoal
Unit	Tons/yr	Tons/yr	Tons/yr	Tons/yr	%	Tons/yr	Tons/yr	Tons/yr
Amount	45,901,539	27,164,380	27,113,485	10517465	100	19724725	22819390	5713700

Source: Ethiopian ministry of water and energy development of biomass fuel, 2013

From the above data in Ethiopia bio-mass is the largest source of household energy. This excessive dependence on biomass energy sources (mainly fuel wood, animal dung, crop residues) has given important suggestions for human health, soil and land management, agricultural land productivity, and environmental effects through channels like clearance of the vegetative cover of land, deforestation, soil erosion and other complex consequences for climate change. As a result thousands of people commonly women and children are die early every year because of exposure to indoor air pollution from biomass.

2.1.10 Coal Reserve in Ethiopia and its Occurrences

Coal is one of the non- renewable energy sources and use as the primary source for different daily industrial, domestic and other activities of the present day. It delivers the major useful and consumable energy sources for industrial sectors, commercial organizations, as well as household consumption throughout the world. Exploration of coal in Ethiopia was started in the year 1935 at Nejo and Wuchale (Wolela, 2007) but, still have not put into economic function at efficiently. Even if the current worldwide energy crisis and increase the price of chemical fertilizer they become initiated the government to explore its own natural resources and started coal have been explored in different parts of the country. However no one try to use indigenous coal for domestic applications. The major applications which have got more attention are the utilization of coal as a raw material for the production of fertilizer and as source of energy for power and heat generation, especially in cement industries. The Ethiopian geological survey studies have been carried out at various scales from inspection to detailed drawing and preliminary to deep drilling to determine the amount of coal deposit in the country. Massive knowledge has been picked up about the geological distribution, geological setting, and geochemical characteristics of Ethiopian coals. Therefore after the investigations they can be identify more than 23 coal occurrences area some of them are as shown below in the table.

Table 2.7 Coal Deposited area in Ethiopia

Areas	Thickness (m)	Reserved in tons (10^6)	Administrative region
Yayu		229	
Moya	0.1-0.2	40-50	Illubabur
Dilbi	0.1-2.2 (varies from block to block)	20	Illubabur
Chilga	In average 4.22	20	Gonder
Nejo	1.3	3	Welega
Wuchale	0.5-1.5	3.3	Wello
Mush valley	1.75	1.5-2	Shao

Source: Ethiopian geological survey

The availability of coal deposits in different regions has played a vital role for the country as well as the regional societies to facilitate the national economy through agricultural and industrial development. In order to reduce the price of fuel as well as the chemical fertilizer, develop the awareness in the importance to utilize indigenous energy resources to secure sustainable growth.

2.1.11 Carbon Emission from Biomass and Fossil Fuel

Burning biomass emits more CO_2 than fossil fuels per mega joule energy generated; Wood inherently emits more carbon per MJ than other fuels (Energies, 2011):

Table 2.8 Carbon emission from biomass and fossil fuels

Fuel sources	Fuel type	CO_2 emission (g/MJ)
Natural gas	Fossil fuel	50.6
Bituminous Coal	Fossil fuel	88
Wood	Biomass fuel	91.4

Source: Partnership for Policy Integrity info@pfpi.net

Wood is often wet and dirty, which reduces the content of heating value; typical moisture content of wood is 45 – 50%, which means its kcal content per kg is smaller than the other fuel source. Before "useful" energy can be derived from burning wood, some of the wood's energy are required to evaporate all that water (Energies, 2011).

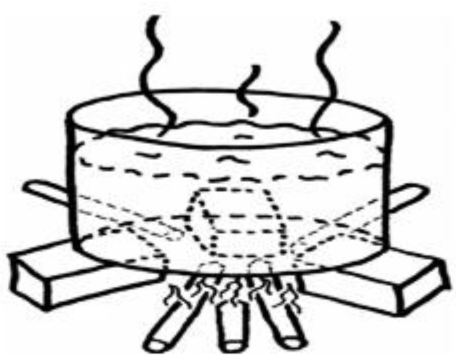
2.1.1.1 Practices of Cooking

Half of the world's human population cooks their food on an open fire inside their homes by burning different forms of biomass such as wood, charcoal, dung and crop residues. As a result the biomass fuels emit harmful chemicals and large amounts of particles, which harmful chemicals have detrimental effects on human health, global climate and regional ecosystems from which the fuel is extracted(Zube, 2010). A large amount of biomass consumption occurs in developing countries where 90% of rural households as a means to provide for their heating and cooking needs.

Individuals in developing countries who cook their food indoors by inefficiently burning biomass fuel often produce a significant amount of indoor air pollution (IAP). IAP is a broad term associated with the emission of several indoor air pollutants that include particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and other products of incomplete combustion (PICs) (Zube, 2010).

2.1.11.1 Traditional Cooking

The ineffective traditional cooking methods in our country Ethiopia can be seen into two basic classes. The most common method is the "three-stone fire" – involves building a fire directly on the ground, and placing a pot or pan atop three stones that surround the fire. Which type of cooking method is the most common method throughout the country this type of activity is exposed indoor air pollution and consume more energy, because of un balanced air supply to the biomass the fuel burns rapidly and too large amount of energy is released as waste.

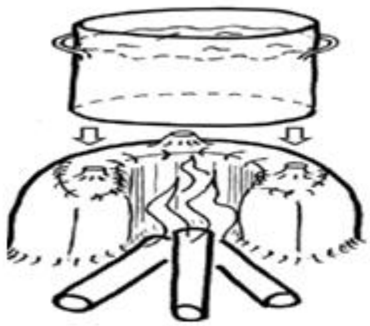


(a)

(b)

Figure 2.8 Three stone fire

The second common method is the "built-in stove" which is a slight modification of the three-stone fire in that a more permanent structure is built around the fire using local earthen(clay, stone, mud or sand) materials.



(a)

(b)

Figure 2.9 Built in stove fire

The above two figures are the most common cooking methods which share some common advantages and disadvantages. One of the most common advantages is it needs very low capital cost and the familiarity of the user has with its easy operation. And also has common disadvantage which is both involved the firing place is directly on the ground. This causes two major problems; heat is lost to the ground through conduction from the fire and the surface area of fuel exposed to primary air is reduced. As a result incomplete combustion of fuel is occurred and also increases in IAP because of air to fuel ratio is unbalanced. One advantage of the three-stone fire is the possibility to place the pot very close to the fire to maximize radiation heat transfer. Considering these drawbacks and benefits to three-stone fires, studies have shown average thermal efficiency values to be roughly 14-25%. (Zube, 2010)

Built-in stoves provide some advantages over three-stone fires; the first one is constructing a wall that surrounds the fire, which restricts the amount of fuel that can be fed into the fire it limiting fuel use. Secondary benefit to the built-in stove is the more bounded walls are important to control the amount inlet excess ambient air this allows to operate the stove at optimum air to fuel ratio. And as the same time can protect radiative heat loss and increase convective heat transfer to the pot(Thompson et al., 2011).

3. MATERIAL AND METHODS

The main objective of this chapter was to discuss the materials, equipment, experimental methods and where experimental location used in laboratory analysis of the mush valley coal. All analysis and tests used for this research are according to the American Society of Testing material (ASTM) methods of testing. Laboratory performing test were proximate analysis, ultimate analysis and designed stove and constructed of stove finally checked the performance of the stove. In proximate analysis moisture content, ash content, volatile matter, amount of fixed carbon and its calorific value laboratory procedures were described. The stove design part also described ways of testing and its performance.

3.1 Experimental Location

The main part of the study was conducted at Addis Ababa University Institute of Technology. Size analysis was carried out at unit operation Laboratory. Proximate analysis was done at school of Chemical and Bio-Engineering thermal and analytical chemistry laboratory, however heating value (calorific value) were done at Ethiopian Geological survey (Mekanissa branch) and Bahir Dar University Institute of Technology, School of Chemical and Food Process Technology Laboratory, Ultimate analysis was prepared in Addis Ababa University 4 kilo campus, College of Natural and Computational science, Department of Chemistry Laboratory. However, manufacturing and assembling the whole part of stove, except the clay part was manufactured at Kalit, Solomon metal and aluminum work shop (PLC), but the clay part was done in Kechene area. Finally the performance of constructed stove was tested at school of Chemical and Bio-Engineering, thermal lab. The work was started in December and ends in May, 2018 a total of six months were spent for analysis, construction and testing stove in the laboratory.

3.2 Materials used for analysis

The experimental material used for characterization was coal, this coal were exploited from North Shoa Zone, namely, Mush Valley area. The coal was exploited and collected from different point of that area. Then the coal was organized and place 25 Kg sample in a sack randomly taken from the field and transported to Addis Ababa University in December, 2017.

3.3 Equipments Used

The most basic apparatus and instruments with its importance that was used in the laboratory were pick axe used to exploited the coal, sac used for holding the exploited coal, drying oven for removing the moisture content of the coal, digital balance to measure the required amount of sample, longs or clamp important to catch the hot parts, desiccators is sealable enclosure containing desiccant used for preserving moisture sensitivity, clay crucible is a container that can with stand very high temperature and is used for ash analysis, electric furnace is used for high temperature heating and this temperature is used for ash and volatility analysis, metal crucible with its cover also a type of high temperature resistance and is used for volatility analysis , stop watch is used for recording time in the laboratory, sifter is used for separating wanted elements from unwanted material or to characterize based on particle size distribution of a sample, jaw crusher used for breaking of large particles into smaller one, oxygen bomb calorie meter in measuring the heat of combustion of a particular reaction, thermometer that measure temperature, CHNS analyzer used to know the ultimate composition of coal. Finally to burn and utilized such characterized mush valley coal for domestic use, it is required to construct especial stove, therefore, the following were the major materials used for the construction of coal burning stove, those are clay which is the top part of the stove used as heat transfer media to heat up the item or pots that put on it. Internal and external mild steel casing is used for supporting the combustion chamber and it resist high heat, metal rod to carry the grate also customize for stove leg, insulating material (fiber glass) to reduce heat loss through the cylindrical wall of the combustion chamber, metal sheet used for as smoking ring, saw is a hand tool which used for cutting meals, angle iron is used to bolted together two separate parts, water used for testing stove performance, fire and aluminum pots are the main important things was used during laboratory work in water boiling test and thermometer.

The overall structure of the experimental works is shown in Figure 3.1

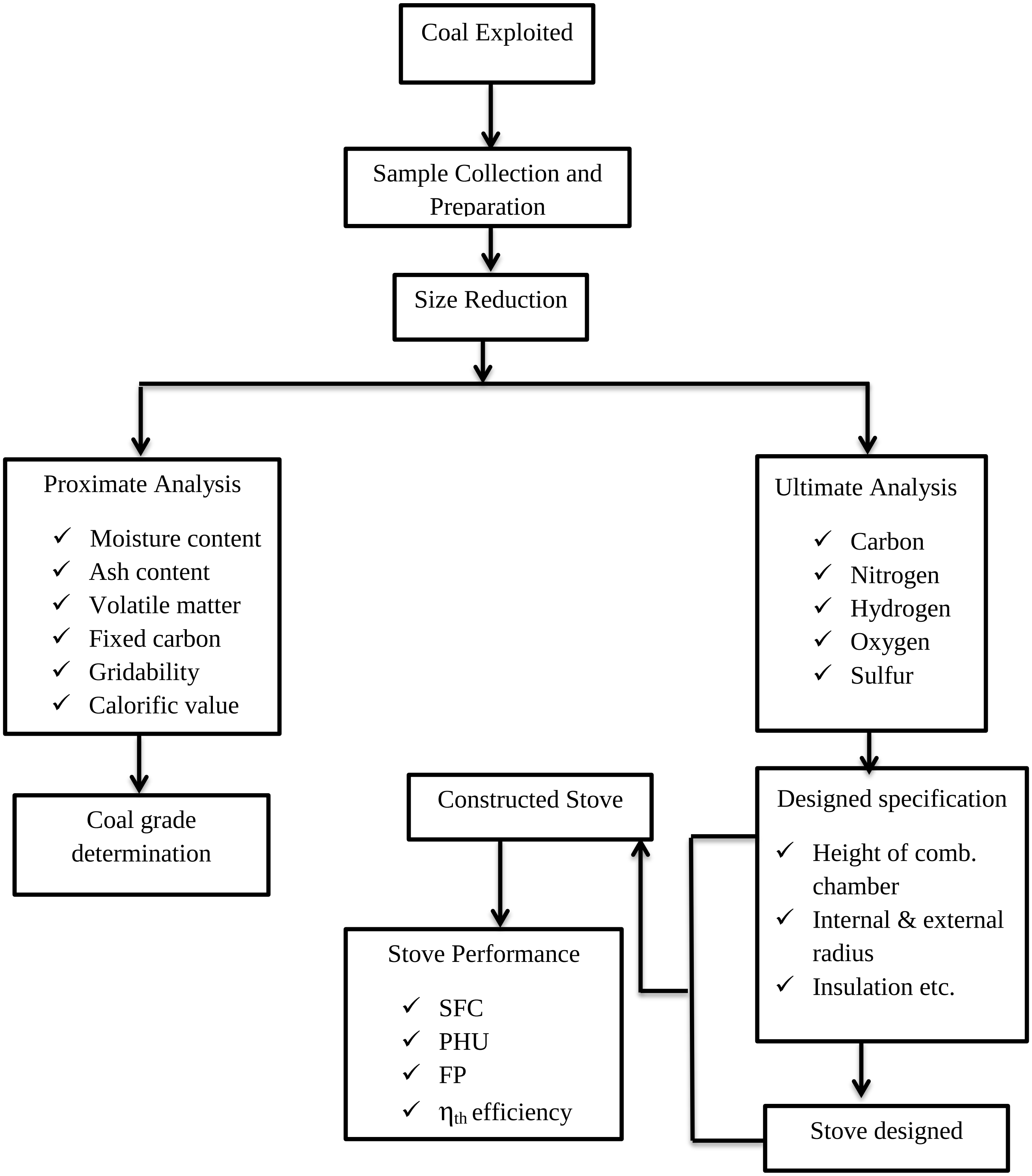


Figure 3.1 Frame work of the experiment

3. 4 Methods Used for the Analysis of Mush Valley Coal

3.4.1 Sample Preparation

Total 10 numbers of coal samples were collected from Mush Valley area, exploited randomly with some distance interval and about 1.5 kg of coal samples were collected in an air tight plastic pack for each. Such collected coal samples were air dried to remove the free moisture of the coal.

After air dried, the required amount of coal was taken from each sample and ready for size reduction. Size reduction was the process by which a coal sample was reduced in particle size without a change in weight. The steps in the sample preparation process was pre-crushed the coal with jaw crushers to reduce the coal size, depending on the jaw crusher model, the sample material and the chosen gap width, a final fineness of 0.5‑5 mm can be obtained. Then ready to fine grinding, before started to analysis some portion selected and crushed in a fine grinder and passed through (250 µm) sieve. Powdered samples were collected and stored in plastic bag and these samples were used for analyses in the laboratory.

3.4.2 Proximate Analysis

The proximate analysis of coal includes the determination of moisture, volatile matter (VM), ash, fixed carbon and calorific value. The first three are determined in laboratory and the fixed carbon is found out by difference of one hundred and the summation of the first three determined analysis (moisture, volatile and ash), the calorific value was also determined by oxygen bomb calorimeter. The proximate analysis was carried out by adopting the procedures as recommended in recognized ASTM D3173 standard method to determine it. In proximate and ultimate analysis each sample was done two times and reported the average value of the duplicate results.

3.4.2.1 Moisture Content

Moisture in coal may be present as adsorbed water on external surface of coal or capillary of pores present in the coal and this was termed as free or accidental moisture. Moisture determination depends on the extent of sample preparation and the condition of the coal sample. The whole process for determining the moisture in coal, after collecting the coal sample, begins with preparing the sample for analysis. If the coal sample is sufficiently dry, it may be reduced immediately and then air dried. If the sample is too wet to reduce in size, it should be air dried, before size reduction, at ambient temperature. The free moisture can be removed by air-drying but the inherent moisture can only be removed completely by drying in an oven at 105°- 110° C until the mass is become constant. Cleaned and dried prepared petri dishes for holding coal samples and weight of the petri dish was taken and one gram of coal was weighed in the petri dish (W_1). Coal was spread with a brush in the whole area of the dish. Which was heated in an oven out of contact with air (to avoid oxidation) at 105°C temperature for until the mass was constant. After heating, the petri dish was transferred to a desiccator and reweighed (W_2). The difference in weight (i.e., ΔW), Percentage moisture was determined by dividing ΔW by the load mass all in grams (g) then give the amount of moisture. Several trials were conducted, the aim being to establish the accuracy of the method and so as to determine representative results.

3.4.2.2 Volatile Matter

The volatile matter, which consists mainly of the combustible gases such as hydrogen, carbon monoxide, and hydrocarbon as well as incombustible gases like steam and vapour are liberated from coal when it was heated at high temperature. To determine the volatile matter 1 gm of coal was taken in a metal crucible with cover. The cover was used to avoid oxidation. The weight of the crucible and coal was denoted by (Y). The coal was then heated for 7 minutes at a constant temperature of 950°C inside a muffle furnace. After seven minute the heated crucible was transferred to a desiccator and cooled. In few minutes the temperature was approached to atmospheric temperature, the crucible was re-weighed and denoted by **(**Z**).** Finally the volatile matter could be calculate and obtained in percent. The amount of volatile matter in the coal was expressed in percent as follows in the following way:

$$\%\ V.M = \frac{Y-Z}{Y-X} * 100 \qquad (3.1)$$

Where: X = Weight of crucible in grams

Y = Weight of coal + crucible in grams (before in heating)

Z = Weight of coal + crucible in grams (after in heating)

3.4.2.3 Ash Content

The residue left after burning of coal was known as ash. Ash was generally composed of inorganic substances. 1 gram of coal was weighed in a silica crucible which denoted by (M). Then the crucible was kept inside a muffle furnace and the temperature was gradually raised up to 800°C. At 815 $\pm$ 10°C the temperature was kept constant and the incineration of coal was completed by heating the coal for 3hr at that temperature. After incineration the crucible was transferred to a desiccator and allowed to cool. The crucible temperature was reach at atmospheric temperature the crucible was re-weighed and denoted by (N) and recorded the result. The ash content could be calculated from the recorded data obtained from the experiment and put in percent.

$$\% \text{ Ash} = \frac{N-L}{M-L} * 100 \text{ ....} (3.2)$$

Where: L = Weight of crucible in grams

M = Weight of coal + crucible in grams (before in heating)

N = Weight of coal + crucible in grams (after in heating)

3.4.2.4 Amount of Fixed Carbon

Fixed carbon in coal was the carbon that remains in the coal sample after volatile matter was driven off. It was not determined directly, the fixed carbon was calculated by subtracting from 100 the resultant summation of moisture, volatile matter and ash content, all as a percentage mass fraction on the same moisture reference basis.

Fixed carbon = 100 - (%Moisture + %Ash + %Volatile matter) …………………………….……… (3.3)

3.4.2.5 Amount of Calorific Value

Weighed some amount of coal and was placed in the silica crucible. The crucible was supported over the ring. A thin magnesium wire touching the fuel coal sample is over extended across the conductors. Oxygen supply was forced into the bomb till a pressure of 25-30 atm was reached. Initial temperature of the water in the calorimeter was well-known after thorough stirring. The current was switched on the fuel in the crucible burns with the progress of heat. The heat produced by the burning of fuel was transferred to water which was stirred throughout the experiment by the electric stirrer. Maximum temperature shown by the thermometer was recorded. Finally the calorific value of the coal could be calculated. This experimental work was done in Bahir Dar University and Ethiopian geological survey. The appropriate equation to calculate the calorific values of coal was as follows in eqn.3.4.

Calorific value of coal = temperature rise in (^{0}C/ gram) * standard benzoic acid (Cal/^{0}C)………….. (3.4)

3.4.2.6 Coal Grade Determination

The calorific value was recalculated, in Moist mineral - matter- free Btu, to classify the ranks of the coal. To determine it the ASTM method of Parr formulas were used. In the ASTM classification, the basic criteria are the fixed carbon and the calorific values calculated on a mineral-matter-free basis. To establish the rank of the coals used a "dry, mineral-matter-free fixed carbon or volatile" as a good criterion for older coals but not suitable for the rank of younger coals, for younger coals by moist, mineral-matter-free Btu. These were defined by the Parr formulas shown below:

Parr Approximate formulas

1) Dry m.m – free FC = $\frac{FC}{100-(M+1.1*A+0.1*S)} * 100\%$ ……………………………………………… (3.5)
2) Dry m.m-free V.M = 100- Dry m.m – free FC% ………………………………………… (3.6)
3) Moist m.m-free Btu = $\frac{Btu}{100-(1.1*A+0.1*S)} * 100$, per lb ……………………………………….. (3.7)

Where:

M-M = mineral matter

Btu = heating value per lb

FC = fixed carbon, %

VM = volatile matter, %

M = moisture, %

A = ash, %

S = sulfur, %

3.4.2.7 Determination of Hardgrove Grindability Index

Some amount of coal sample was taken and crushed by jaw crusher and to pass through 4 mm sieve. The resulting sample was put in two sieves of 1mm sieve (upper sieve) and 510 μ size (lower sieve). Sieve the material for 2 minutes until the entire material pass through 1mm sieve. The 1mm by 510μ size coal was mixed thoroughly and some amount of the sample was removed for sample divider. The 50gm sample was taken in a ball mill along with 8 iron balls. Close the mouth of the ball mill and set to rotate for exactly 60 revolutions. After the required rotation, the machine stopped automatically. The sample left in the ball mill was then collected along with any powdered substance sticking to the surface of the machine by help of a brush. The sample was then put in a sieve of 75μ size and was shaken for about 10 minutes. After sieved, the sample which passes through 75μ size was weighed on the balance.

HGI = 13 + 6.93 W ………………………………………………………………………….. (3.8)

W = weight of the test sample passing through 75μ sieve after grinding, (gram)

3.5.3 Ultimate Analysis by Using CHNS/O Analyzer

Ultimate analysis of coal was done by the device EA 1112 flash CHNS/O analyzer; at the conditions carrier gas flow rate of 120ml/min, reference flow rate 100ml/min, oxygen flow rate 250 ml/min, furnace temperature of 900^0C, oven temperature of 75^0C and oxygen injection time was for 5 sec. For CHNS determination, the Flash Smart EA Analyzer operates with the dynamic flash combustion of the sample. 1 mg samples were weighed in tin containers and introduced into the combustion reactor through the Thermo Scientific™ MAS Plus Auto sampler with oxygen. After combustion the resulted gases were conveyed by a helium flow to a layer filled with copper, then swept through a GC column that provides the separation of the combustion gases, and finally, detected by a Thermal Conductivity Detector (TCD). The total run time is less than 10 minutes. The following equation is the standard equation used for the calculation of the oxygen content on an air-dried basis.

Oxygen % = 100 - (N%+C%+H%+S%+M% +A %) ………………………………………………. (3.9)

3.5.4 Methods Used for Designing and Constructing Stove

The coal stove was circular (cylindrical in shape) and generally consists of a combustion chamber, a top section, grate, ash tray and others. The fireplace of the combustion chamber was made of mild steel the outside of which was lined with fiberglass and covered in a steel casing. The combustion chamber is where coal is burnt and heat is generated. The grate or coal burning bed was at the base of the combustion chamber. The grate was circular in shape and made from sheet metal. It was welded to the finished cylinder and the air hole was stamped closely below the grate, the function of air holes stamped near to the grate is: to facilitate primary air supply, to provide means of passages of ash after combustion and to deliver efficient burning coal.

The base of the stove consists of a door for loading fuel coal into the combustion chamber, and four openings which help as combustion air inlets to the chamber. The door was attached to the combustion chamber. The bottom of the door was placed at the top of the air holes while the top was below the bottom of the pot seat so that hot gases do not exit through the door but are directed up around the door. The door was used for feeding the coal before burning operations and also employed in removing remaining trace coal after burning. Locks were provided on the door to keep the coal from discharging and to help regulate air flow rate and smoke release through the door.

At the base or the bottom of the stove ash was collected on the tray the ash tray was circular in shape and placed under the stove for collecting and disposing of ash during and after burning. The ash tray helps in keeping clean the environment where the stove is being used.

The top of the stove consists of the pot or pan seat, which was flat to accommodate different sizes of pot, and a chimney. The chimney was made of sheet metal and incorporated at the edge of the top of the stove to convey smoke and other by-products of combustion out of the kitchen. The design specification was considered the domestic stove size and by tri and error method to approach the right specification of the different parts of the stove size.

3.5.4.1 Stove Performance Test (Water boiling test)

The stove and pot were thoroughly cleaned and dried. The testing area should be well protected from the wind. A required amount of coal (1.50 kg) was weighed out for each test. It was important that the initial mass of coal be the same for each test in every test. After the coal was burnt out the pot was put on the stove, the pot lid and thermometer were ready, and then a fixed amount of water was added, the lids should close tightly and the thermometers should sit well immersed in the water. The temperature of the water and any actions to control the fire were recorded every five minutes. The moment that the pot comes to a vigorous boil, the pot with lid and with water was weighed and their weights recorded. After boiling, the coal and the pot and water are again weighed and recorded values. The test was carried out on the constructed stove in Addis Ababa university Department of chemical and bio- Engineering, thermal Lab between 8 to 10 may, 2018.

In analyzing the data, four parameters were calculated for each phase the firepower (P), the percent heat utilized (PHU), the specific fuel consumption (SFC) and thermal efficiency (η_{th}). These three parameters were calculated by using the following formula.

$$P = \frac{\text{Amount of coal consumed} * \text{calorific value of coal}}{60 * \text{time elabsed}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.10)$$

The percent heat utilized PHU is calculated by:

$$PHU = \frac{4.186\text{kj/kg.k} * \text{intial mass of water } (Tf - Ti) + 2256 * (Mwi - Mwf)}{\text{amount of coal consumed} * \text{calorific value of coal}} * 100\ \% \ldots\ldots\ldots \ (3.11)$$

$$SFC = \frac{\text{Amount of coal consumed}}{\text{mass of water at the end of test}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.12)$$

$$\eta_{th} = \frac{4.186\text{kj/kg.k} * \text{intial mass of water } (Tf - Ti) + 2256 * (Mwi - Mwf}{\text{time taken to boil} * \text{calorific value of coal} * \text{burning rate}} \times 100\% \quad \ldots\ldots\ldots\ldots \ (3.13)$$

Where:

M_{wi} = initial mass of water

M_{wf} = final mass of water after boiling

T_i = initial temperature of water, T_f = final temperature of water or boiling temperature of water

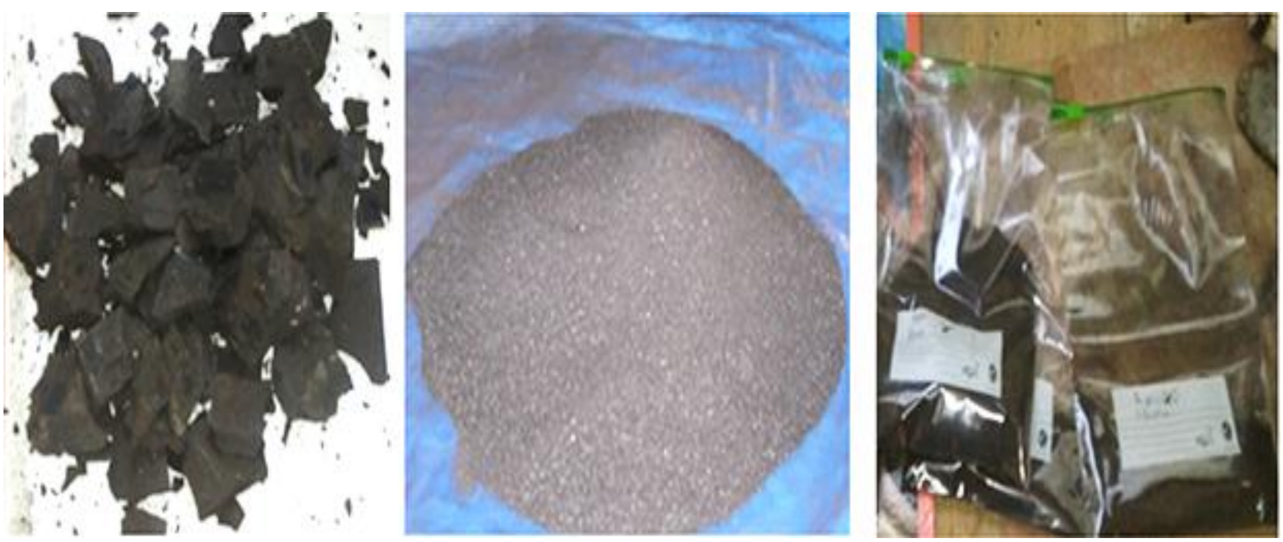
4. RESULTS AND DISCUSSION

4.1. Coal characterization

The results obtained from the chemical analysis of the coal sample were presented and discussed in this chapter. The outcomes obtained from the chemical analysis of the coal sample are provided in tables and figures. It includes those for the proximate analysis (ash content, volatile matter, moisture content, grindability and amount of fixed carbon) and the ultimate analysis (the composition of carbon, hydrogen, nitrogen, sulfur and oxygen in the coal) were determined. Depending on the values of the proximate and ultimate analysis the main factors that affect the coal quality and the important parameters of the coal were discussed.

4.1.1 Prepared Coal Samples

The mined coal contains a mixture of different size fractions together with unwanted impurities such as rocks and dirt. Coal preparation is the stage in coal production when the mined coal is processed into a range of cleaned grinded coal products that was based on the standards. Therefore to achieve the required results ten number of coal sample had collected from mush valley area, at randomly with some distance interval. The collected or mined coal sample were prepared based on the ASTM coal preparation method, the required coal sample as received basis and the prepared one were shown in the next figure 4.1.



(a) Coal as received (b) bulk pulverized coal (c) final prepared coal sample

Figure 4.1 Prepared coal Sample

Figure 4.1 (a) was shows the coal as received basis, in the condition as received for sample analysis, this kind of coal includes all contents; organic constituents and inorganic constituents or inherent and free moisture. The indicated figure 4.1 (b) was the bulk pulverized coal as a large amount, that is ready for final sampling and figure 4.1 (c), shows the (250 µm size) final prepared powdered samples are collected and stored in air tight plastic bags to minimize oxidation during preparation and these samples were used for chemical analyses in the laboratory. Sample preparation is an important step for achieving good result in the laboratory analysis.

4.1.2 Proximate analysis

During the proximate analysis, the inherent moisture content, ash content, volatile matter, grindability of coal and amount of fixed carbon were determined using the standard procedure as recognized ASTM method to determine it. The results obtained in proximate analysis of coal were shown in the form of table and graphs. Proximate analysis is important to determine the quality and rank of the coal, which means the analysis result below shows the coal purities as well as standards of the coal, the most important one from it to indicate the coal quality were the calorific value of the coal. The results of each sample analysis were seen in the next consecutive page.

4.1.2.1 Determination of Moisture Content

According to Vassilev et al., (2010) the fluid matter of coal includes moisture, gas, and gas-liquid inclusions associated with both solid organic matter (OM) and inorganic matter (IM). The increased contents of this physically and chemically adsorbed water are characteristic of lower-rank coals, while the decreased values of this parameter are typical of higher-rank coals Stach et al., (1982). The recorded result of the moisture content was obtained from experimental results appendix –A table A-3, the average value was taken from each sample and reported on figure 4.2, the moisture content of the coal ranges from 16.5 % to 21.2%, and a total average value of 19%, these sample number- 6 has highest moisture value but sample number 8 has smallest moisture content as compared with the other remaining sample numbers. Therefore sample number-6 has more moisture content, which replaces combustible matter; it decreases the heat content per kg of coal, as a result increases heat loss, due to evaporation and superheating of vapour and sample number - 8 has relatively less in percent and has less effect on the heat content of the coal. The presence of more moisture is an important factor in both the storage and the utilization of coal, as it adds unnecessary weight during transportation, reduces the calorific value and possess some handling problems.

Generally the moisture content of the mush valley coal is moderately high, which can affect the burning efficiency of the coal and will take large time to evaporate it.

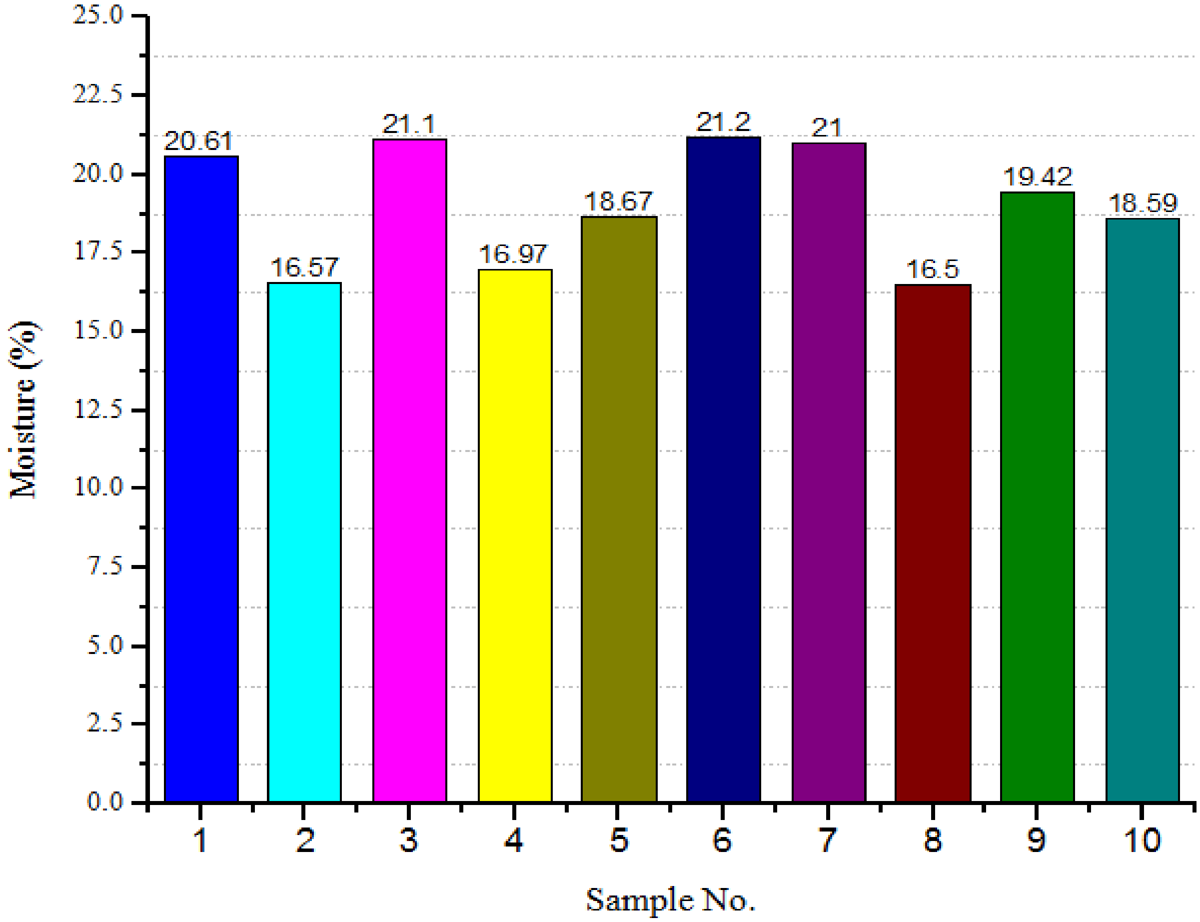


Figure 4.2 Moisture content vs. sample number graph

4.1.2.2 Determination of Volatile Matter

The result that shows in table 4.1 were obtained, from experimental values of appendix A table A-1, reported only the average value of each sample result. The volatilities are mainly of the combustible gases such as hydrogen, carbon monoxide, and hydrocarbons as well as incombustible gases like steam and vapour are liberated from coal when it is heated at high temperature. The result indicates that the coal sample has volatile matter content values in the range of 22.3 - 38.1 %. When sample number-8 has highest volatile matter, which increase in percentage of volatile matter in coal proportionately increase flame length and helps in easier ignition of coal. The volatility of the examined sample were reported in table 4.1, all are above 30% except sample number 1 and 10, that can be ignite easily. The amount of volatile matter in the sample is high; this specifies the rank of the coal is low. That means the quantities of the combustible gases are increases, the amount of fixed carbon decreases, consequently the heating value of the coal decreases.

Table 4.1 Amount of volatile matter obtained from experiment

Sample No	Volatile matter %
01	22.3
02	32.5
03	31.8
04	35.3
05	31.9
06	30.6
07	32.3
08	38.1
09	32.8
10	25.8
Average value	31.34

4.1.2.3 Measurement of Ash Content

Ash is an impurity that will not burn; figure 4.3 specifies the results of ash content of the investigated coal sample that was obtained, from experimental results of appendix A, table A-2 reported only the average value of each sample, it is varied largely from (3.2% – 24.5%) and average value of 11.58%. The result has very large variation as shown, except sample number-4 and 8; majority of the coal sample has highest ash content. The outcome of increasing the ash content is reduces burning capacity, increases handling costs, affects combustion efficiency and causes for large slagging. The amount of ash and its behavior at high temperatures affect the design and type of ash handling system employed in coal-utilization process. At high temperature coal ash become sticky and eventually forms molten slag. The amount of ash content increases the quality or the rank of coal decreases, because the volumes of impurity are high which reduce the coal efficiency. When the ash content decreases the amount of non-burnt part are small or the quantity of impurities like rock, dirt and others were relatively presented in small amount.

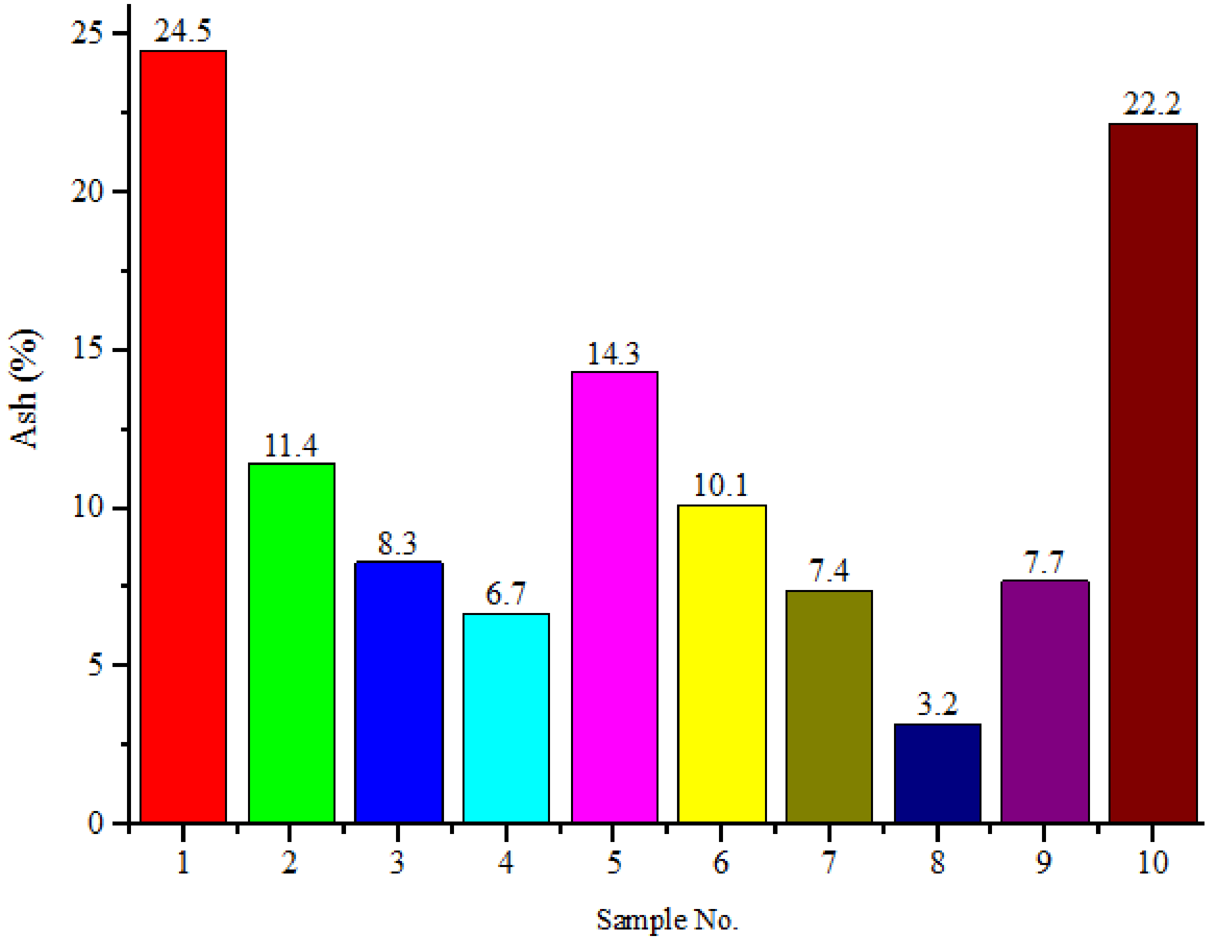


Figure 4.3 Amount of Ash content in percent

From figure 4.3 shown sample number-1 and 10 has relatively high amount of ash content, those shows the quantity of impurities or the non-burnt part are high, the two samples will have relatively low carbon content and gives small amount of heat energy, but sample number 4 and 8 has small amount of ash content per sample, it indicates the purity of the coal moderately high.

The general relation between ash, moisture and volatile matter can be seen in the form of graph to understand the relation easily. As we observed from figure 4.4 sample No.8 has the highest volatile matter, but the lowest moisture and ash content, however sample No.1 and sample No. 10 has almost the lowest volatile matter and the highest ash and moisture content. Therefore from this result we conclude that coal sample No.8 can be ignite easily and are highly reactive in combustion application. Its moisture content is small as compared with the remaining samples, which means the quantity of clinker or remaining residue will be small and the amount of heat loss due to evaporation is reduced. As the same thing the volume of the ash content is small the coal has high purities or the non-burnt part is also small which increase burning capacity and will reduce handling cost.

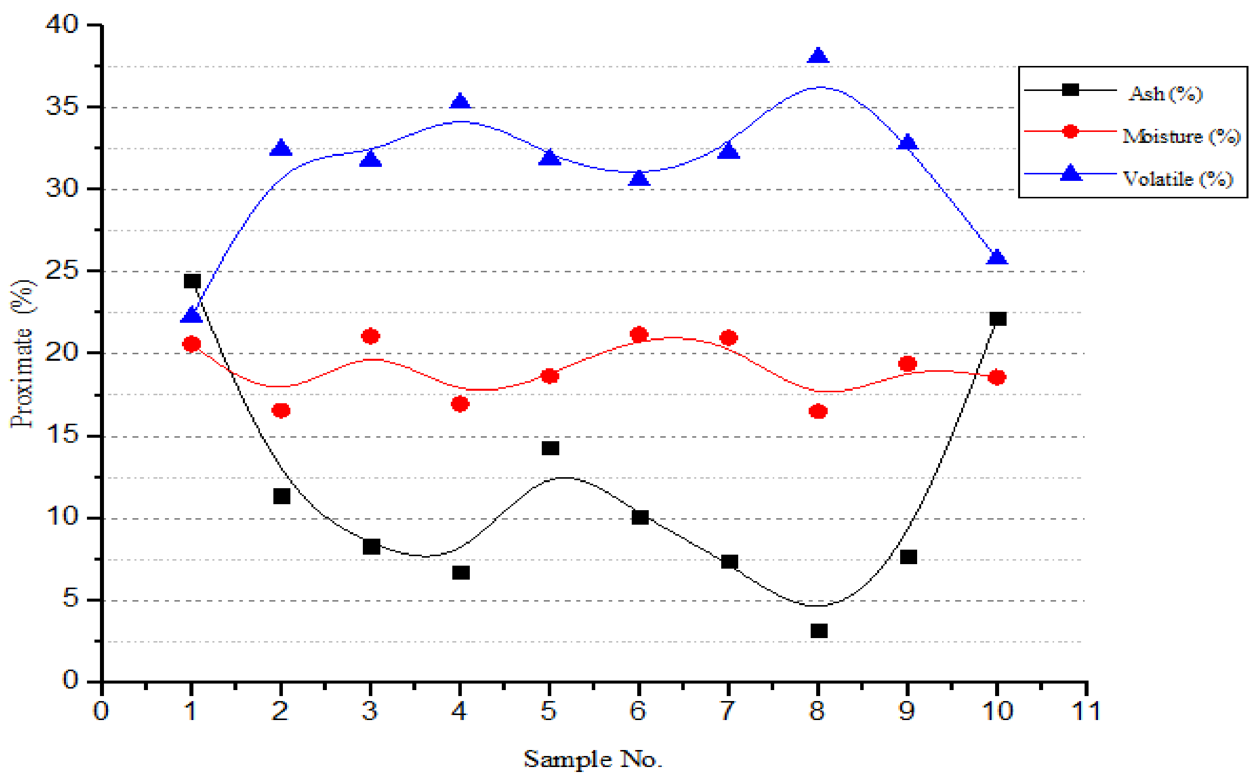


Figure 4-4 The relation between Ash, Moisture and Volatile matter

In general the three proximate values such as volatile mater, ash and moisture content were shows in the above figure 4.4, when the amount of ash content increases the volatility of the coal sample decreases and via-versa. And also the presence of moisture content decreases relatively the volatility of the coal increases, and moisture increase volatility decrease. The relation of moisture and ash from figure 4.4 shows when the moisture content increases the ash content also some amount increases.

4.1.2.4 Amount of Fixed Carbon

Fixed carbon gives a rough estimate of heating value of coal. It is well known that the FC content increases with coal rank said Vassilev et al., (2010). If the amount of ash, volatile matter and moisture content is high the fixed carbon content of coal is small that conclude from the result obtained. It could be observed from table 4.2 that the fixed carbon content of 7 samples are below 40% and it is expected that, their calorific value would be low. This means the fixed carbon content has a direct relation with the calorific value. From the result sample No.4, 8 and 9 has highest fixed carbon content as compared with the other samples, expects highest calorific value from it.

The results of proximate analysis for all the coal samples are presented in the following table 4.2.

Table 4.2 Amount of fixed carbon present in the coal (%)

Sample No	Moisture (%)	V.M (%)	Ash (%)	Fixed carbon (%)
01	20.61	22.3	24.5	32.59
02	16.57	32.5	11.4	39.53
03	21.10	31.8	8.3	38.8
04	16.97	35.3	6.7	41.03
05	18.67	31.9	14.3	35.13
06	21.20	30.6	10.1	38.1
07	21.00	32.3	7.4	39.3
08	16.50	38.1	3.2	42.2
09	19.42	32.8	7.7	40.08
10	18.59	25.8	22.2	33.41
Average value	19.06	31.34	11.58	38.02

4.1.2.5 Determination of Calorific Value of Mush Valley Coal

The calorific value of the given coal could be determined by using Bomb calorimeter, it is an apparatus used for measuring the performance of coal in term of heat of combustion. The calorific value is the quantity of heat produced by the complete combustion of a given mass of a coal. The calorific value of the coal are shown in the table 4.3 below, as explained before the highest calorific value was recorded on sample No. 4, 8 and 9, because the amount of fixed carbon is high, calorific value also high. Sample

No. 8 has highest heating value and sample No.6 has smallest value. Finally the recorded value of the experimental result was reported in table 4.3.

Table 4.3 Calorific value of mush valley coal (Kcal/kg)

Sample No	Temperature rise in (°C/ gram)	Standard benzoic acid (cal/°C)	Calorific value (kcal/kg)
01	1.660	2402.1	3987
02	1.784	2402.1	4285
03	1.734	2402.1	4165
04	1.953	2402.1	4691
05	1.508	2402.1	3622
06	1.507	2402.1	3620
07	1.633	2402.1	3923
08	2.03	2402.1	4876
09	1.819	2402.1	4369
10	1.512	2402.1	3632
Average value			4117

The proximate analysis values of the fixed carbon content and its calorific value which has a direct relation, because fixed carbon gives a rough estimate of calorific value of coal. The fixed carbon is varied between 32.6 % - 42.2% are shown in the table 4.3 and figure 4.5. The final observed values of mush valley coal from table 4.3 the value of the fixed carbon content of the majority of the given samples are below 40%. The relation of fixed carbon and calorific value are shown in the figure 4.5 below.

The following figure 4.5 shows that the calorific value of the coal is highest in sample number 4 and 8 and also smallest for sample number 1 and 10. Generally figure 4.5 indicates when the amount of fixed carbon increases the calorific value also increases.

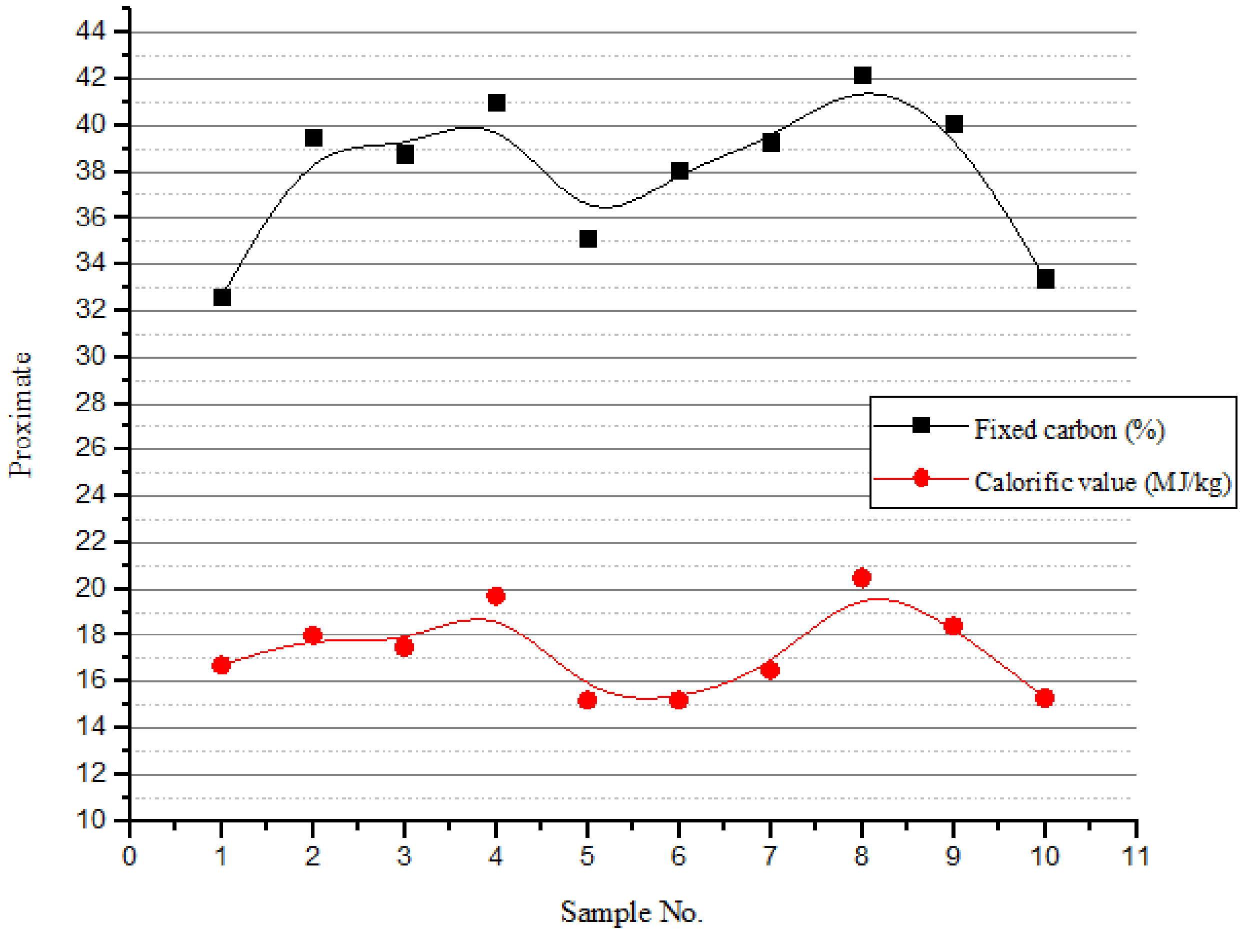


Figure 4.5 Plot of Sample number vs. its proximate value

4.1.2.6 Coal Grade Determination by Using Parr Formula

In the ASTM classification, the basic criteria are the fixed carbon and the calorific values calculated on a mineral-matter-free basis. It is necessary, in establishing the rank of coals, to use information showing an appreciable and systematic variation with age. As it is the calorific value cannot be determine the coal ranks so, it should be recalculate as "moist, mineral-matter-free Btu, which varies little for the older coals but appreciably and sType equation here.ystematically for younger coals, according to Bartoszewicz et al., (2007). ASTM D 388, is used for classification according to rank or age reported by

Kłosowiak et al., (2007). Since in this work moist-mineral matter free calorific value is used to determine the rank of the coal because, it is more effective for the high-volatile bituminous, subbituminous and lignite coals.

Table 4.4 Analytical balance of mush valley coal on mineral matter free basis

Sample No	Calorific value as received basis		M.m.m.f basis		D.m.m.f fixed carbon	D.m.m.f volatile matter	Group
	Kcal/kg	Btu/lb	Kcal/kg	Btu/lb	%	%	-
01	3987	7176.6	4382.2	7888	53.8	46.2	Lig A
02	4285	7713	4903.8	8826.8	55.9	44.1	Sub b C
03	4165	7497	4597	8274.6	55.7	44.3	Lig A
04	4691	8443.8	5166.8	9300.2	54.3	45.7	Sub b C
05	3622	6519.6	4299.9	7740	53.6	46.4	Lig A
06	3620	6516	4670.5	8406.9	46.7	53.3	Sub b C
07	3923	7061.4	4275.3	7695.5	55.5	44.5	Lig A
08	4876	8776.8	5309.5	9557.1	52.8	47.2	Sub b B
09	4369	7864.2	4776.4	8597.5	55.6	44.4	Sub b C
10	3632	6537.6	4574.3	8233.7	58.8	41.2	Lig A

Based on the moist-mineral matter free basis formula, the calorific value of the mush valley in Btu/lb are reported in the above table 4.4, the calculated value shows the mush valley coal is found under the range of lignite-A and Sub-bituminous-B group. It means the mush valley coal is the low grade coal. However sub-bituminous-B has relatively high heating value as compared the remaining lignite coals. Therefore the quality of the coal will affect the burning efficiency of the stove.

4.1.2.7 Hardgrove Grindability Index

The grind ability of Coal is a measure of the comfort with which it can be ground fine enough for use as suitable for burning & it also shows the physical properties of coal like hardness, inflexibility and split. There is a fixed relationship between Grind ability and rank of coal in the natural series of brown coal & anthracite coal. However the presence of different mineral constituents in the coal are influence grind ability. The hard groove index of coal is affected by its moisture and mineral content and hence on the humidity of the atmosphere in which the test is carried out. Figure 4.6 shows the gridability index of mush valley coal, the hard grove gridability index value is small, it means it is difficult to grind.

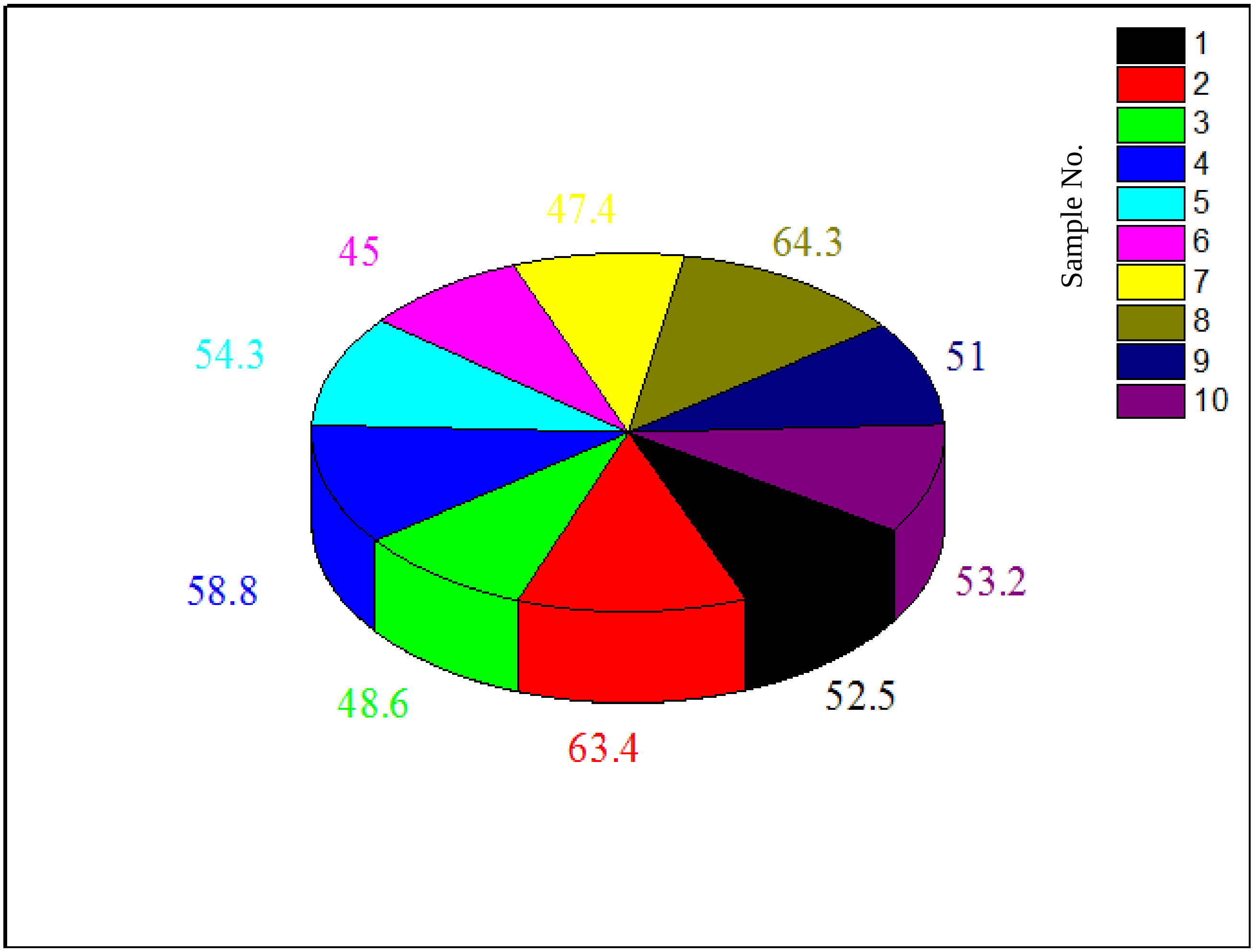


Figure 4.6 Sample number vs. hard grove gridability Index

The measurement of the coal resistance to crushing is said to be the gridability of a coal. HGI is an important, used to show how difficult coals are to grinding. According to Terchik & A, (1963) the high HGI value shows softness of coals, and a low HGI value is suggestive of hard coal. The ranges of HGI values and their meaning are given by Terchick & F., (2008) later study, he was explained that any coal with HGI ranging between 40 and 60 is hard while the values HGI is greater than 60 (≥ 60) means a soft coal or medium hard coal. Typically, mush valley coals possess HGI values from figure 4.6, ranging between 45 and 64.3 was reported. Based on the Terchick & F (2008) conclusions the HGI results suggests that sample number-2 and 8 was soft or medium hard coal because (HGI > 60) which implies can grind easily. While the remaining sample HGI value is less than 60, it indicates the coal is hard and difficult to grind.

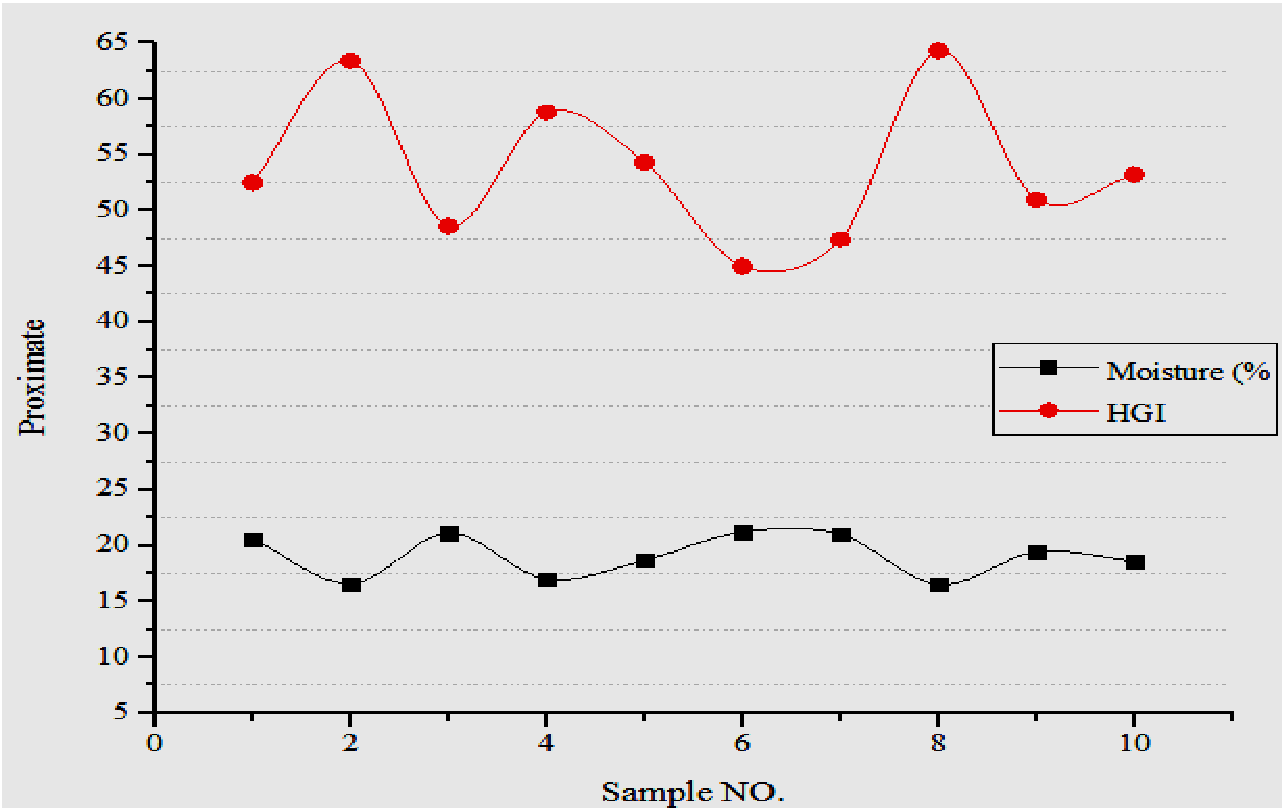


Figure 4.7 Graph of Sample No. vs. its proximate value (HGI and moisture relation)

Normally, lignite and anthracites are more resistance to grinding than bituminous coals was reported by Terchick & F., (2008) . From figure 4.7, moisture is major factors, of coal grindability when the moisture content increases the gridability of coal decreases. The moisture content or the moistness of the coal is the main factors that affect the HGI values. Basically from the result obtained in figure 4.7 the lignite is more resistance to grinding than sub-bituminous coals.

4.1.3 Ultimate Analysis

Ultimate analysis determines the percentage mass fraction of the major constituents of coal such as nitrogen, carbon, hydrogen, sulfur and oxygen. It is used to perform combustion calculations such as the determination of, the quantity of air required for combustion, sulfur emissions and composition of the combustion gases. As there is no satisfactory method for the direct determination of oxygen, it is calculated by difference, that is, sum total of carbon, hydrogen, nitrogen, ash, moisture and organic sulphur and deducted from 100 is taken as oxygen Kavšek et al., (2013). Samples were run in duplicate and the average value has to be taken.

Table 4.5 Mush valley coal ultimate analysis value (%)

Sample No	N %	C %	H %	S %	O %
1	3.35	41.86	3.84	1.44	18.93
2	2.96	39.89	2.99	0.95	22.63
3	3.05	44.94	3.76	0.65	17.03
4	3.21	42.2	3.51	1.32	19.18
5	3.0	38.7	2.85	0.75	22.12
Average	3.12	41.5	3.35	1.1	20.00

Nitrogen:

The Nitrogen content in the coal samples of the studied area ranges between 2.96 to 3.35 % with an average value of 3.12 %. According to Dobrogorskii, (1981) study, the decreased values of N are regularly more typical of lignite coal while increased contents of the element generally more characteristic of higher-rank coals.

Carbon:

The Carbon content in the collected coal samples from the study area varies from 38.7- 44.94%. Based on Norbert & Berkowitz's (1979) investigation that the Carbon content in coal increases steadily with increasing coal rank. The measurement of carbon concentration in coal is still the leading and most accurate parameter Li et al. (2010) among other chemical characteristics for evaluation of coal rank, even with some limitations. Subsequently the value of fixed carbon from proximate analysis and amount of carbon from ultimate analysis are small which implies the coal is low grade.

Hydrogen**:**

The Hydrogen content of the sample is found between 2.99 to 3.84 % with an average value of 3.34 %. The highest content of H is normally more characteristic of low rank coals, Kler et al., (1987)while the lowest values are commonly more typical of higher-rank coals.

Sulphur: - The Sulphur content in the investigated samples result ranges between 0.75 and 1.44w % with an average value of 1.1 %. The increased content of Sulfur is increase the amount of poisonous gas, the result of increasing sulfur can cause acid rain and lung cancer.

Oxygen:

The Oxygen content in the samples is ranges between 17.03 and 22.12 %. The increased oxygen content is specifying of low rank coals, whereas the decreased concentration is typical of higher-rank coals. The increased Oxygen concentration is in agreement with greater contents of moisture and hydrated minerals or as a result of advanced coal weathering. The average ultimate value of mush valley coal were shown in figure

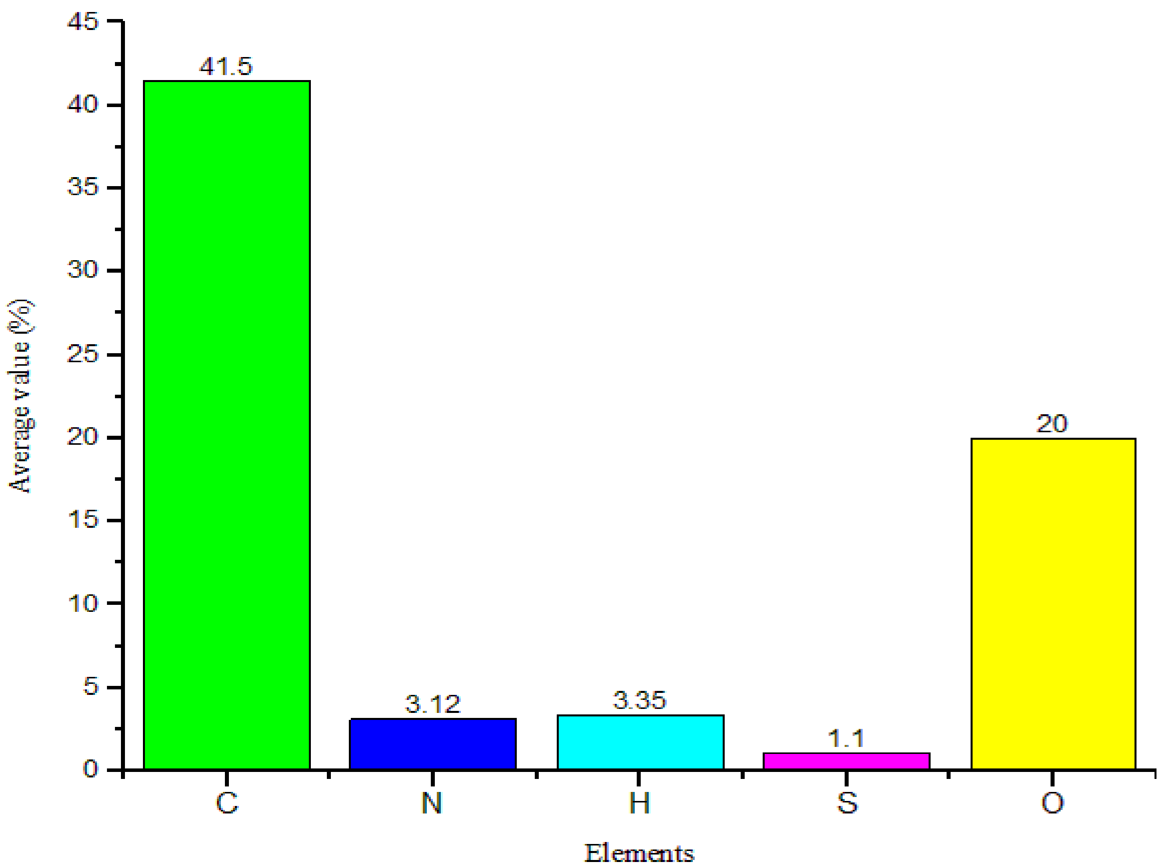


Figure 4.8 The average ultimate value of the mush valley coal sample

The average ultimate value of mush valley coal are shown in figure 4.8, from this value the amount of sulfur in the coal relatively small, which is one of the good advantage for utilizing for house hold application, because it reduces the amount of sulfur cause pollution and disease overcome. The amount of hydrogen is moderately high as a result it reduces the quality of coal, the same thing oxygen amount is high, so the element composition is high the purity of the coal will reduces.

4.2 Design Description, Analysis and Calculation

4.2.1 Design Description

The main things to be considered to design coal stove are:

- ✓ Costs of Production: The stove was manufactured as much as possible with locally available materials to keep the cost as low as possible to increase affordability by low-income recipients.
- ✓ Ease of Manufactured and Ensuing Maintenance: The design of the stove was such that needs minimal technical skills welders would be required in fabricating and succeeding replacing components parts of the stove.
- ✓ Thermal Efficiency: The thermal efficiency of a stove depends mainly on how well the heat generated is transferred from the fuel to the pot. To achieve maximum heat transfer, the coal fuel-bed-to-pot distance was kept as close as possible to minimize heat losses.

4.2.2 .Design Specifications

Based on the choice of a domestic-size stove, and try and error the following parameters are selected for the design: Height of the combustion chamber, Lcc = 180 mm, Internal radius of combustion chamber, r_1 = 65 mm, Internal radius of mild steel casing r_2 = 105 mm, Internal radius of insulation lining, r_3 = 135 mm, External radius of mild steel casing, r_4 = 140 mm, Height of stove leg H_{SL} = 100 mm, Atmospheric external temperature of combustion chamber, To = 30^oC, Measured internal temperature of combustion chamber T_i = 300^0C, Thermal conductivity of fiber glass, $K_{insulation}$ = 0.039 W/mK, Thermal conductivity of mild steel, K mild steel = 39W/mK

4.2.2.1 Calculation of Combustion Air Require

The reaction of fossil fuels such as, coal or natural gas with oxygen liberates heat and the heat is used for various purposes. The main combustion products of burning of fuels are carbon dioxide and water. Combustion is the reaction of a fuel substance with air or pure oxygen to form combustion products. The combustion process is always exothermic and it liberates heat. The combustion reaction may be written as:

Fuel + O_2 → products + Heat ………………………………………………………………… (4.1)

In solid fuel, carbon is the main combustible component which is combined with an equivalent amount of oxygen to form carbon dioxide. Carbon monoxide may also be formed for incomplete combustion, which is further reacted to form carbon dioxide. Hydrogen and sulphur are converts to H_2O vapour and S_2O respectively.

The various reactions observed in the combustion of coal are as follows:

$C + O_2 \rightarrow CO_2$ ………………………… (4.2)

$C + ½ O_2 \rightarrow CO$ ………………………… (4.3)

$H_2 + ½ O_2 \rightarrow H_2O$ ………………………… (4.4)

$S + O_2 \rightarrow SO_2$ ………………………… (4.5)

A definite amount of oxygen is required for the conversion of carbon to carbon dioxide. As per the stoichiometry of equation (1) to determine the amount of oxygen required and produced carbon dioxide from the above reaction.

12 kg of carbon + 32 kg of oxygen → 44 kg of carbon dioxide

1 kg of carbon + 32/12 kg of oxygen → 44 /12kg of carbon dioxide

So 1 kg of carbon requires 2.667 kg of oxygen, and similarly 1 kg of carbon requires 1.33 kg of oxygen from 28 kg of carbon monoxide.

1 kg of sulphur requires 1 kg of O_2. The theoretical air can be calculated for a particular coal if carbon, hydrogen, nitrogen, oxygen and sulfur contents in weight percent are known by ultimate analysis.

Typical mush valley coal has the following average ultimate values that obtained from the analysis of the above table 4.5 or figure 4.8 by mass as shown in the table below.

Element	C	H_2	O_2	N_2	S	Ash
Mass (%)	41.5	3.35	20	3.12	1.01	11.58

The theoretical combustion air is:

Oxygen required for burning of carbon, hydrogen and sulphur are as follows:

Basis: 1 kg coal burned:

Carbon: $C + O_2 \rightarrow CO_2$ ………………………… (4.6)

0.415kg of carbon + $\frac{32*0.415}{12}$ kg of oxygen → $\frac{44*0.415}{12}$ kg of carbon dioxide

Oxygen required = 1.11 kg O_2 / kg of coal

Carbon dioxide produced = 1.52 kg of CO_2/kg of coal

Hydrogen: $H_2 + ½ O_2 \rightarrow H_2O$ …………………………………………………………………….. (4.7)

2 kg of hydrogen + 16 kg of oxygen → 18 kg of water vapor

1 kg of hydrogen + 8 kg of oxygen → 9 kg of water vapor

Therefore, 0.0335 kg H_2 + 8* 0.0335 kg of oxygen → 9 *0.0335 kg of water vapor

Oxygen required = 0.268 kg O_2 /kg of O_2 – 0.2 kg of O_2 = 0.068 kg

Which means 1 kg of hydrogen consumes 8 kg of oxygen and 0.2 kg of oxygen is initially present in coal which should be subtracted from the total required oxygen)

Water produced = 0.302 kg H_2O/ kg of coal

Sulfur: $S + O_2 \rightarrow SO_2$ ………………………………………………………………………… (4.8)

0.0101 * 1 kg = 0.0101 kg of oxygen

Total oxygen required to accomplish the complete burning = (1.11+ 0.068 + 0.0101) kg

= 1.2 kg

In other way, oxygen or theoretical air may be approximately determined by the general equations as, shown.

Oxygen required per kg coal = 2.667 C + (H * 8- O) + S kg

= 2.667 * 0.415 + (0.0335 * 8 – 0.2) + 0.0101 = 1.2 kg

Air required per kg carbon = 4.32× (C × 2.667 + (H * 8- O) + S)

= 11.521 C + 34.56 H + 4.32(S-O) kg

= 11.521 * 0.415 + 34.56 * 0.0335 + 4.32 (0.0101 – 0.2) = 5.15 kg

Where C, H, O and S are weight on the basis of 1 kg fuel and the oxygen present in the fuel is subtracted from the required oxygen for burning of fuel as shown in the equation. In other words the required air can be found from mole balance, which is the ratio Oxygen to Nitrogen in the proportion of 21:79 or 1 mole of oxygen is accompanied by 3.762 mole of nitrogen. Total moles of air are equal to 4.762 moles. The molecular weight of air and oxygen are 29 and 32 respectively, since one kg of oxygen are equivalents to 4.762 * 29/32 = 4.3155 kg ~ 4.32 kg of air. Therefore, total amount air needed for the burning of above coal sample will be 1.2 × 4.32 = 5.14 kg, which is the theoretical air requirement.

The above result can be arranged in the following table given below; the ultimate composition of coal:

Table 4.6 Summarized ultimate composition of coal required and products

Elements	Mass fraction	Oxygen required (kg/kg of coal)	Product mass (kg/kg of coal)	
			H_2O	CO_2
C	0.415	1.11	-	1.52
O	0.2	-	-	-
H	0.0335	0.068	0.302	-
N	0.0312	-	-	-
Ash	0.1108	-	-	-
S	0.0101	0.0101	-	-
Total		1.19	0.302	1.52

In other words by using the approximate of air (mole basis):

0.21 O_2 +0.79 N_2 (Mole basis) ………………………………………..…………………………… (4.9)

0.21*32 = 6.72 g O_2

0.79*28 = 22.12 g N_2

N_2/O_2 mass ratio = 22.12/6.72 = 3.29

The approximate air mass fraction of oxygen = $\frac{6.72}{(6.72+22.12)}$ = 0.233 = 23.3%

The approximate air mass fraction of nitrogen = $\frac{22.12}{(6.72+22.12)}$ = 0.767 = 76.6%

Hence the stoichiometric air/fuel (A/F) ratio = $\frac{100}{23.3} * O_2$ required = = $\frac{100}{23.3}$ * 1.19 = 5.11: 1

Analysis of the product of combustion Nitrogen associated with this air to fuel ratio = 6.23 * 0.767 = 4.78, since air contains 76.7 % N2 by mass. Total nitrogen = 4.78 + 0.0312 = 4.81

Table 4.7 Analysis of the product of composition by mass

Products	Mass (kg)	% dry	% wet
CO_2	1.52	27.38	25.98
H_2O	0.302	-	5.16
N_2	4.03	72.62	68.88
Total wet = 5.85 Total dry = 6 – 0.302 = 5.55			

In a combustion process, the complete burning cannot be accomplished with the exact theoretical amount of air. Therefore it is essential to supply an excess amount of air for the combustion of fuel. For an actual air supply which is 20% in excess of stoichiometry, actual air/fuel ratio, is obtained from the relation:

$$\text{Percentage excess air} = \frac{\text{actual Air/Fuel ratio} - \text{stoichiometric A/F}}{\text{stoichiometric A/F}} \quad \ldots\ldots\ldots\ldots \text{(4.10)}$$

$(\text{Air /Fuel})_{\text{actual}}$ ratio = percentage excess air * stoichiometric Air/Fuel ratio + stoichiometric A/F

= 0.2 * 5.11 + 5.11

= 6.132

For complete combustion of 1 kg of coal, 6.132 kg of air are required, which is from actual air to fuel ratio, but the stoichiometric air to fuel ratio was 5.11 to 1.

4.2.2.2 Combustion Air Inlet Design

First determine the burning rate of fuel coal ($\dot{m}$) by using the following formula.

$$\dot{m} = \frac{100\,(Wi - Wf)}{(100 + M)\,t} \quad \ldots\ldots\ldots\ldots \text{(4.11)}$$

Where: W_i = 0.3, initial weight of fuel at start of test, kg;

W_f = 0.0345, final weight of fuel at end of test, kg;

M = 19, moisture content of fuel, %;

t = 1.5, total time taking for burning fuel, hr.

Substitute the value of the above parameters in to equation (4.1)

$$\dot{m} = \frac{100\,(0.3 - 0.0345)}{(100+19)\,1.5} = 0.16 \text{ kg/hr}$$

Then the actual air supply rate corresponding to the mass burning rate can also be expressed as,

$$\dot{M}_{air} = A/F_{actual} * \dot{m} = 6.132 * 0.16 = 0.98 \text{ kg/hr}$$

This value gives the volume flow rate of air supply, which is based on air density of 1.225 kg/m^3

$$\tilde{V}air = \frac{\dot{M}\,air}{\rho} = \frac{0.98 kg/hr}{1.225\ kg/m3} = 0.8\ m^3/hr$$

According to Parker et al. (1969), the area of air opening, air is related to the volume flow rate as:

$$\tilde{V}air = 23.6\ A_{air} * \sqrt{h}$$

For an air opening being rectangular in section with assuming vertical dimension, h = 40 mm

$$0.8\ m^3/hr = 23.6 * \sqrt{0.04} * A_{air}$$

$A_{air} = 1.696 * 10^{-3} m^2 = 1696\ mm^2$ which is an area of air opening.

Since the horizontal dimension L = 42.5 mm.

The appropriate inlet air opening area is important to control the amount of oxygen running the fire tank to the air vent. Oxygen is a very important when it comes to fire, but too much of it can cause the fire to burn through the fuel very quickly and you risk over firing the stove and too quickly burn the coal.

4.2.2.3 Chimney Design Calculation

The design of the chimney is basically for the appropriate diameter of the chimney. In practice, the following inequality is used for the determination of the diameter of the chimney, According to Parker et al. (1969).

$a_c \leq 10$ Air inlet area ……………………………………………………….……..…...(4.12)

Where ac = cross-sectional area of chimney.

Substituting for the area of side air opening in the inequality gives the diameter, dc, of the chimney as follows:

$$a_c \leq 10*1.696*10^{-3}\ m^2$$

$$a_c \leq 1.696*10^{-2}\ m^2$$

$$d_c \leq 0.067\ m$$

The importance of to calculate the area of chimney is to know the required space to vent the flue gas to rise out of the room, and which prevent toxic gases from backing up in to the room. Therefore in this design the cross-sectional diameter of the stove is 6.7 cm has been used.

4.2.2.4 Conduction Heat Loss through the Cylindrical Stove Wall

Heat transfer is the movement of heat energy from an object of higher temperature to one of lower temperature, while heat loss is the movement of heat from an object to its surroundings. The heat transferred into and out of an object depends not only on the conductivities, to and from the surface, but also on the conductivity within the object itself, dust or different layers and air at the surface of the material itself. Heat is transferred by conduction is a process by which heat is transferred from the hot area of a solid object to the cool area of the environment. Though in this cylindrical shaped coal stove was have heat loss through the cylindrical wall of the heating chamber.

The heat loss across the cylindrical wall of the heating chamber is expressed by Fourier's law:

$$\mathrm{Qr} = -\frac{\mathrm{KAdt}}{\mathrm{dr}} = \frac{\mathrm{KA\Delta T}}{\Delta r} \quad \text{(4.13)}$$

Where: K is the thermal conductivity of the cylinder material;

A is the area of the walls of the cylinder heating chamber across which heat transfer occurs; and

dT/dr is the radial temperature gradient across the walls.

ΔT – is the temperature difference b/n the internal and external temperature.

For a steady heat flow in which Qr is independent of r and T_i > To, the equation can be integrated and rearranged to become:

$$Q_r = \frac{\mathrm{Ti-T0}}{\frac{1}{2\pi \mathrm{rLk}}\ln(ro/ri)} \quad \text{(4.14)}$$

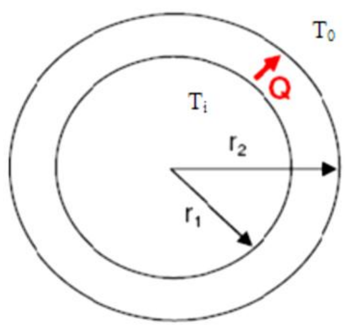
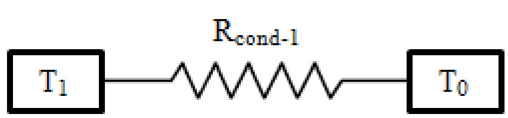


Figure 4.9 Cross-sectional view of the combustion chamber

The conduction resistance of figure (4.9) is for the cross-sectional view of the combustion chamber.



$$\mathrm{R} = \frac{\ln(r2/r1)}{2\pi * K_{\text{mild steel}} * L}$$

Where the subscribe i & o define inside and outside surface of the cylinder respectively.

$$Q_r = \frac{\mathrm{Ti-T0}}{\frac{1}{2\pi \mathrm{Lk}}\ln(ro/ri)} \quad \text{(4.15)}$$

Heat loss before insulating the combustion chamber of the stove could be calculated by using equation

(4.15) and the measured value of internal temperature of the combustion chamber (Ti = 300^0C) and external temperature of the combustion chamber (To = 100^0C) of the stove.

$$Q_r = \frac{\mathrm{Ti} - \mathrm{T0}}{\frac{1}{2\pi \mathrm{Lk}} \ln(r2/r1)} = \frac{(300-100\,)k}{\frac{1}{2\pi*0.18*39} \ln(105/65)} = 1838.5 \text{ W}$$

4.2.2.5 Insulation Thickness or Maximum Radius of Insulation

Insulation is material designed to prevent heat from being transmitted from one area to another. In general insulation means normally used to keep heat in or out of the system. Thermal insulation is a general term used to describe products that reduce heat loss or heat gain by providing a barrier between areas that are significantly different in temperature. Maximum /critical/ radius of insulation: - is a radius in which transfer of heat become minimum. To achieve it one of the mechanisms is to select material have low thermal conductivity, therefore, the most suitable insulating material is mineral wool like fiber glass whose thermal conductivity (k = 0.039) W/m.k.

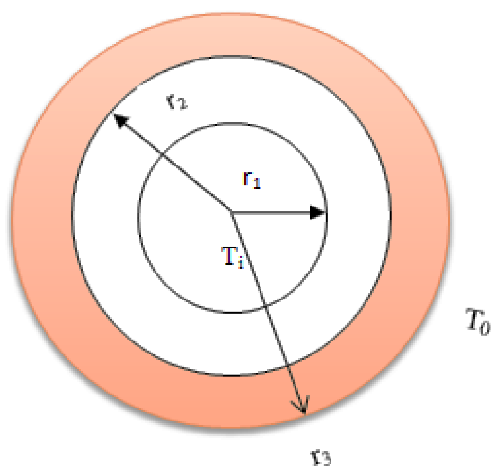
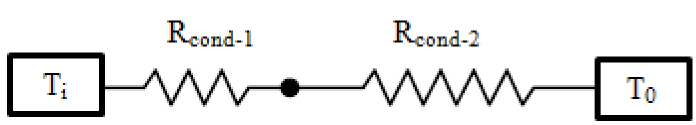


Figure 4.10 Cross-sectional view of cylindrical wall insulation thickness

And the conduction resistance of figure (4.10) is as follows



$$R = \frac{\ln(r2/r1)}{(2\pi * K_{\text{mild steel}} * L)} + \frac{\ln(r3/r2)}{(2\pi * K_{\text{insulation}} * L)}$$

For composite cylinder with *n* layers of different materials and known inside and outside surface temperature of the stove, equation (4.13) becomes:

$$Q_r = \frac{Ti - T0}{\frac{1}{2\pi L}\ \Sigma_{i=1}^{n}\ \frac{1}{ki}\ln\left(\frac{ri+1}{ri}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.16)$$

therefore based on equation (4.16) for two layers of different materials and known inside and outside surface temperature of the stove with the calculated value of heat loss, the required insulation thickness was calculated in the following way:

$$Q_{loss} = \frac{T_i - T_0}{\frac{\ln(r2/r1)}{(2\pi * K_{mild\ steel} * L)} + \frac{\ln(r3/r2)}{(2\pi * K_{insulation} * L)}}$$

$$18385W = \frac{(300 - 100)}{\frac{\ln(0.105/0.065)}{(2\pi * 39 * 0.18)} + \frac{\ln(r3/0.105)}{(2\pi * 0.39 * 0.18)}}$$

$$806 = \frac{200}{0.000476 + \ln\left(\frac{r3}{0.105}\right)}$$

$$0.247 = \ln\left(\frac{r3}{0.105}\right)$$

$$r_3 = 0.105 * e^{0.247} = 0.1354 \text{ m}$$

Since, insulation thickness = $r_3 - r_2 =$ 0.1354 – 0.105 = 30 mm

4.2.2.6 Conduction Heat Loss after Insulation

Finally let as compute conduction heat loss after insulating the composite cylindrical wall of the stove with radii r_1, r_2, r_3 and r_4, are shown in the figure below.

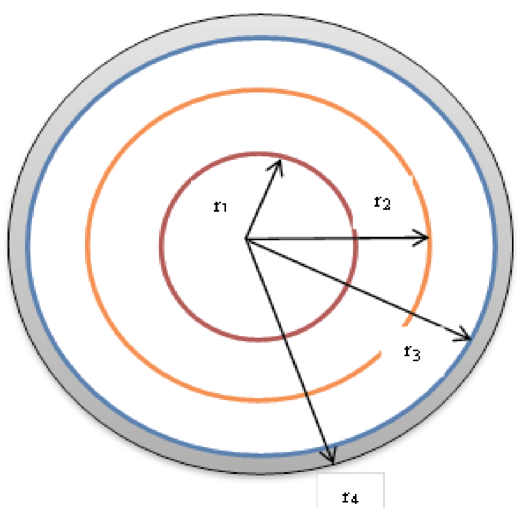
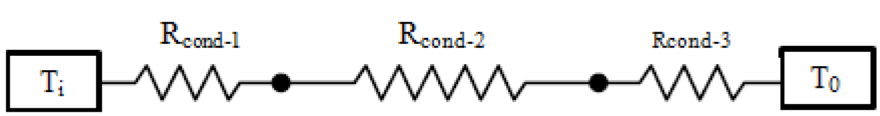


Figure 4.11 Cross-sectional view of composite cylinder



The cross- sectional view of composite cylinder was constructed from different materials; such as mild steel and insulating materials (fiber glass). The internal part of the cylinder is the combustion chamber (r_1), the first layer is internal mild steel casing (r_2), the second layer; insulating materials (r_3) and third layer was the external mild steel casing (r_4). The thickness of each layer and thermal conductivity of its material was defined in the previous section above. T_i is the internal temperature of the combustion chamber and T_0 also defined the outside temperature of the combustion chamber or the ambient air temperature.

The total resistance of the composite cylinder could be:

$$R_{tot} = R_{cond1} + R_{cond2} + R_{cond3}$$

$$\text{Rtot} = \frac{\ln(r2/r1)}{2\pi * K_{\text{mild steel}} * L} + \frac{\ln(r3/r2)}{2\pi * K_{\text{insulation}} * L} + \frac{\ln(r4/r3)}{2\pi * K_{\text{mild steel}} * L} \quad \text{.............................. (4.17)}$$

$$Q_r = \frac{\Delta T}{\text{Rtotal}} \quad \text{.. (4.18)}$$

Next substitute equation (4.17) and (4.13) in to equation (4.18), finally obtain the heat loss through the wall.

$$Q_r = \frac{T_i - T_0}{\frac{\ln(r2/r1)}{(2\pi * K_{mild\ steel} * L)} + \frac{\ln(r3/r2)}{(2\pi * K_{insulation} * L)} + \frac{\ln(r4/r3)}{(2\pi * K_{mild\ steel} * L)}} \quad \text{..................... (4.19)}$$

Then substitute the numerical value in to equation (4.6):

$$Q_r = \frac{(300 - 30)\text{k}}{\frac{\ln(105/65)}{2\pi*39*0.18} + \frac{\ln(135)/105)}{2\pi*0.039*0.18} + \frac{\ln(140/135)}{2\pi*39*0.18}} \qquad 8.36$$

$$Q_r = \underline{\underline{34.7 \text{ W}}}$$

Before insulated the combustion chamber, the amount of conduction heat loss through the cylindrical wall was 1838.5 W. However after insulated the chamber the loss by conduction is reduced to 34.7 W, thus the insulating material is effectively minimize the amount of heat loss.

4.3.3 Design Description of Coal Stove

The Combustion chamber: The combustion chamber is where coal is burnt and heat is generated. Their thicknesses are 2 mm and 180 mm height with internal radius of 65mm. The chamber consists of coal loading door, air-inlet hole and grate. The grate or fuel bed is at the base of the combustion chamber. The base of the stove consists of a door for loading fuel coal into the combustion chamber, and four openings which serve as combustion air inlets to the chamber.

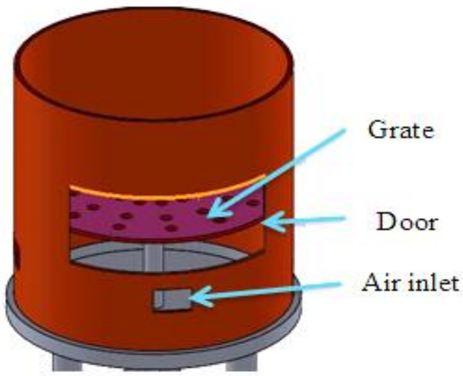


Figure 4.12 Combustion chamber parts

Grate***:*** The grate is a metal for holding coal. It is made from metal sheet of 2 mm thick. Sufficient holes were drilled on the plate for easy air and ash passage. The grate was supported by one steel rods welded to the plate, the rod is used to support and can move up and down with the grate why because to optimize the appropriate distance of the flue and the pot seat or to minimize heat loss due to large gap.

Figure 4.13 Grate with movable rod support

Chimney pipes: it was fabricated from metal sheet of 2 mm in thickness; it is a hollow pipe of 70 mm in diameter. A metal cap is necessary to attached at the top of chimney to prevent dust from blowing into chimney pipe. The chimney is incorporated at the periphery of the top of the stove to convey smoke and other by-products of combustion out of the kitchen.

Door: it is designed precisely, in order to control the amount of air going into the fire and also the body of the stove gets hot and eventually radiates heat into the room. And it is important for coal load in to the combustion chamber.

Stove top (pot seat): The stove top is circular in shape and it mounted at the top of the combustion chamber, the smoking ring should be attaché through it, to prevent smoke pass through the joints of the combustion chamber and the seats. The distance between the fuel bed and the pot seat is also selected to allow for enough time for the complete combustion of the burning fuel particles before it strikes the base of the pot mounted on the pot seat. All components of the stove were designed separately and finally assemble each part carefully to form a full shape of coal burning stove as follows.

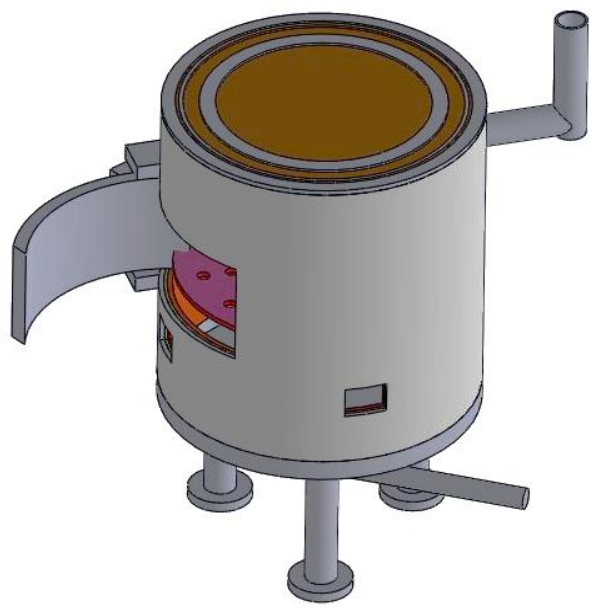


Figure 4.14 Final image of the stove

Figure 4.14 shows the whole parts of the designed stove, such as the door is opened, the air inlet holes, the chimney, grates inside the combustion chamber, the top parts of the stove, smoking ring, legs, and other parts of the stove are clearly seen in the above figure 4.14.

4.3.4 Stove Testing and Data Analysis

The designed and constructed coal stove was set in the test where a number of tests have been carried out on it. And check the stove performance and compare with the biomass stove that was given from the literature. Therefore water boiling test (WBT) was carried out in order to generate the data required for assessing the stove's performance.

4.3.4.1 Stove Performance

The test conducted on the coal stove is water boiling test; the tests were conducted with the measure of the fuel consumed and time required for cooking. The investigation operates under different operating conditions to check the expected stove performance. Finally the data obtained were used to compute the thermal efficiency of the stove.

To solve the performance of the constructed stove, the unknown parameters values are required, such as Specific heat of water = 4.186 KJ/kg K, Latent heat of vaporization of water at atmospheric pressure and 100^0C = 2256KJ/kg, coal burning rates = 0.16 kg/hr and average calorific value of coal = 4117kcal/kg (17,250 kj/kg) found from the proximate analysis of mush valley coal.

Figure 4.15 Experimental set up for water boiling test

4.3.4.1.1 Thermal Efficiency, PHU, SFC and Fire Power of the Stove

Based on the data obtained in table 4.8 and from appendix B table B1- B4, could be calculate the efficiency of the manufactured stove, which means the thermal efficiency of a stove depends mostly on how well the heat generated is transferred from the fuel to the pot, Olorunsola (1999). In order to obtain maximum heat transfer, the fuel-bed-to-pot distance or the combustion chamber distance should be appropriate for efficient ignition as well as reducing heat loss; it means kept as close as possible to minimize heat losses. The appropriate formula employed in the calculation for thermal efficiency, percent heat utilized, specific fuel consumption and fire power based on the approach used Olorunsola (1999) and Bolaji & Olalusi, (2009), was shown in chapter three equation 3.9 -3.12 and the experimental value was in appendix- B. The calculated value of the specific fuel consumption, PHU, fire power and thermal efficiency was recorded in table 4.8 below.

Table 4.8 Final summery of the result obtained from water boiling tests

Test No.	1	2	3	4
Initial mass of coal, kg	1.5	1.5	1.5	1.5
Final mass of coal, kg	0.735	0.745	0.725	0.735
Mass of coal burnt, kg	0.765	0.755	0.775	0.765
Mass of pot, kg	0.255	0.255	0.255	0.255
Initial mass of pot with water, kg	1.255	1.255	1.255	1.255
Initial mass of water , kg	1	1	1	1
Final mass of pot with water , kg	1.105	1.085	1.115	1.095
Final mass of water, kg	0.85	0.83	0.86	0.84
Mass of water evaporated, kg	0.15	0.17	0.14	0.16
Tame taken to boil, minute	23	21	24	22
Fire power, KW	9.5	10.2	9.3	9.9
Percent heat utilized, %	49.8	50.9	45.8	49.2
Specific consumption	0.765	0.755	0.775	0.765
Thermal efficiency, %	58.7	60	55.5	59

To maximize heat transfer rate to the pot needs properly sized gaps. Getting heat into pots or griddles is best done with small channels. The hot flue gases from the fire are forced through these narrow channels, or gaps, where it is forced to scrape against the pot or griddle. If the gap is too large the hot flue gases mostly stay in the middle of the channel and do not pass their heat to the desired cooking surface. If the gaps are too small, the draft diminishes, causing the fire to be cooler, the emissions to go up, and less heat to enter the pot. To solve such kind of problem the grate possibly move up and down instead of attached on the combustion chamber, until the fire stays hot and vigorous the gap could be 180 mm, while after hot it the gap reduce to 100 mm.

Water boiling test was used to measure the overall performance of the stove. Four tests were conducted on the constructed stove mainly to evaluate the thermal efficiency. The four recorded tests were conducted at different times of the day. The two tests that were conducted in the morning at the time of 9:00 AM – 9:24 AM, and 11:00 AM-11:23 AM, generally took longer times before water started to boiling, which are 24 and 23 minutes respectively (see experimental result test -3 and test-1 respectively on figure 4.16). The duration resulted from the fact that air was calm mostly in the morning and the flow was by natural convection. As a result the thermal efficiency was 55.5 % and 58.7 % respectively, are shown in table 4.14, which was relatively small as compared with test-2&4. The remaining two tests conducted in the afternoon, which has thermal efficiency of 59 % and 60 % were shown in table 4.8, relatively high in performance and take less time shown in figure 4.16.

The results show that the constructed coal stove has a maximum thermal efficiency of 60% and minimum 55.5 %, fire power delivery of 9.3- 10.2 kW, percent heat utilized 45.8-50.9 % and specific fuel consumption of 0.765. This indicates a better performance when compared to the average thermal efficiency value of 17.9% for traditional mud stove as reported by (George, 1997) and the average thermal efficiency value of 14 % for three-stone-fire as described by (zube,2010).

The constructed stove performance was also better when compared to the Improved Vented Mud stove (IVM) which has the average thermal efficiency values across fuels that varies from 10% to 23% which is comparable reported by Pal et al. (1989). However the thermal efficiency of the constructed stove was not highly efficient because the mush valley coal quality was found in low grade coal.

Even if the coal grade was low, but there is performance improvement due to a number of factors. The first is the insulation provided round the combustion chamber.

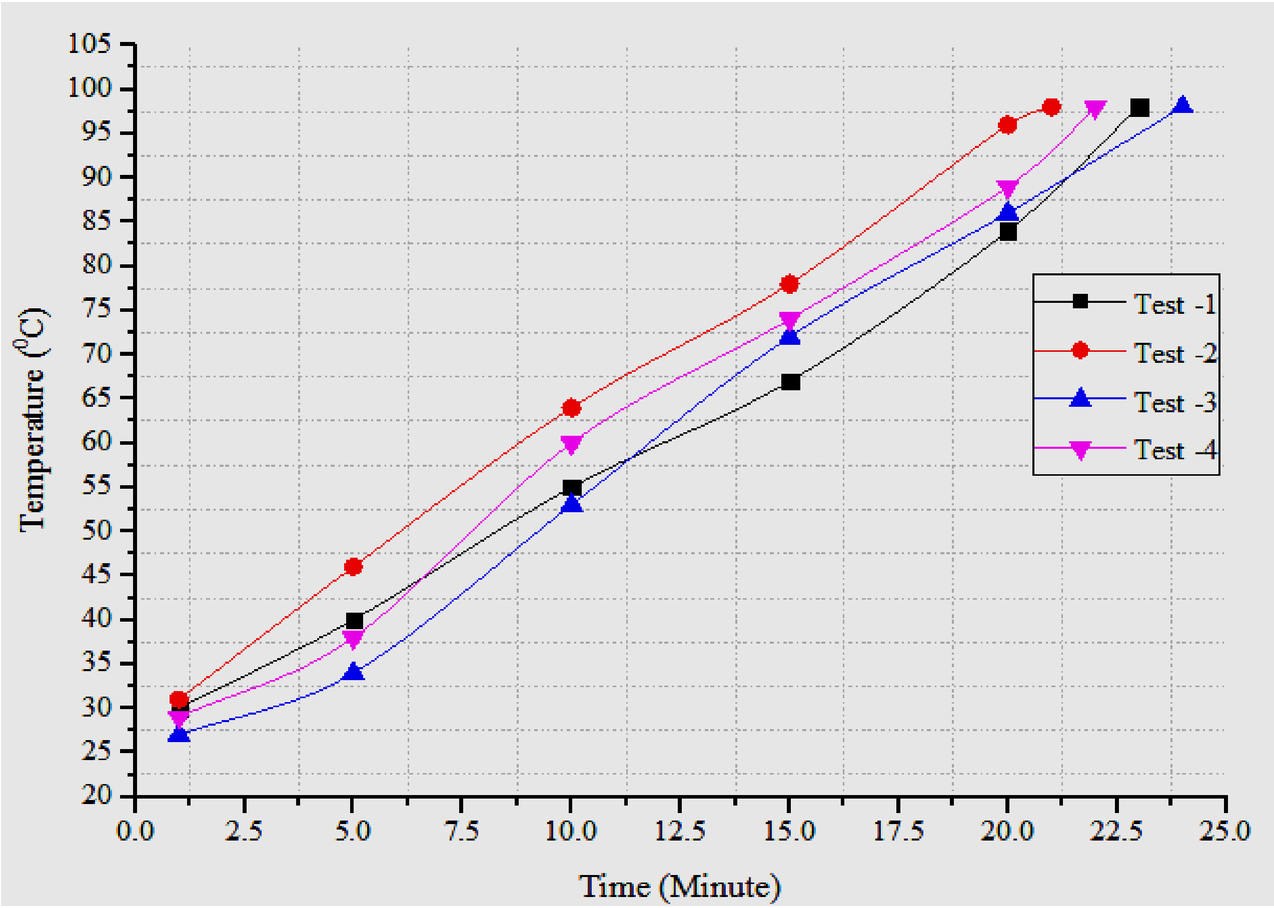


Figure 4.16 Rate of temperature rise of water using constructed coal stove with change in temperature

This minimizes the rate of heat loss across the wall of the combustion chamber by conduction and ensures that a good proportion of heat is conserved within the chamber and directed towards the top of the chamber. As we have seen from figure 4.16 all tests have taken almost the same time elapsed to boil one liter of water or there no that much time difference between each tests.

The amount of coal burnt to boiled one liter of water for each sample had no big difference, that the recorded data shown on table 4.8. The general decision for the tests was at any time that we can cook in the day time, because the amount of fuel consumption and the elapsed time were almost similar, but not seen in the night condition.

5. CONCLUSIONS AND RECOMMENDATION

5.1. CONCLUSIONS

Major part of the population in Ethiopia depends on biomass fuels (round woods, Leafs, Branches and charcoals) are used for three-stone–fire for cooking and heating. The result of burning of biomass fuels in the traditional and ineffective cook-stoves has an undesirable impact on the health of household participants, due to indoor pollution and mostly can affect the environment as a cause of high rate of deforestation. To minimize the rate of deforestation, alternative source of energy should be seen to substitute and supplement the biomass energy. For such situation coal could be one of the substitutes of the domestic biomass energy source as house hold function. Consequently, in this study the characteristic of mush valley coal and its burning stove was designed, fabricated and was tested the thermal performance of the stove to compare with the existing three-stone fires.

Proximate and ultimate analyses were performed for 10 coal samples originating from a Mush valley area. It could be conclude from the proximate analysis value, the collected coal samples for the study was shows that the deposits coal, moisture content ranges from (16.5 - 21.2%), volatile matter (22.3 – 38.1 %), ash content (3.2-24.5 %) and calorific value (3620 – 4876 kcal/kg). The grindability index of majority of the coal samples has the range (45-58.8), which HGI values of the Mush valley coal samples indicate that most of the samples can be characterized as lignite; it is very difficult to grind as well. This characterization is in accordance with coal ranking using the Parr approximate formula of moist mineral matter free basis as the criteria. The result shows the Mush valley coal is fall under the rank of lignite A to sub-bituminous B groups. It means the coal has low quality and low heating value as compared with bituminous and anthracite coal.

The ultimate analysis result of the coal has the average value of Sulphur 1.1 %, Hydrogen 3.35 %, Nitrogen 3.12 %, Carbon 41.5 % and Oxygen 20 %. From the result obtained the amount of sulfur is relatively small, which will have low sulfur emission to the environment, but the amount of hydrogen, nitrogen and oxygen are high, which increases the impurity of coal as a result the quality of the coal is reduced. The coals are expected to give rise to some amount of harmful pollutants during burning, because the presences of volatile matter of the coals were very high.

The main things to be considered to design coal stove are cost of manufacturing stove as much as possible locally available material to minimize the price of stove, ease of manufactured & ensuring maintenance, also the thermal efficiency of the stove should be careful.

The design part of stove focused on, the insulation around the combustion chamber to minimize conduction heat loss through the cylindrical stove wall, the required insulation thickness was used 30 mm. Another focused part in the design of stove were air inlet to ensure the accessibility of sufficient air for the complete combustion of the fuel coal, and the integration of chimney to convey flue gases away from the place of use or to remove indoor pollution the stove chimney should be stretched out of the house through the house wall until pass the top of the roof.

To maximize heat transfer to the pot was required properly sized gaps. Getting heat into pots or griddles is best done with small channels. If the gap is too large the hot flue gases mostly stay in the middle of the channel and do not pass their heat to the desired cooking surface, while the gaps are too small, the draft diminishes, causing the fire to be cooler, the emissions to go up, and less heat to enter the pot. To solve such kind of problem the grate possibly move up and down instead of attached on the combustion chamber, until the fire stays hot and vigorous the gap could be 180 mm, while after hot it the gap reduce to 100 mm.

The performance evaluation shows that average fuel firepower of 9.7 KW, average specific fuel consumption of 0.765, an average percent heat utilized of 49 % and thermal efficiency of 58.3%. The results of coal stove showed a better performance than traditional three stove fires.

5.2. RECOMMENDATIONS

It is a well-known fact that there are some levels of imperfections associated with constructing stove parts, everything was made by man. So there is always opportunity for improvement of the stove and characterization of coal. Further investigations are recommended to understand the performance and to explore for household application of the coal and stove.

- ✓ In this research work the characteristic of mush valley coal was carried out to determine the proximate analysis values, like moisture content, ash content, volatile matter, fixed carbon, gridability of coal and ultimate analysis was studied. But there is a possibility to see the wash ability of coal to minimize the ash content and amount of sulfur content in the coal and reduce pollution factors.
- ✓ It needs more research work on the quantity of environmental pollutants released during burning of coal in the stove and the way how to reduce such pollutants.
- ✓ The coal samples are better to collected by experienced coal geologists directly from freshly exposed seam faces are more recommended, because they know more how to take the sample in advance and can check the deviated results from these results.
- ✓ It needs further investigation on the air ventilation system of the stove, instead of using atmospheric pressure can use forced pressure, like compressor to inject air through air inlet holes to facilitate and efficiently combust the coal inside the combustion chamber.
- ✓ In addition to cooking and heating application, one face of the stove can cover by highly thermal resistance and light transparent glass to use as a source of light for the house, which reduces the amount of cost, discharged for lighting purpose, to achieve it require detailed research work.
- ✓ The top parts of the stove or the pot seat was made from clay which has relatively low thermal conductivity, in its place can substitute by high thermal conductive materials to improve the thermal performance of the stove.
- ✓ In this study the stove performance was done, water boiling test were used to obtain the necessary data for performance test, to boil it the coal should be start to ignite as quickly as possible, but it is difficult to ignite easily, hence it needs further investigation on impregnating material to burn simply.

REFERENCE

Agency, I. E., Review, B. P. S., Energy, W., Global, T., Production, C., States, M. U., … Poland, M. (2015). Coal Facts 2015, 44(0), 4–5.

Ahmed, W. (2008). Fossil Fuel Energy Resources Of Ethiopia. Bulletin Of The Chemical Society Of Ethiopia, 22(1), 67–84.

Ash, C., Using, C., Temperature, H., Furnace, T., Methods, C., & Analysis, U. (2013). Ultimate Analysis Of Coal And Coke 1, 89(Reapproved 2002), 3178–3180.

Bolaji, O. B., & Olalusi, A. (2009). Development Of An Improved Coal Stove For Cooking In. Au J.T, 12(3), 182–187.

Chelgani, B. S. & S. C. (2016). Modeling Of Fine Coal Flotation Separation Based On Particle Characteristics And Hydrodynamic Conditions. International Journal Of Coal Science & Technology, 3(4), 429–439. Https://Doi.Org/10.1007/S40789-016-0147-9

Contribution, M. S., & Civilization, T. O. (1981). Introduction To Mining 1 (1) 1–24.

Damte, A., & Koch, S. F. (2011). Coping With Fuel Wood Scarcity : Household Responses In Rural Ethiopia Coping With Fuel Wood Scarcity : Household Responses In Rural Ethiopia, (November).

Demoze, E. A. (2007). Utilization Of Coal In Metal Industries (Case Of Akaki Metal Products Factory) School OfGraduate Studies Environmental Engineering Program Utilization Of Coal In Metal Industries 3(4), 29– 35

Dobrogorskii, N. (1981). Quality Of Coal Ash And Its Utilization. Vichta Shkola, Kiev (Russia) 24 (3), 46–57.

Dreier, J., Högger, P., & Sorg, C. (1998). Laboratory Methods. Dna And Cell Biology, 17(1709), 321–323. Https://Doi.Org/10.1089/Dna.1998.17.321

Ethiopian Economics Association. (2007). Report On The Ethiopian Development, Prospects Economy Energy Sector And Challenges Of The Energy Sector In Ethiopia (Vol. Vii). Retrieved From Http://Www.Eeaecon.Org/Sites/Default/Files/Publications/Report On The Ethiopian Economy_Volume Vii_2007_08_Development Prospects And Challenges Of The Energy Sector In Ethiopia_0.Pdf

F., T. (2008). Contribution To Determination Of Coal Grindability Using Hardgrove Method. Geo. Science Engineering, 1, Pp, 27–32.

Geissler, S., Hagauer, D., Horst, A., Krause, M., & Sutcliffe, P. (2013). Biomass Energy Strategy: Ethiopia. Energy For Development3(4), 45– 89.

George, R. T & E. R. (Teri). (1997). Commercialization Of Technology For Domestic Cooking Applications In Biomass Energy Systems. (Venkata Ra). New Delhi, India 86(5), 105– 205 .

Gravalos, I., Xyradakis, P., Kateris, D., & Gialamas, T. (2016). An Experimental Determination Of Gross Calorific Value Of Different Agroforestry Species And Bio-Based Industry Residues, 8 (3) 57–68.

Kavšek, D., Bednárová, A., Biro, M., Kranvogl, R., Vončina, D. B., & Beinrohr, E. (2013). Characterization Of Slovenian Coal And Estimation Of Coal Heating Value Based On Proximate Analysis Using Regression And Artificial Neural Networks. Central European Journal Of Chemistry, 11(9), 1481–1491. Https://Doi.Org/10.2478/S11532-013-0280-X

Kler, V., Volkova, G., Gurvich, E., Dvornikov, A., Jarov, Y., Kler, D., Nenahova, V., Saprikin, F., Shpirt, M. (1987). Metallogeny And Geochemistry Of Coal And Shale Bearing Stratum In Ussr: Geochemistry Of Elements. Nauka (P. 240). Moscow.

Kłosowiak, R., Bartoszewicz, J., & Urbaniak, R. (2005). Characteristics Of Coal Fluidised Bed, 9 (45) 4–5.

Li, Z., Ward, C.R., Gurba, L. W. (2010). (2010). Occurrence Of Non Mineral Inorganic Elements In Macerals Of Low-Rank Coals. International Journal Of Coal Geology 81, 242–250.

Logan, S. D., & Wickstrom, L. (2008). State Of Ohio. Early Childhood Education, 45 (8) 20–21.

Matin, S. S., & Chelgani, S. C. (2016). Estimation Of Coal Gross Calorific Value Based On Various Analyses By Random Forest Method. Fuel, 177, 274–278. Https://Doi.Org/10.1016/J.Fuel.2016.03.031

Mesroghli, S., Jorjani, E., & Chelgani, S. C. (2009). International Journal Of Coal Geology Estimation Of Gross Calori Fi C Value Based On Coal Analysis Using Regression And Arti Fi Cial Neural Networks. International Journal Of Coal Geology, 79(1–2), 49–54. Https://Doi.Org/10.1016/J.Coal.2009.04.002

Miller, B. G., & Tillman, D. A. (2008). Coal Characteristics. Combustion Engineering Issues For Solid Fuel Systems, (October), 33–81. Https://Doi.Org/10.1016/B978-0-12-373611-6.00002-1

Neavel, R. C., Hippo, H. J., Smith, S. E., & Miller, R. N. (1980). Coal Characterization Research: Sample Selection, Preparation, And Analyses. Acs Division Of Fuel Chemistry, Preprints, 25(3), 246–257.

Norbert Berkowitz's (Professor Of Fuel Science At The University Of Alberta). (1979). An Introduction To Coal Technology (Energy Science And Engineering: Resources, Technology, Management, An International Series; Light Fading, Light Edge Wear To Exterior). London: Academic Press 28(3), 245–259.

Osborne, D. G., & Gupta, S. K. (2013). 1 - Industrial Uses Of Coal. The Coal Handbook: Towards CleanerProduction.WoodheadPublishingLimited(Vol.1) 45- 58. Https://Doi.Org/Http://Dx.Doi.Org/10.1533/9780857097309.1.3

Pal, R.C.; And Joshi, V. (1989). Improved Cook Stoves For Household Energy Management - A Case Study., 53–59.

Radovic, L. R. (1997). Chapter 7 Rest Of World. Energy And Fuels In Society: Analysis Of Bills And Media Reports, (1), 114–136.

Rattanakawin, C., & Tara, W. (2012). Characteristics Of Mae Moh Lignite : Hardgrove Grindability Index And Approximate Work Index, 34(1), 103–107.

Schweinfurth, S. P. (2009). An Introduction To Coal Quality. The National Coal Resource Assessment Overview: Professional Paper 1625-F, 16. Https://Doi.Org/10.1111/J.1749-6632.2010.05890.X

Song, D. (2010). Coal Burning And Its Effect On The Environment,6 (3) 1–9.

Stach, E., Mackowsky, M.-T., Teichmüller, M., Taylor, G. H., Chandra, D., & Teichmüller, R. (1982). Stach's Textbook Of Coal Petrology. Book, 545-535.

Taylor, P., Street, M., Wt, L., Chelgani, S. C., Hart, B., Grady, W. C., & Hower, J. C. (2011). Access Details : Access Details : [Subscription Number 932653925] International Journal Of Coal Preparation And Utilization Study Relationship Between Inorganic And Organic Coal Analysis With Gross Calorific Value By Multiple Regression And Anfis, (932653925).

Https://Doi.Org/10.1080/19392699.2010.527876

Thompson, C., Scott, G., Neal, J., & Baca, J. (2011). Design And Engineering Of A Cleaner Burning Cook Stove For India. Journal Of Usability Studies, 1(1), 27–45. Retrieved From Http://Citeseerx.Ist.Psu.Edu/Viewdoc/Summary?Doi=10.1.1.102.6218

Vassilev, S. V, Vassileva, C. G., Baxter, D., & Andersen, L. K. (2010). Relationships Between Chemical And Mineral Composition Of Coal And Their Potential Applications As Genetic Indicators . Part 1 . Chemical Characteristics, (4), 21–41.

Verma, A K., Singh, T. N., & Monjezi, M. (2010). Intelligent Prediction Of Heating Value Of Coal, (April), 8 (45) 32–38.

Williams, E., Keith, L. (1963). Relationship Between Sulphur In Coals And The Occurrence Of Marine Roof Beds. Economic Geologiy 58, 720–723.

Wolela, A. (2007). Fossil Fuel Energy Resources Of Ethiopia: Coal Deposits. International Journal Of Coal Geology, 72(3–4), 293–314. Https://Doi.Org/10.1016/J.Coal.2007.02.006

Yi, L., Feng, J., Qin, Y. H., & Li, W. Y. (2017). Prediction Of Elemental Composition Of Coal Using Proximate Analysis. Fuel, 193, 315–321. Https://Doi.Org/10.1016/J.Fuel.2016.12.044

Zha, Z., Ma, L., Li, K., Ding, X., & Xiao, S. (2017). Comparative Study Of Mining Methods For Reserves Beneath End Slope In Flat Surface Mines With Ultra-Thick Coal Seams. International Journal Of Mining Science And Technology. Https://Doi.Org/10.1016/J.Ijmst.2017.10.002

APPENDICES

Appendix A: proximate Analysis Experimental Results

$$\% \text{ V.M} = \frac{Y-Z}{Y-X} * 10$$

Where X = Weight of crucible in grams, Y = Weight of coal + crucible in grams (before in heating)

Z = Weight of coal + crucible in grams (after in heating)

Table A-1 Experimental results of volatile matter of Mush valley coal

Sample No	X	Y	Z	Volatile mater (%
01	24.287	25.288	25.0645	22.35
02	24.287	25.287	24.964	32.66
03	24.287	25.289	24.972	31.72
04	24.287	25.287	24.933	35.4
05	24.287	25.288	24.979	30.9
06	24.287	25.287	24. 996	29.1
07	24.287	25.290	24.963	32.7
08	24.287	25.288	24.92	36.8
09	24.287	25.292	24.953	33.95
10	24.287	25.288	25.017	27.1
Duplicate – 01	24.287	25.288	25.0655	22.25
Duplicate – 02	24.287	25.287	24.964	32.34
Duplicate – 03	24.287	25.289	24.98	31.88
Duplicate – 04	24.287	25.287	24.935	35.2
Duplicate – 05	24.287	25.288	24.959	32.9
Duplicate – 06	24.287	25.287	24.966	32.1
Duplicate – 07	24.287	25.290	24.971	31.9
Duplicate – 08	24.287	25.288	24.894	39.4
Duplicate – 09	24.287	25.292	24.976	31.65
Duplicate – 010	24.287	25.288	25.043	24.5

The experimental results of the ash content that obtained from the analysis could be calculated as.

$$\% \text{ Ash} = \frac{Z-X}{Y-X} * 100$$

Where L = Weight of crucible in grams

M = Weight of coal + crucible in grams (before in heating)

N = Weight of coal + crucible in grams (after in heating)

Table A -2 Ash content experimental result of mush valley coal

Sample No	L	M	N	Ash (%
01	33.235	34.235	33.474	23.9
02	31.341	32.349	31.453	11.2
03	31.878	32.878	31.913	3.5
04	30.878	31.939	30.959	8.1
05	31.562	32.565	31.712	15
06	33.235	34.235	33.333	9.8
07	31.341	32.342	31.408	6.7
08	31.878	32.88	31.912	3.4
09	30.878	31.878	30.961	8.3
10	31.562	32.562	31.771	20.9
Duplicate – 01	33.235	34.235	33.486	25.1
Duplicate – 02	31.341	32.349	31.457	11.6
Duplicate – 03	31.878	32.878	31.909	3.1
Duplicate – 04	30.878	31.939	30.931	5.3
Duplicate – 05	31.562	32.565	31.698	13.6
Duplicate – 06	33.235	34.235	33.339	10.4
Duplicate – 07	31.341	32.342	31.422	8.1
Duplicate – 08	31.878	32.88	31.908	3.0
Duplicate – 09	30.878	31.878	30.949	7.1
Duplicate – 010	31.562	32.562	31.797	23.5

To determine the moisture content use the same procedure as volatile matter in the above table A-1. Use the same formula for each sample analysis

Table A- 3 Experimental value of moisture content in percent

Sample No	Moisture content (at 100 + 5^0c) in %
01	21.02
02	16.72
03	21.0
04	16.94
05	18.7
06	21.10
07	20.9
08	16.65
09	19.2
10	18.46
Duplicate – 01	20.20
Duplicate – 02	16.42
Duplicate – 03	21.2
Duplicate – 04	17.0
Duplicate – 05	18.64
Duplicate – 06	21.15
Duplicate – 07	21.1
Duplicate – 08	16.35
Duplicate – 09	19.42
Duplicate – 010	18.54

Appendix B: Data analysis For Stove Test

Amount of coal used for the test

Initial mass of coal = 1.5 kg

Final mass of coal = 0.735 kg

Mass of coal burnt M_c = (1.5 – 0.735) = 0.765 kg

Weight of water and pots

Mass of pot = 0.255 kg

Initial mass of pot with water = 1.255 kg

Initial mass of water, M_w = (1.255 – 0.255) kg = 1kg

Final mass of pot with water = 1.105kg

Final mass of water, M_f = (1.105 – 0.255) kg = 0.85 kg

Mass of water evaporated M_v = (1 – 0.85) kg = 0.15 kg.

Table B-1 Data obtained in water boiling test-1

Time (minute)	Temperature (^oC)
11:00 AM	30
11:05 AM	40
11:10 AM	55
11:15 AM	67
11:20 AM	84
11:23 AM	98

The amount of times taken for boiled was 23 minutes which is found from the above table 4.1.

The firepower for test – 1 is calculated as:

$$P = \left[\frac{0.765 \text{ kg} * 17{,}250 \text{ kj/kg}}{60 * 23}\right] = 9.5 \text{ Kj/s}$$

P = 9.5 KW

The percent heat utilized PHU is calculated by:

$$\text{PHU} = \left[\frac{4.186\text{kj/kg.K} * 1\text{kg}\ (98-30)+2256\ \text{kj/kg}(1\text{kg}-\ 0.85\text{kg})}{0.765\text{kg} * 17{,}250\ \text{kj/kg}}\right] * 100\%$$

= 49.8%

Specific fuel consumption is the amount of coal consumed or burnt out by the stove for each unit of power output. The specific fuel consumption was calculated as given:

$$\text{SFC} = \left[\frac{0.765\text{kg}}{1\text{kg}}\right] = 0.765$$

Table B-2 Data obtained for water boiling test-2

Mass of coal and water before and after boiling	Amount in (kg)	Time (minute)	Temperature (^{o}C)
Initial mass of coal	1.5	3:15 AM	31
Final mass of coal	0.745	3:20 AM	46
Mass of coal burnt	0.755	3:25 AM	64
Initial mass of water	1	3:30 AM	78
Final mass of water	0.83	3:35 AM	96
Mass of water evaporated	0.17	3:36AM	98

Time taken to boil 1 liter of water in stove test number -2, was 21 minutes, from table 4.11.

The calculated value of the specific fuel consumption, PHU, fire power and thermal efficiency was in recorded in table 4.14.

Table B-3 Data obtained for water boiling test-3

Mass of coal and water before and after boiling	Amount in (kg)	Time (minute)	Temperature (^{o}C)
Initial mass of coal	1.5	9:00 PM	27
Final mass of coal	0.725	9:05 PM	34
Mass of coal burnt	0.775	9:10 PM	53
Initial mass of water	1	9:15 PM	72
Final mass of water	0.86	9:20 PM	86
Mass of water evaporated	0.14	9:24 PM	99

Time taken to boil 1L of water for test- 3, was 24 minutes as shown in table 4.12.

The calculated value of the specific fuel consumption, PHU, fire power and thermal efficiency was in recorded in table 4.14.

Table B- 4 Data obtained for water boiling test-4

Mass of coal and water before and after boiling	Amount in (kg)	Time (minute)	Temperature (^oC)
Initial mass of coal	1.5	5:10 PM	29
Final mass of coal	0.735	5:15 PM	38
Mass of coal burnt	0.765	5:20 PM	60
Initial mass of water	1	5:25 PM	74
Final mass of water	0.84	5:30 PM	89
Mass of water evaporated	0.16	5:32 PM	98

Time taken to boil 1L of water for taste- 4, was given 22 minutes, from table 4.13.

Appendix C: Stove production cost

Table C: stove production cost

No.	Item	Price (Birr)
1	Metal sheet	150
2	Stove leg or support	80
3	Grate	50
4	Welding	100
5	Paint	90
6	Clay	150
7	Fiber glass	120
8	Mild steel	200
Total		940

Appendix-D: Laboratory raw materials and equipment used for the analysis

Figure D_1: Coal deposited in mush valley area

Figure D_2: Exploited coal sample at the field

Figure D_3: Jaw crusher

Figure D_4: crusher

Figure D_5: Sieve analyzer

Figure D_6: prepared sample in plastic bag

Figure D_7: Moisture analyzer.

Figure D_8: Desiccator.

Figure D_9: Furnace for volatility and ash analysis

Figure D_{10}: insulating material (fiber glass)

Appendix E: Designed Stove parts and its assembling process

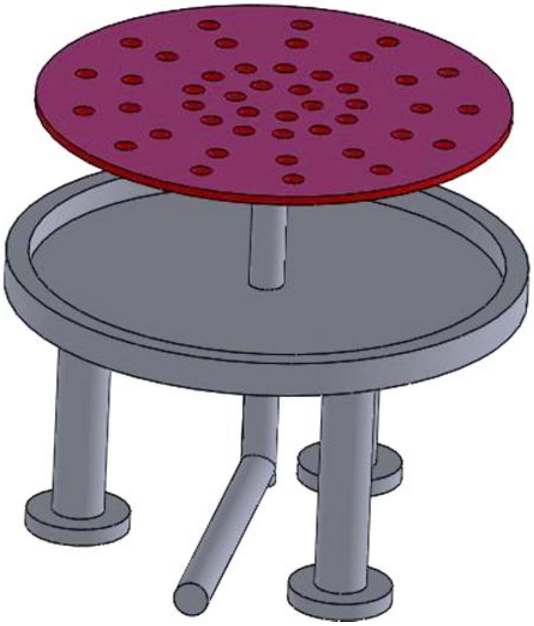


Figure E_1: Grate with its movable road

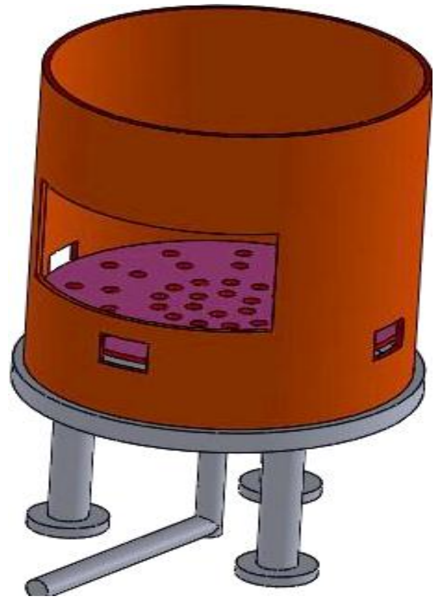


Figure $E_{2:}$ Combustion chamber around grate

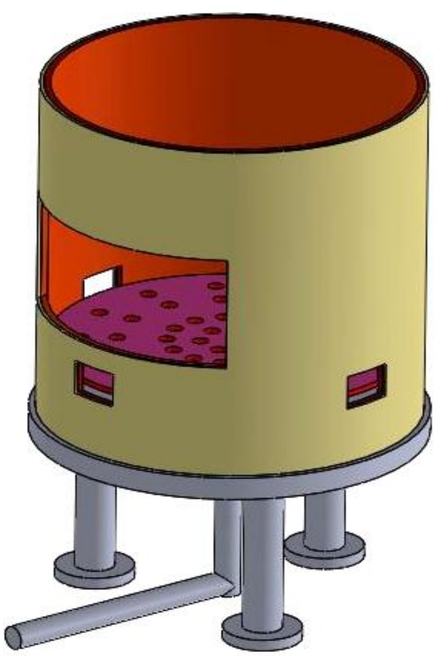


Figure $E_{3:}$ Cover insulator over combustion chamber

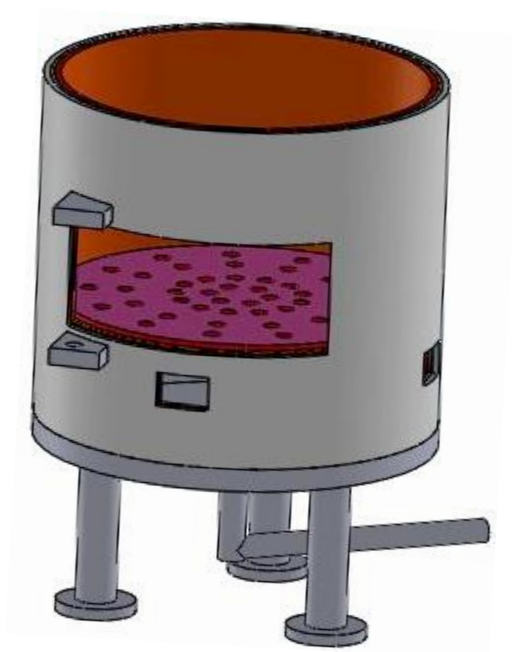


Figure E_4: External mild steel casing

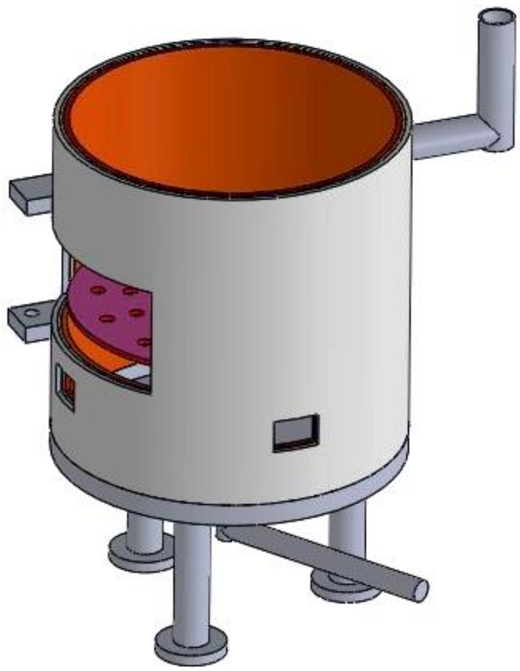


Figure E_5: Assembled stove chimney

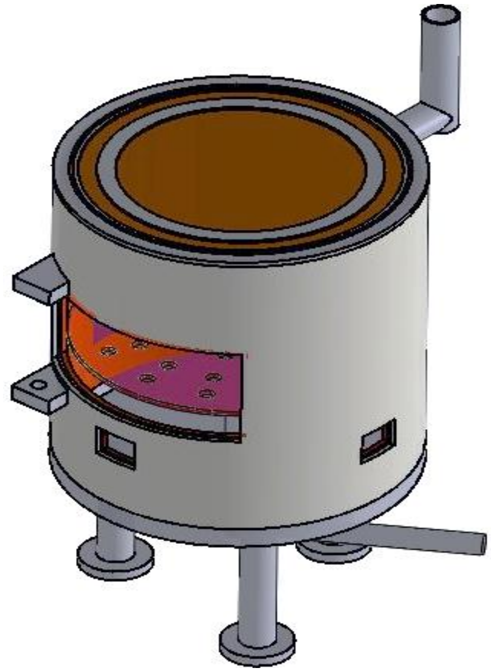


Figure $E_{6:}$ Constructed stove top

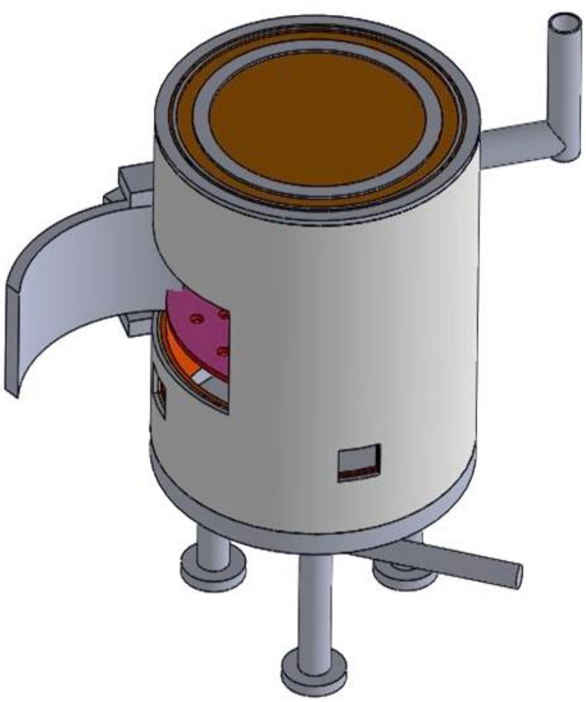


Figure $E_{7:}$ Assembled stove door

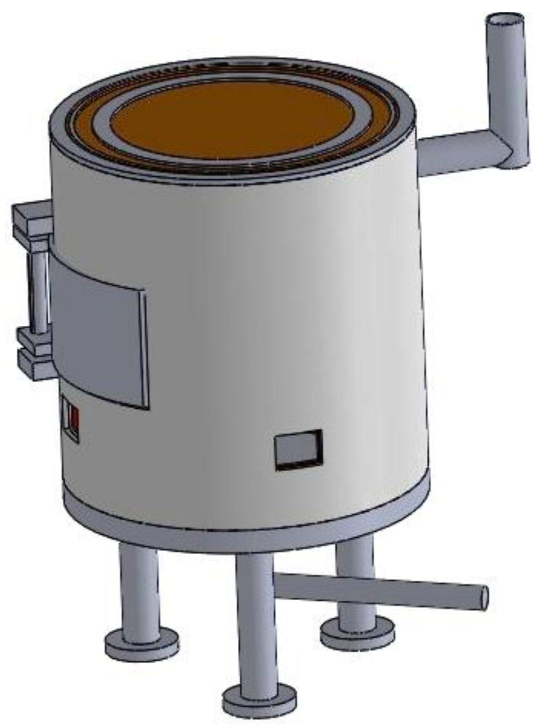


Figure $E_{8:}$ Final shape of stove

Appendix F: Constructed stove and its performance testing

Figure $F_{1:}$ Constructed stove at open door

Figure $F_{2:}$ Stove with closed door and its chimney

Figure $F_{3:}$ Water boiling test