STUDY OF THE EFFECT OF MOISTURE CONTENT OF BIOMASS FUEL IN THE PERFORMANCE OF DIFFERENT TYPE OF COOKING STOVES

A THESIS SUBMITTED TO THE DEPARTMENT OF “MECHANICAL ENGINEERING” IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

Submitted by

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Mirpur Cantonment, Dhaka

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STUDENT DECLARATION

This is to certify that the thesis entitled, **"STUDY OF THE EFFECT OF MOISTURE CONTENT OF BIOMASS FUEL IN THE PERFORMANCE OF DIFFERENT TYPE OF COOKING STOVES"** is an outcome of the investigation carried out by the author under the supervision of, **Dr. A.K.M. SADRUL ISLAM,** former Professor and Head Mechanical Engineering Department**,** BUET. This thesis or any part of it has not been submitted to elsewhere for the award of any other degree or diploma or other similar title or prize.

SUBMITTED BY

Shahriar Shah	Nayeem Imtiaz	Asrar Bin Islam
Student No. 201418026	Student NO. 201418042	Student No. 201418056

SUPERVISOR CERTIFICATION

This is to certify that **SHAHRIAR SHAH**, Student no: 201418026; **NAYEEM IMTIAZ**, Student no: 201418042; **ASRAR BIN ISLAM**, Student no: 201418056 have completed their undergraduate thesis report on **"STUDY OF THE EFFECT OF MOISTURE CONTENT OF BIOMASS FUEL IN THE PERFORMANCE OF DIFFERENT TYPE OF COOKING STOVES"** under my supervision. To the best of my knowledge, the report is their original work and was not submitted elsewhere for other purpose.

I wish their ever success in life.

APPROVED BY

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Dr. A.K.M. SADRUL ISLAM,

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Dhaka.

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ABSTRACT

Current attention to improved cook stoves (ICS) focuses on the "triple benefits" they provide, in improved health and time savings for households, in preservation of forests and associated ecosystem services, and in reducing emissions that contribute to global climate change. Despite the claimed economic benefits of such technologies, however, progress in achieving large-scale adoption and use has been remarkably slow. This paper shows a simulation analysis to evaluate the claim that households will always reap positive and large benefits from the use of such technologies. Our analysis allows for better understanding of the variability and benefits of ICS use in developing countries. This paper is an attempt to address such a need and endeavors to improve on the technological development of cook stoves. In our experimental program comparing the performance of a household traditional cook stove in Bangladesh with an improved cook stove, showed that the thermal efficiency is almost doubled which has been evaluated in this paper. The effect of moisture content of biomass fuel on the performance of both type-cooking stoves was also included in the evaluation.

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NOMENCLATURE

$\boldsymbol{m_w} = \ initial\ weight\ of\ water\ (Kg)$

$\boldsymbol{C_p} = \ \ specific\ heat\ of\ water\ constant\ pressure\ (= 4.186\ KJ/Kg$°C)

$\Delta\boldsymbol{T} = \ \ temperature\ difference\ of\ watre\ before\ and\ after\ heating$ (°C)

$\boldsymbol{m_{we}} = weight\ of\ watre\ evaporated$ (Kg)

$\boldsymbol{L_w} = latent\ heat\ of\ evaporation\ for\ water$ (= 2260 KJ/Kg)

$\boldsymbol{m_f} = weight\ of\ wood\ fuel\ burnt$ (Kg)

$\boldsymbol{H_f} = higher\ heating\ value\ of\ wood\ fuel$ (= 35000 KJ/Kg)

$\boldsymbol{m_k} = weight\ of\ kerosene\ burnt\ (Kg)$

$\boldsymbol{h_k} = higher\ heating\ value\ of\ kerosene$ (KJ/Kg)

$\boldsymbol{W_w}$ = *wet weight of wood*

$\boldsymbol{W_0}$= *oven-dry weight of wood*

ABBREVIATION

ICS= Improved Cook Stove

MC= Moisture Content

Chapter One:

Introduction

1.1 General Overview

In Bangladesh, biomass fuel is the most widely used fuel for domestic cooking. About majority of the population in Bangladesh depends on biomass fuels and other sources to obtain favorable heating condition and for cooking.

It estimated that about 94 percent of the energy to meet household cooking needs comes from biomass sources. There are about 50million households in Bangladesh. The rural household are the majority ones among them. At present, an estimated 500,000 improved cook stoves are functioning nationwide in Bangladesh.

The greatest barrier for economic growth in Bangladesh is the energy shortage. Nonetheless government of Bangladesh has speculated to supply electricity to all by 2021.According to the data obtained through Government statistics the gap between electricity supply and demand is about 500-800MW. People having access to electricity output are around 49%. **[1]**

Food is important for survival of human being. Cooking of food material requires thermal energy and such energy in developed countries is meeting through electricity. Underdeveloped or developing nations such as our country Bangladesh are still striving for constant supply of electricity. Biomass such as firewood, charcoal, coke etc. is the primary energy source to meet the domestic thermal energy requirement in developing nations. The biomass is available everywhere and can be burnt directly in the cook stove. It is inexpensive than other fuels and considered as a renewable source of energy. There are numbers of initiative has taken by many government agencies to promote the energy efficient biomass cook stove to improve the fuel efficiency.

Cooking is obligatory work that has performed by human for millenniums since the inception of civilization. This work requires an extensive amount of fuels every day in the entire world. Therefore, even if a little bit of efficiency is increased an incredible amount of output energy can achieve globally and in in our country Bangladesh and this is the main target of this thesis.

1.2 Background of the study

Among the various technologies introduced in the realm of efficient household heating and cooking methods, stoves are the most popular and widespread in both urban and rural communities. Most developing countries and underdeveloped countries still are not capable enough to produce power required to meet the demand of its population in this 21^{st} century. It also hampers these countries industrial sectors. Bangladesh is not an exception in this case. Even in Bangladesh 51% of our population are deprived of electricity. So particularly in rural areas this stoves with well-calculated and experimented moisture content and calorific value of the biomass fuel comes handy.

Especially in developing countries, stoves occupy a central place in the health, environmental, economic and social domains of life. By improving the efficiency of wood burning stoves, the amount of toxic smoke produced can be reduced and health risks to the family be minimized. In view of these and other concerns, a good cooking stove is defined as one that meets technical, scientific and safety standards, and has high combustion quality, technical efficiency, minimal smoke emission, ergonomics and structural stability. Most sources cite the fuel-efficiency of traditional stoves as five to ten percent, which is not enough.

Since about 1.5 billion people in the world use traditional stoves for cooking (and heating), efforts to improve the efficiency of cook stoves have been increasingly popular in the developing world. So why should our country Bangladesh be an exception. Improved stoves come in different forms and sizes. Improved Cook Stoves (ICS) can be designed and built in various ways, depending on the local conditions. At their simplest, ICS provide an enclosure for the fire to reduce the loss of radiant heat and protect it against the wind. In addition, attention can be given to methods of controlling moisture content and evaluating calorific value to increase the transfer of heat to the cooking pot. Many of these stoves are made of mud or sand since both are almost free and readily available.

1.3 Objectives of thesis

The main objectives of this thesis include:

1. To study the effect of moisture content of biomass fuel on the efficiency of stoves.
2. To study different types of biomass fuel.
3. To compare between traditional cooking stoves and improved cooking stoves.
4. To observe variation of outputs of the aforesaid factors.
5. To come to a decision about which fuels suits better among the used ones and comment on any modifications can be done for further improvement.

1.4 Biomass fuel and its position in Bangladesh

Bangladesh is an agro-based country and about 90% of her population lives around villages. Frequently available fuels are biomass energy. Only a small portion of the total biomass produced by photosynthesis process is used as fuel. Commonly used biomass fuels in Bangladesh are fuel wood, agricultural residues and animal dung.

Biomass fuels accounts for 68% of the total energy consumption of the country. The remaining 32% is being made by common fuels such as natural gas, oil, electricity & coal. The biomass fuel wood, contributes 41% of the natural figure, while non-wood biomass contributes only 26.97%. **[2]**

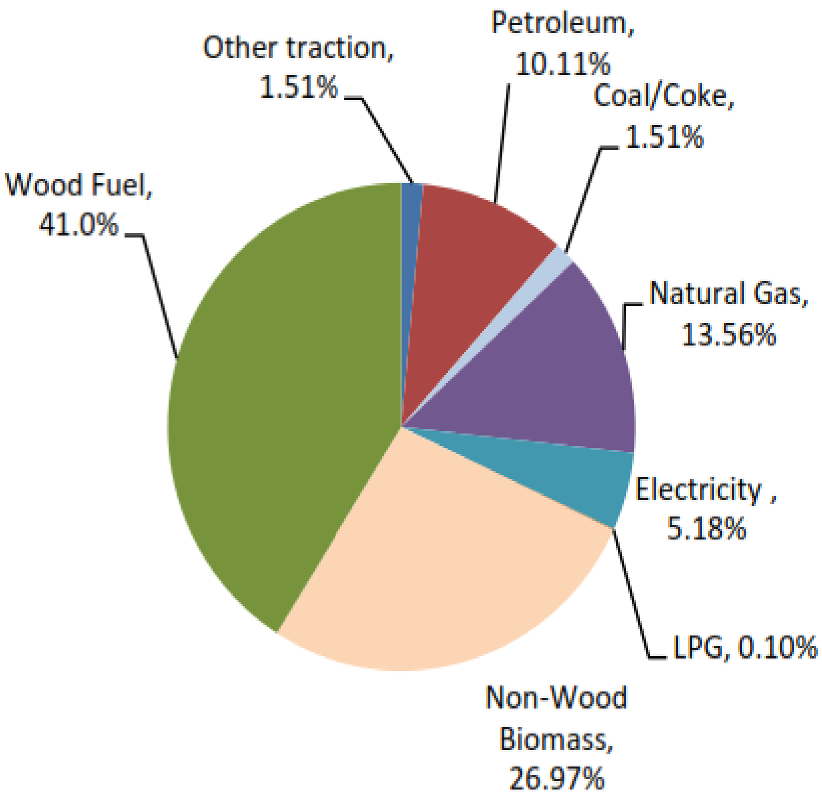

Figure 1.1: Energy consumption by sources (planning commission of Bangladesh) 2002 [2]

Domestic sectors consume 60.4% of the total energy showing that a big of the energy is used for cooking and other heating purposes. Industries take part in 21.5% of total natural energy consumption. [3]

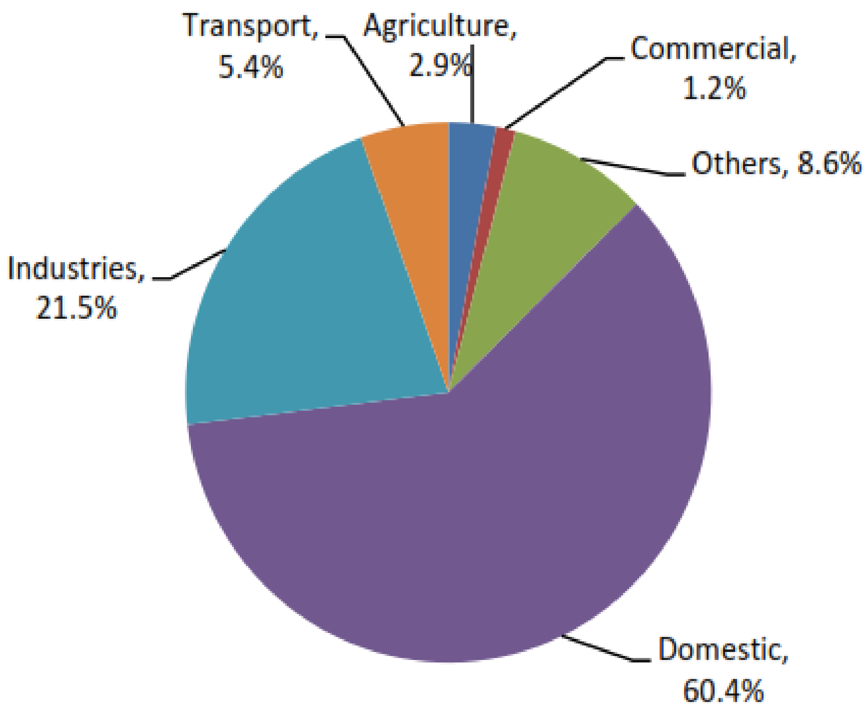

Figure 1.2: Energy consumption by sectors (planning commission of Bangladesh) 2002 [3]

Fuel wood is most important rural energy source, accounting for some 44% of the total energy consumption. Including leaves and twigs, the share of the tree-based biomass is nearly 60% of the total household energy. Kerosene is used primarily for lighting. A small number of households in the country are supplied with natural gas. As a result, most of the people use fuel wood for cooking and other heating purposes. Some 44 million tons of biomass fuels are being consumed annually, which constitute 68% of total energy consumption of the country. [4]

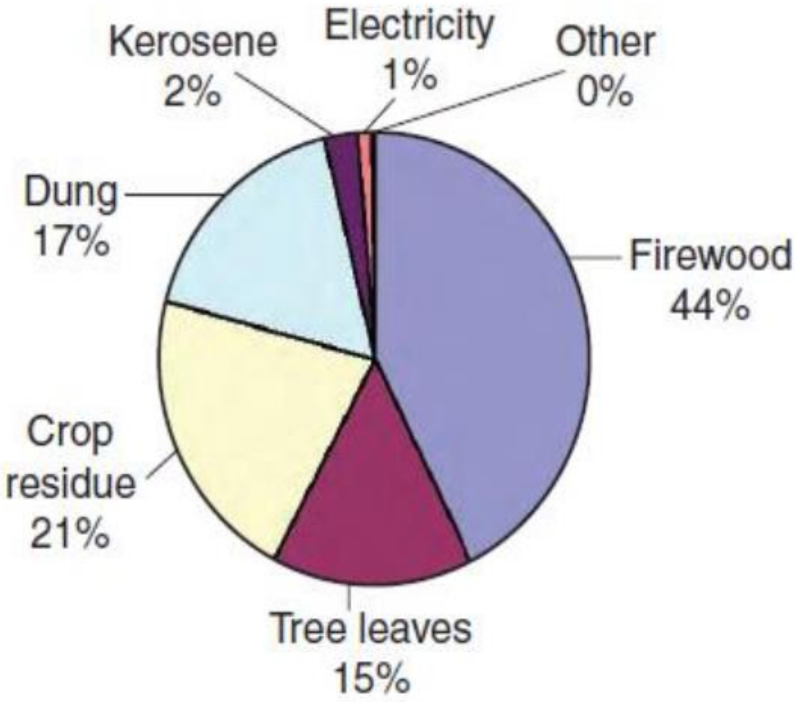

Figure 1.3: Rural Household Energy Consumption by sources (%energy consumption) [5]

The traditional appliances commonly used for cooking and other heating purposes across the country are called "Chullas" which generally use fuel wood, agricultural residues, cow dung cake etc. as fuel. Traditionally used stoves in Bangladesh are usually mud built cylinder with three raised points on which cooking materials rest. One space in between three raised points is used as fuel porting port and the other two for the flue gas exit. However, the performance of these mud built stoves are a long way from being improved. It is because they emit a lot of black smokes and there is substantial loss of heat while heating. Improved Cook Stoves or ICS are those traditional stoves which has been modified so that a better thermal efficiency can be obtained and to reduce the emission of pollutants in the environment. In a simpler way to make eco-friendly and efficient stoves the idea of Improved Cook Stoves or ICS has been made.

1.5 Outline of the thesis

This study deals with comparative energy analysis of some cooking stoves used on the basis of water boiling test by using 3 types of biomass fuel on varying moisture content. They are Jackfruit, Mango and Rain tree. Suitable biomass fuels have been collected from local market. The data from experimental analysis has been collected for different types of fuel on varying moisture content and evaluated for the cooking stoves models in the study.

Chapter Two:

Literature Review

2.1 Biomass

Biomass refers to the biological material derived from living, or recently living organisms. In the context of biomass for energy the term is often used to mean plant based material, but can also apply to both animal and vegetable derived material.

Biomass is a key building block of biofuels – it can be specially grown for electricity production or to produce heat in the energy context, as an alternative to fossil fuels.

Biomass is composed largely of carbon, hydrogen and oxygen. Nitrogen and small quantities of other atoms, including alkali, alkaline earth and heavy metals can also be found. Biomass is the building block or 'feedstock' for many other fuels.

The key difference between biomass and alternatives like fossil fuels is the difference between the times it takes to replenish the source of each. Biomass takes carbon out of the atmosphere while it is growing, and returns it as it is burned. If it is managed on a sustainable basis, biomass is harvested as part of a constantly replenished crop. Either this is during woodland or agricultural management or as part of a continuous programmed of replanting with the new growth taking up CO2 from the atmosphere at the same time as it is released by combustion of the previous harvest.

In contrast, when a fossil fuel is burnt the CO2 in the atmosphere increases as it takes hundreds of millions of years for the fossil fuel source to be replenished

Alternatively, it often refers to plants or plant derived materials which are specifically called lignocellulose biomass. It is most abundantly available raw material on the earth for production of bio-fuels, mainly bio-ethanol. It is composed of carbohydrate polymers (cellulose, hemicellulose), and an aromatic polymer (lignin). As energy source, biomass can be used either directly by combustion to produce heat or indirectly after converting it into various forms of biomass fuels.

Biomass is one of the most plentiful and well-utilized sources of renewable energy in the world. Broadly speaking, it is organic material produced by the photosynthesis of light. The chemical material (organic compounds of carbons) is stored and can then be used to generate energy. The most common biomass used for energy is wood from trees. Wood has been used by humans for producing energy for heating and cooking for a very long time.

Biomass has been converted by partial-pyrolysis to charcoal for thousands of years. Charcoal, in turn has been used for forging metals and for light industry for millennia. Both wood and charcoal formed part of the backbone of the early Industrial Revolution prior to the discovery of coal for energy.

Wood is still used extensively for energy in both household situations, and in industry, particularly in the timber, paper and pulp and other forestry-related industries. Woody biomass accounts for over 10% of the primary energy consumed in Austria, and it accounts for much more of the primary energy consumed in most of the developing world, primarily for cooking and space heating.

It is used to raise steam, which, in turn, is used as a by-product to generate electricity. Considerable research and development work is currently underway to develop stoves that would produce greater efficiency. For the moment, however, biomass is used for off-grid electricity generation, but almost exclusively on a large industrial-scale.

2.2 How biomass energy works

To many people, the most familiar forms of renewable energy are the wind and the sun. But biomass (plant material and animal waste) is the oldest source of renewable energy, used since our ancestors learned the secret of fire.

Biomass is a renewable energy source not only because the energy in it comes from the sun, but also because biomass can re-grow over a relatively short period of time compared with the hundreds of millions of years that it took for fossil fuels to form. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates—complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burned, they turn back into carbon dioxide and water and release the energy they captured from the sun.

Several recent studies show little to no economic potential to increase bio power in the Bangladesh over the next two decades because of its relatively high costs compared with other renewable energy and low carbon technologies. Other studies of nearly decarbonizing the power sector by mid-century show that more efficient, advanced bio power technologies using low carbon feedstock's, such as agricultural residues and energy crops, could provide a modest contribution of up to 15 percent of electricity generation in developing countries.

But like all our energy sources, bio power has environmental risks that need to be mitigated. If not managed and monitored carefully, biomass for energy can be harvested at unsustainable rates, damage ecosystems, produce harmful air pollution, consume large amounts of water, and produce net global warming emissions.

Assessing the potential role of bio power as a climate solution requires a look at its lifecycle carbon emissions, which vary according to the type of feedstock, the manner in which it is developed and harvested, and the scale at which it is used and the technology used to convert biomass into electricity. The lifecycle carbon emissions of bio power should also be compared to the fossil fuels it's displacing and other zero and low carbon solutions it's competing with.

The most obvious form of biomass energy production is wood burning. In this, wood pellets, chips or logs are burned in stoves or biomass boilers to create warmth in a single room or to power central heating and hot water systems. This process can be used on a small-scale level in individual homes, or on a much larger scale in businesses and bigger buildings.

Biomass energy is also created in waste-to-energy plants. Here, waste organic matter that would otherwise end up in landfill (food waste for example) is burned on a large scale to produce steam. This steam rises, which spins turbines to create electricity.

While this usually takes place in specialist plants, some manufacturing businesses burn their own waste materials to create energy that contributes to their power needs.

Another form of biomass energy is biogas. When organic waste such as manure, sewage waste and agricultural waste breaks down it creates a mixture of methane gas and carbon dioxide. This is called anaerobic digestion.

Anaerobic methane digesters trap large amounts of this waste at high temperatures with reduced oxygen to speed up the breakdown process. This creates the gases more quickly than natural decomposition.

The clever technology then traps the resulting gas, which can then be used for the same purposes as natural gas: heating, cooking and so on. Some vehicles even use the gas as an alternative fuel.

Biomass energy is renewable because we have a boundless capacity to grow plants, and in turn, we will always produce biomass waste with those plants. Collectively, biomass energy lessens our dependency on foreign oil, strengthens our economy both locally and nationally, reduces harmful greenhouse emissions, and will hopefully contribute to the phasing out of fossil fuels altogether someday.

2.3 Biomass energy resources

Biomass energy can be harnessed in many ways. Out of several sources, only the noted few are discussed below:

2.3.1 Wood burning

It is probably the most used and most common biomass energy sources. Since the advent of fire thousands of years ago, we've been using wood to keep us warm, cook food, and more recently, produce electricity.

In fact, wood was the main source of energy across the planet until fossil fuels took over in the mid-1800s.

Today, we still use wood for heating and cooking (especially in developing countries such as Bangladesh), but most of it is for industrial purposes.

Wood can be burned for electricity production by using the heat to create steam for spinning turbines. Some manufacturing plants even burn their own wood waste (paper, wood scrap, wood chips, sawdust, and bark) to contribute to power needs.

Figure 2.1: Wood burning

2.3.2 Waste-to-Energy Plants

Garbage and waste from landfills can be used as an energy source. About half of the waste in our landfills contains organic biomass matter that can be converted to energy. This content is sometimes called biogenic matter. All biogenic matter contains potential energy.

Paper, grass clipping, cardboard, wood, and food scraps are all good examples of biomass energy sources.

We create an incredible amount of waste. In fact, it’s estimated that an average American produces about 5 pounds of waste every single day. This all adds up quickly in our landfills if the waste isn’t properly managed.

There are a few things we can do with this waste. One option is to just simply burn it in solid waste incinerators and be left with compacted ash which takes up less space.

A better alternative is to put the waste to good use in a Waste-to-Energy Plant. These plants can make use of heat energy by burning waste to produce steam which spins turbines to generate electricity.

Currently, waste-to-energy plants provide about 15 million kilowatt-hours. This is enough electricity to power around 1.5 million homes.

Not only can we reduce waste in our landfills, but we can also use it for our own energy needs. Waste-to-Energy plants still cost more than other standard electricity production methods, but as technology continues to improve this will not be as much of an issue. In addition, one could argue the benefits of cleaning up our landfills makes it worthwhile, not to mention further reducing our need for fossil fuels.

2.3.3 Biogas Production

Another source of energy that comes from landfills is biogas. Other sources of biogas include manure, sewage waste, industrial waste, and agricultural waste.

Biogas comes from microorganisms that digest (break down) organic waste which becomes a mixture of methane gas and carbon dioxide. This is called anaerobic digestion.

On farms and sewage treatment plants, manure and human waste is a good source of biogas. An anaerobic methane digester traps large amounts of waste with limited oxygen and high temperature to induce bacteria into breaking it down – or digesting it. Obviously, the inherent odor can become an issue if the digester is too close to a residential community.

Biogas contains a much lower percentage of methane than standard natural gas. To reach standards necessary for practical use, biogas has to be upgraded.

Depending on the use, methane levels are increased and carbon dioxide levels are decreased before it can be used. Certain things, like boilers, don’t require high quality biogas. On the other hand, when used as a fuel source biogas quality must reach a much higher standard.

Essentially, it is a renewable natural gas which can be substituted for the more common natural gas found deep within the earth. It can be used for any purpose that already uses natural gas such as heating, cooking, lighting, steam production, electrical production, and can even be used as an alternative fuel in natural gas vehicles.

2.3.4 Biofuel Production

Biofuels such as ethanol and biodiesel can be used as clean fuel sources for vehicles of every sort.

They are usually blended with standard fuels as “green” supplement, but they can also be used on their own in specialized vehicles.

2.3.4.1 Biodiesel Fuel

Biodiesel is made from organic materials such as animal fat, recycled grease, and vegetable oil. It’s renewable, nontoxic, biodegradable, clean, and safe.

Biodiesel is made by separating biomass into fatty acid methyl esters (FAME) and glycerin. The methyl esters are what make up the biodiesel. The glycerin is a byproduct that can be used in cosmetics, pharmaceuticals, soaps, and food additives.

Most of the biodiesel production source comes from businesses that already use animal fats or vegetable oils in their product.

An appealing aspect of biodiesel is that it’s compatible with most diesel engines. It can be blended with regular diesel in any amounts with no modifications needed to the engine.

Specific labels are used to indicate the ratio of biodiesel used. For example, B20 contains 20% biodiesel and 80% petroleum diesel. B100 contains 100% biodiesel.

B100 can be used with some newer engines (1994 and newer) although there are some drawbacks. The higher the amount of biodiesel, the more likely it is to freeze in colder temperatures since it has a higher freezing point than petroleum. The freezing point depends on the source product used. For example, canola oil has a much lower freezing point than tallow (animal oil).

Nitrogen oxide emissions are higher in biodiesel, but many more harmful emissions are avoided. It can be harder on rubber engine components, and you can expect gas mileage to be about 8% lower. Only engines that use the highest quality biodiesel and are specifically equipped to handle these limitations should use B100.

B20 is the by far the most popular biodiesel mixture and can overcome most of the limitations of the B100. It can withstand cold weather, and is much easier on certain engine components.

Obviously, the higher the blend, the better it will be for the environment and public health. It is also less combustible and safer if there is ever any kind of spill.

2.3.4.2 Ethanol Fuel

Ethanol, also known as grain alcohol, is a liquid fuel made from energy crops such as corn and sugarcane. When these crops undergo yeast fermentation, they release ethanol. It can then be used as a transportation fuel source for automobiles.
The very first automobiles ran on ethanol. In fact, Henry Ford even claimed it to be “the fuel of the future”. Eventually gasoline took over the market because of its superior fuel efficiency (ethanol is 34% less energy efficient than gasoline) and cheap production costs.

Most of the cars in the US are capable of running on a blend of ethanol, usually up to 10%. More than half of all gas stations now add ethanol. In some states, it's even required by law to have ethanol added to gasoline. Recently, more flex-fuel cars are coming into the market. Flex-fuel cars are capable of running on E85 fuel (85% ethanol, 15% gasoline), gasoline by itself, or a combination of the two.

The most common crop used for ethanol production in the US is corn. In Brazil (the second largest ethanol producer), sugarcane is the crop of choice.

It doesn't necessarily matter what the source crop is, the ethanol will always be the same and of the same quality. The main factors in determining which crop to use are availability and cost. Certain crops grow more readily in different parts of the world.

Much research is going into finding alternative sources of ethanol and ways to grow these crops faster and cheaper. The quality of the crops isn't as much of a concern since they aren't used for food.

Other ethanol crops include potatoes, sorghum, sawgrass, and barley. Also, certain cellulosic feedstock like wood, grass, newspaper, crop residues, and nonedible portions of plants can be used. These cellulosic crops are more difficult to produce ethanol from since they must first break down into simple sugars before they can be fermented.

There are many benefits of using ethanol fuel. It reduces our dependence on foreign oil (ethanol is produced domestically) and reduces harmful greenhouse gas emissions. It strengthens the agricultural industry, and creates renewable energy jobs.

Ethanol is biodegradable, so if there's ever a large spill it will pose little threat to the environment or public health. Also, the price of ethanol is always decreasing because of technological improvements in production and greater consumer demand for cleaner fuels.

Figure 2.2: Extracting ethanol fuel from corn [6]

2.4 Environmental and health Impact of Biomass Energy

When biomass is burned, it releases the same amount of carbon dioxide as fossil fuels. So why is biomass considered to be a clean energy? It's because of a natural process called the carbon cycle.

The carbon dioxide emissions from biomass can be offset whenever new plants are grown. Through photosynthesis, plants absorb roughly the same amount of CO_2 as is given off through the burning of them. This results in a healthy and natural balance in CO_2 levels in which net carbon emissions remain stable.

Technically, fossil fuels are derived from ancient organic biomass material, but they do not play a role in the carbon cycle. When fossil fuels are burned, nothing new is planted to make up for the carbon output. It's because of this that they contribute to air pollution and global warming.

Biomass power plants produce much less harmful emissions than fossil-fueled power plants. For example, coal gives off sulfur (the prime cause of acid rain and smog) and mercury (a harmful neurotoxin). They also produce much less NOx emissions (nitrogen oxide) which also contributes to poor air quality.

It's important that energy crops are replanted and grown at the same rate as they are harvested for energy production. Not only is this important to preserve the balance of the carbon cycle, it also prevents crop and soil depletion for future sustainability.

Over half the world still uses solid biomass or coal fuels for basic cooking and heating. Increasing attention is being paid to the consumption of such fuels because of their role in producing damages at three distinct scales. At the household and village level, combustion of solid fuels produces pollution that is damaging to health and a large contributor to the global burden of disease and imposes a high time burden on those collecting fuelwood, typically women and girls. At the community and national level, when fuel wood is harvested in unsustainable ways, its consumption contributes to the loss of forest and associated ecosystem services. Finally, at the regional and global scale, the burning of biomass and coal in inefficient household stoves, which represent roughly 15% of global energy use, releases large amounts of black carbon and carbon-based greenhouse gases. **[7] [8]**

Many of these gases fall into the category of products of incomplete combustion, which are more damaging in terms of global warming potential than the carbon dioxide released from more fossil fuel-burning stoves. These emissions contribute to global warming, particularly where such fuels are harvested non-renewably.

Another concern is the displacement of trees, grasslands, forests, and savannas to make room for biomass crops. The destruction of these lands can lead to a chain reaction which impacts food production on many levels. Beneficial biomass resources will provide the needed crops for energy production without negatively affecting the environment or food sources. A delicate balance must be reached through careful analysis before any major biomass energy operation breaks ground.

Cooking over a traditional open fire or mud stove can cause increased health problems brought on from the smoke, particularly lung and eye ailments, but, also birth defects. The health problems associated with cooking using biomass in traditional stoves affect women and children most strongly, as they spend the most time near the domestic hearth. Replacing the traditional 3-rock cook stove or mud stove with an improved one and venting the smoke out of the house through a chimney can significantly improve a family's health. There are many well-documented adverse health effects of exposure to pollutants from indoor cook stoves, including acute respiratory infections (ARIs), chronic obstructive pulmonary disease (COPD), pulmonary tuberculosis (TB), cataracts, low birth weight (LBW), increased perinatal and infant mortality, nasopharyngeal and laryngeal cancer, and lung cancer. It is estimated that 4% to 5% of the global mortality and disability-adjusted life-years (DALYs) are from ARIs, COPD, TB, asthma, lung cancer, ischemic heart disease, and blindness attributed to solid fuel combustion when cooking in developing countries.

Deforestation and erosion often result from harvesting wood for cooking fuel. The main goal of most improved cooking stoves is to reduce the pressure placed on local forests by reducing the amount of wood the stoves consume, and to reduce the negative health impacts associated with exposure to toxic smoke from traditional stoves

Behavioral change interventions, in reducing childhood household exposures, have the potential to reduce household air pollution exposure by 20 to 98%. Indoor Air Pollution (IAP)exposure can be greatly reduced by cooking outdoors, reducing time spent in the cooking area, keeping the kitchen door open while cooking, avoid leaning over the fire while attending to the meal preparation, staying away while carrying children when cooking and keeping the children away from the cooking area. Opportunities to educate communities on reducing household indoor air pollution exposure include festival collaborations, religious meetings, and medical outreach clinics. Community health workers represent a significant resource for educating communities to help raise awareness regarding reducing the effects of indoor air pollution. **[7] [8]**

Mechanism of major health effect due to different pollutants present in the smoke during burning of biomass fuel in traditional stove is given in the following tables:

Serial No.	POLUTANTS	MECHANISM OF HEALTH EFFECT
1	CARBON MONOXIDE	Inhalation into Respiratory System: • Absorption into blood in lungs. • Elevated COHb levels in blood. • Reduce Oxygen to Cells. (Possible Cilia-Static impact on Lung Clearance Mechanism)
2	PARTICULATES	Inhalation into Respiratory System: • Disposition in respiration tract. • Irritation and toxicity.
3	POLYCYCLIC ORGANIC MATTER	Inhalation into Respiratory System: • Disposition and absorption in lungs metabolic activation. • Precursor to Cancer.
4	FORMALDEHYC	Irritation of Mucous. Toxicity to Cilia. • Reduction in Lung clearance ability. • Possible carcinogen.

Table 2.1: Emission of Major Health Effect Pollutants from biomass cooking stoves [9]

Following table represents the toxicity of Carbon monoxide:

Chemical Reactions
$O_2 + Hb \Rightarrow O_2Hb \ldots\ldots\ldots\ldots\ldots (1)$
$CO + Hb \Rightarrow COHb \ldots\ldots\ldots\ldots.. (2)$
$O_2Hb + CO \Rightarrow COHb + O_2 \ldots\ldots\ldots.. (3)$
COHb is responsible for health hazards.

Table 2.2: Toxicity OF Carbon Monoxide [9]

Almost Two-thirds of all households in developing countries (mainly Bangladesh) depend on unprocessed biomass fuel for cooking. Traditional stoves have poor combustion capacity which produces heavy smoke and numerous harmful pollutants. Switching to Improved Cooking Stove (ICS), a well-designed earthen made stove equipped with a chimney could be beneficial for health. A study was conducted which dictates the way to assess the importance of ICS on maternal health in rural areas of Bangladesh. A quasi-experimental design method was adopted to conduct the study. The study selected 150 Households from 5 villages (intervention) and 150 Households from 2 villages (control) from the Manikgonj District of Bangladesh during January 1, 2012 to July 30, 2012. Differences between control and intervention group were examined by applying one-way analysis of variance (ANOVA). The conventional cut-off value of 0.05 was taken as statistical significance. Results: Most of the respondents (62%) were less than 30 years of age. About 94% participants resided in tin-shaded houses, and 51% kitchens were small. After the intervention period, the measured mean concentrations of Particulate Matter (PM2.5) for the intervention and control group were 259 µg/m3 and 1285 µg/m3, respectively. However, lung function test (LFT) did not reveal significant differences between the two groups. Conclusion: ICS reduced the incidence of respiratory illness among the intervention group. Therefore, this study found ICS might have the potential to be used to improve the maternal health in rural Bangladesh. The above test and stats are by author Sojib Bin Zaman, Maternal and Child

Health Division, International Centre for Diarrheal Disease Research, Bangladesh (ICDDR, B). **[10]**

In Bangladesh, some set of activities has been speculated to build a sustainable, improved cook stoves market. This will be achieved through expanding the market for improved biomass cook stoves by supplying the market with improved biomass cook stoves and by providing strength in businesses involved in the cook stove supply chain and better understanding consumers in order to generate market demand. CCEB or Catalyzing Clean Energy in Bangladesh will work closely and coordinate with Government of Bangladesh (GOB), the Global Alliance for Clean Cook stoves, other donors, the private sector, and civil society to establish a consistent market on both the supply and demand sides for clean cooking solutions.

There is a rapid deforestation and ultimately a change in the eco-system leading to changes in the climate pattern. In Bangladesh, only 12% of the total land area is covered by government-managed forest and this is rapidly decreasing because of the vast population growth and the vast growth of the industries. Industries such as tobacco-curing, lime manufacture, conversion of date palm juice to molasses, sericulture, small textile, match manufacturing industry, paper and pulp industry etc. depend entirely on fuel wood and thus leading to shortage of wood for use as fuel or raw materials. Conservation of the traditional sources of fuel has therefore, become a necessity to preserve our forest wealth. In order to tackle this situation, the Government of Bangladesh has undertaken sets of responsibilities for large-scale afforestation which will lead to induction of more efficient improved cooking stoves in Bangladesh.

Biomass energy as it is known as a cleaner source of energy and there is a huge concern regarding greenhouse gas emission or pollutants at not only nation level but also global level. Beneficiaries will be lead to “green power” generated by biomass owing to its various environment benefits. It will minimize global warming to a huge extent and allow “zero net carbon dioxide”, which means that CO2 emission will be equal to amount absorbed by environment and atmosphere. Energy from biomass reduces Sulphur emissions to almost zero and it ultimate’s helps to alleviate acid rain.

2.5 Biomass stoves

A biomass cook stove is heated by burning wood, charcoal, animal dung or crop residue. Cook stoves are commonly used for cooking and heating food in rural households. Nearly half of the world's population, approximately 3 billion people, uses solid fuels such as coal, wood, animal dung, and crop residues for their domestic energy needs. Among those who use indoor cooking stoves, the poorest families living in rural areas most frequently use solid fuels, where it continues to be relied on by up to 90% of households.

The challenge of cook stove design is not only a technical issue but a social issue as well. How and what we cook greatly depends on our culture, lifestyle and resources. In many areas and for many people, the three stone open fires are used extensively and continually. A good should be able to boil water quickly, simmer foods and cook an almost infinite variety of foods in different ways depending on the culture while minimizing fuel use and emissions produced. They need to be easy to handle, require little attention, safe, aesthetic and respond quickly when needed. To achieve this goal, an engineer cannot work independently from the cook thus an integrated approach for the cook stove design and implementation is necessary. Research results so far show that one stove may be efficient, another maybe heat faster, another safer, and each of them pollutes more or less than the other. It therefore depends on the stove designer to pick out a design that will best suit the locality and food types for which it is intended.

Households in developing countries consume significantly less energy than those in developed countries; however, over 50% of the energy is for cooking food. The average rural family spends 20% or more of its income purchasing wood or charcoal for cooking. The urban poor also frequently spend a significant portion of their income on the purchase of wood or charcoal.

Biomass stoves burn compressed wood or biomass pellets to create a source of heat. By slowly feeding fuel automatically from the storage container (called the hopper) into the burn tray, a constant flame is created and monitored to ensure maximum efficiency.

In our thesis, the following traditional and improved cooking stove has been used:

Figure 2.3: Front and Top view of traditional stove

Figure 2.4: Front and top view of improved cooking stove

2.6 Moisture content

Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, crops, or wood. Water content is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from zero (completely dry) to the value of the materials' porosity at saturation. It is the proportional amount of moisture in a substance. It can be given on a volumetric or mass (gravimetric) basis.

Water in wood can be defined as “water content” and “humidity”. In practice, the terms “water content” and “humidity” are often confused or even equated with one another. However, this is inaccurate.

Water content (M) expresses the mass of water present in relation to the mass of fresh wood. This value describes the quantity of water in the entire moist biomass (fresh mass). This measure is used in the marketing of wood fuels.

The formula for calculating water content (M) is:

MC= (W_w-W_0) /W_w *100

Where,

W_w = wet weight of wood

W_0= oven-dry weight of wood

Wood humidity (u) expresses the mass of water present in relation to the mass of oven-dry wood. This value describes the ratio of water mass to dry mass. Moisture can thus be converted into water content and calculated from this. In summary, wood moisture can be described as the ratio between water and dry substance. Wood moisture is a common term in the wood industry.

This weight can be referred to on wet basis and on dry ash free basis. If the moisture content is determined on a ‘wet’ basis, the water's weight is expressed as a percentage of the sum of the weight of the water, ash, and dry-and-ash-free matter. Similarly, when calculating the moisture content on a 'dry' basis the water's weight is expressed as a percentage of the weight of the ash and dry-and-ash-free matter. Finally, the moisture content can be expressed as a percentage of the "dry and-ash-free" matter content. In that last case, the water's weight is related to the weight of the dry biomass. Because the moisture content affects the value of biomass as a fuel, the basis on which the moisture content is measured must always be mentioned. This is particularly important because biomass materials exhibit a wide range of moisture content (on a wet basis), ranging from less than 10 percent for cereal grain straw up to 50 to 70 percent for forest residues

This thesis deal with different biomass fuel with varying moisture content.

2.7 Calorific value

The amount of energy produced by the complete combustion of a material or fuel. Measured in units of energy per amount of material, e.g. kJ/kg. From the weight of the water obtained and the rise of the temperature, the calorific value may be computed.

The calorific value is one of the most important properties of biomass fuels for design calculations or numerical simulations in thermochemical conversion systems for biomass. There are a number of formulae proposed in the literature to estimate the calorific value of biomass fuels from its elementary components by i.e. proximate, ultimate and chemical analysis composition. In this thesis, these correlations were evaluated statistically by Regression Analysis based on a larger database of biomass samples collected from the open literature. It was found that the correlations based on linear multiple regression analysis is the most accurate. The correlations based on the non-linear regression analysis have very low accuracy. The low accuracy of previous correlations is mainly due to the limitation of samples used for deriving them. To achieve a higher accuracy, new correlations were proposed to estimate the Calorific value by Regression analysis based on present database. The new correlation between the

Calorific value and elemental components of biomass could be conveniently used to estimate the Calorific Value from Regression analysis. The new formula, based on the composition of main elements (in wt. %) C, H, O, N and S based on nonlinear regression analysis

The calorific value is one of the most important characteristics of a fuel, and it is useful for planning and control of the combustion plants. It indicates the amount of heat that develops from the mass (weight) in its complete combustion with oxygen in a calorimeter standardize. It is defined as the amount heat energy released during the complete combustion of unit mass of biomass.

There are two types of calorific value (usually expressed in kcal/kg or MJ/kg) might be considered:

1. Higher heating value (HHV): it is the amount of heat released by a complete combustion of a mass unit of a sample at constant volume in an oxygen atmosphere and at the standard conditions (101.3 KPa, 25°C). The HHV takes into account the latent heat of vaporization of water, and it assumes that the water component is in liquid state at the end of combustion.

2. Lower heating value (LHV), doesn't include the water condensation heat. The high heating value can be determined experimentally in the laboratory with adiabatic calorimeter.

Table 2.3: Calorific value of Different Fuels [11]

Fuels	Values(Kcal/Kg)
Commercial fuels	
Coal(gross calorific value)[a]	
Hard coal	5000
Lignite brown coal	2310
Charcoal	6900
Petroleum products (net calorific value)	
LPG	10800
Gasoline/naphtha	10500
Kerosene	10300
Jet fuel	10400
Fuel oil	9600
Natural gas	8000 - 9480
Electricity	860
Biomass	
Agricultural residues	
Paddy straw	3000
Rice husk	3040
Mango leaves	3390
Groundnut	4200
Sugarcane	3800
Wheat straw	3800
Cotton stalks	4700
Maize stalks	3500
Maize cobs	3850
Bajra straw	3950
Gram straw	3810
Masoor straw	3980
Forestry residues	
Wood wastes	2500 - 3850
Bark	2500 - 2850
Animal wastes	
Cow dung	3290
Cow dung cake	3140

2.8 Advantages of ICS

The benefits of ICS include health improvements from better indoor air quality, cooking time savings, aesthetic improvements and improved social standing from the use of cleaner stoves, and environmental benefits to society, such as reduced black carbon or greenhouse gas emissions and deforestation.

About 40% of the human population, or about 2.8 billion people, find commercial fuels like electricity and gas inaccessible, too expensive or too irregularly supplied to use for cooking and heating **[12]** Instead, they rely on solid fuels like coal, fuelwood, dung and charcoal that are combusted inside their homes. Biomass fuels in particular are often self-collected and easy to use in inexpensive traditional stoves. This leads to severe public health problems, especially for women and children exposed to indoor smoke, and can lead to forest degradation. Without major policy and/or technology changes, the global number of people depending on such fuels projected to remain very large at least through 2030 **[13].**

Improved biomass cook stoves that use less fuel and burn fuel more fully often recommended as relatively affordable ways to deal with these concerns.

There is continued debate as to whether improved biomass cook stoves are “clean enough” to deliver the desired public health benefits. A more fundamental issue, however, is that improved biomass cook stoves can only improve the wellbeing of households and the environment if they actually reduce fuelwood consumption and indoor smoke, and if people are willing to substitute them for more traditional cooking methods. If, for example, the stoves are not used because users find them inconvenient or strange, the technical performance characteristics of the stoves are irrelevant. But that scenario is rarely seen.

Chapter Three: Methodology and Implementation

3.1 Varying the moisture content of biomass fuel

Each type of biomass fuel was divided into three equal sections according to weight. Then the sections were sprayed thoroughly using a bottle sprayer with varying amount of water. Then the moisture content for each section was measured by using a household grill oven and precise digital weight scale. The reason for using a grill oven is that, it provided experimental convenience and gave approximately accurate enough result to thoroughly conduct the experiment.

Figure 3.1: Spraying water on a section of biomass fuel to change moisture content

3.2 Determining the efficiency of cook stove by boiling water

Water was used as the heating subject as it is easily available and can be uniformly heated throughout its volume. Water was heated in an aluminum pot which could be collected from the local market and which has also a satisfactory heat transfer rate. The efficiency of the stoves was calculated from the temperature readings found from the digital thermometer.

Figure 3.2: Boiling water in traditional stove and improved cook stove

Chapter Four:

Experimental setup & procedure

4.1 Experimental setup

Samples of different type of fuel was organized and labeled according to their moisture content. So that the data from the varying samples can be assessed properly.

Figure 4.1: Mango wood samples with varying moisture (wet, medium wet and dry from left to right)

Figure 4.2: Raintree wood samples with varying moisture (wet, medium wet and dry from left to right)

Figure 4.3: Jackfruit wood samples with varying moisture (wet, medium wet and dry from left to right)

The experiment was done in the university premise and all the measurement equipment were collected from the heat laboratory. The stoves were kept on base level while conducting experiment and from a safe distance from flammable objects.

Figure 4.4: Experimental setup of cook stove. ICS (left), traditional (right)

4.2 Experimental Apparatus

Apparatus used in experiment:

1) Improved cook stove (Shakti Chula)
2) Traditional cook stove
3) Biomass fuel
    - Mango wood
    - Raintree wood
    - Jackfruit wood
4) Aluminum pot (two)
5) Kerosene fuel
6) Bottle Sprayer
7) Electric Oven

Apparatus used in measurement:

1) Digital thermometer
2) Commercial weight machine
3) Precision weight machine

4.2.1 Improved Cook Stove

The improved cook stove used in our experiment was "Shakti Chula" which was manufactured by a company called "Future Carbon" which is a global alliance for clean and efficient cook stoves. Shakti Chula is a robust and rugged improved cook stove, made of stainless steel body, improvised thermal insulation, crack prevented design to prolong life span. Intelligent smoke outlet (perforated burner) system engineered to prolong smoke exertion from the burning chamber and forged to maximize the existence of heat into the stove. The design aesthetics considering the local need. The efficiency of this cook stove was untested. The experiment done for this thesis evaluates the efficiency of this improved cook stove for several different type of fuel conditions.

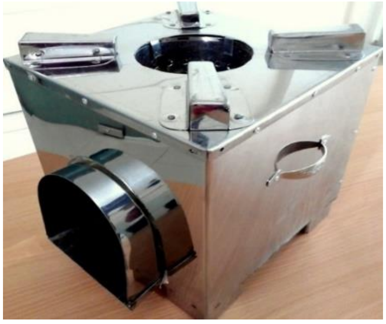

Figure 4.5: Improved cook stove (Shakti Chula)

4.2.2 Traditional cook stove

The traditional cook stove used in the experiment was ordered from a rural village of Gazipur to ensure the validation that the stove used in the experiment was truly used by the village people of Bangladesh. It is a simple clay made cook stove with minimal attention to efficiency and carbon emission.

Figure 4.6: Traditional cook stove

4.2.3 Biomass fuel

Three types of biomass fuel (mango, raintree, Jackfruit) was bought from the local market and was put to dry for a few days.

Figure 4.7: Biomass fuel- mango, raintree and jackfruit (from left)

4.2.4 Aluminum pot

Common aluminum pot was bought from local market which was sufficient in fulfilling the research purpose. The pot weighed around 0.5 Kg.

Figure 4.7: Aluminum pot

4.2.5 Kerosene fuel

Household kerosene fuel was bought from the market to serve as a flame starter of the biomass wood. Kerosene has a higher heating value of 35,000 KJ/Kg, which was taken in consideration whilst calculating stove efficiency.

Figure 4.7: Kerosene fuel

4.2.6 Bottle Sprayer

A typical water bottle having a spraying nozzle cap was used to moisturize the wood fuel.

Figure 4.8: Bottle Sprayer

4.2.7 Electric Oven

A typical household electric oven was used to dry the wood samples for evaluating moisture content.

Description:

- Product Name: Miyako Electric Oven (MT 827W)
- Brand: MIYAKO
- Model: MT 827W

Specification:

- Color: Black
- Power: 1600W
- Capacity: 27 Liter
- Weight (kg) 8
- 0-250 degree temperature selector
- Large interior
- 4 stage heating selector
- chrome plated wire rack
- 120 minutes' timer with bell
- top & bottom heater
- large view window
- rotisserie function
- bake/ roast/ warm function

Figure 4.9: Electric Oven

4.2.8 Digital thermometer

A digital thermometer, which has a thermocouple attached to it, was collected from the heat laboratory. A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature.

Description:

- Product Name: MASTECH MS6514 Dual Channel Digital Thermometer Temperature Logger Tester
- Brand: MASTECH
- Model: MS6514

Specification:

Measurement range:

- K: -200.0C to +1372C / -328.0F to +2501F
- J: -210.0C to +1200C / -346.0F to +2192F
- T: -250.0C to +400C / -418.0F to +752F
- E: -150.0C to +1000C / -238.0F to +1832F
- R: 0C to +1767C / 32F to +3212F
- S: 0C to +1767C / 32F to +3212F
- N: -200.0C to +1300C / -328.0F to +2372F

Accuracy:

- K, J, T, E: +/-(0.2% + 0.5C); R, S: +/-(0.2% + 1C); N: +/-(0.2% + 0.5C)
- Temperature scale: ITS-90
- Applicable standards: NIST-175
- Data Logging: 1000groups
- Display Resolution: 0.1C / 0.1F / 0.1K
- Power supply: 9V battery (Battery is not including in this order).
- Weight: 300g
- Size: 190 x 89 x 42mm / 7.5” x 3.5” x 1.7”

Figure 4.10: Digital Thermometer with thermocouple

4.2.9 Commercial weight machine

A commercial weight machine was used to measure the fuel being used.

Description:

- Product Name: HY T5 platform scale
- Brand Name: HaoYu
- Model: T5

Specification:

- Material: Stainless Steel
- Capacity: 100KG/20G
- Platter Size: 35*45cm
- Certificate: CE
- Display: LED/LCD +backlight
- Power Supply: AC110/220V
- Battery: Rechargeable 4V/4AH battery
- Working time: >600hours if full recharged
- Accuracy: Grade Ⅲ

- Tare: Tare weight = max capacity
- Environmental Conditions: Temperature: 0°C~+40°C, Humidity: R.H≤95%

Figure 4.11: Weight Machine

4.2.9 Precision weight machine

A precision weight machine was used to measure the moisture content preceding in the wood fuel.

Description:

- Product Name: Electronic Digital LCD scale
- Manufacturer: Kitchen Tool
- Model: SF 400

Specification:

- Scale size: 20cm x 15cm x 5cm
- Platform diameter: 15cm
- Measures up to 5kg per 1g
- LCD display
- Measures in pounds, ounces, and grams
- Timer/Countdown function

- Low battery indicator
- Battery included

Figure 4.12: Precision weight machine

4.3 Procedure

4.3.1 Procedure for varying and evaluating the moisture content of fuel

1) Each wood fuel was divided into three groups.
2) In one group, water was sprayed using a bottle sprayer. The weight of water sprayed was equal to the 10% weight of wood fuel of that group.
3) Another group was similarly sprayed with water having 7% the weight of the total fuel of that group.
4) The remaining group was kept unsprayed.
5) The wood fuel was left 24 hours to let the moisture to soak in.
6) A small sample was collected from each group and weighed on a precision weight machine.
7) The samples were then dried for 5 hours at 120°C inside an electric oven.
8) Again, the weight was taken from the dried specimen.
9) From before and after drying weight difference the moisture content was evaluated for each group of wood fuel.

4.3.1.1 Equation to evaluate the moisture content of wood fuel

M= $(Ww\text{-}Wo)\ /Ww$ *100

Where in:

Ww = wet weight of wood

Wo = oven-dry weight of wood

4.3.1.2 Calculating the moisture content of wood fuel

	Wet weight of wood (g)	Oven-dry weight of wood (g)	Moisture content (%)
Mango	35.81	28.34	20.86
	26.15	22.29	14.76
	29.32	25.99	11.37
Raintree	32.42	26.21	19.14
	40.18	34.08	15.18
	41.76	36.69	12.13
Jackfruit	25.08	20.81	17.03
	19.58	16.93	13.53
	28.52	25.76	9.66

Table 4.1: Wood fuel moisture content (%) data

4.3.2 Procedure of evaluating the efficiency of cook stove

1) 1kg of water was put inside the aluminum pot for heating purposes.
2) The open lid pot was placed on top of the stove.
3) Wood fuel was lighted with fire using the help of 10 mL of kerosene for each session.
4) The heating was continued for around 20 minutes' time for each session.
5) Similar process was followed for both traditional cook stove and improved cook stove.
6) The initial and final temperature of the water was taken by using digital thermometer.
7) The commercial weight machine was used to evaluate the amount of wood fuel burnt per session.
8) From the before and after heating weight difference of water the amount of evaporation was calculated.
9) It was observed that in traditional cook stove evaporation phase wasn't in 20 minutes.

4.3.2.1 Necessary equations for calculating cook stove efficiency

$$\text{Efficiency, } \eta = \frac{(m_w \times C_p \times \Delta T) + (m_{we} \times L_w)}{(m_f \times H_f) + (m_k \times h_k)}$$

Here,

$m_w =$ initial weight of water $= 1$ Kg

$C_p =$ specific heat at constant pressure

$\Delta T =$ temperature difference of watre before and after heating

$m_{we} =$ weight of watre evaporated

$L_w =$ latent heat of evaporation for water

$m_f =$ weight of wood fuel burnt

$H_f =$ higher heating value of wood fuel

$m_k =$ weight of kerosene burnt $= 10g\ (= 10mL)$

$h_k =$ higher heating value of kerosene

4.3.2.2 Change of calorific value of Biomass fuel with varying moisture content

To get an analytical overview of the experiment we used three types of firewood, which are the following: Mango tree *(Mangifera indica)*, Raintree *(Samanea saman)* and Jackfruit tree *(Artocarpus hetarophyllus).* These have the following calorific value when 0% moisture is present.

Table 4.2: Calorific Value of Various Fire Wood [14] [15] [16]

Fire wood	**Calorific value (KJ/Kg)**
Mango	6150
Raintree	23400
Jackfruit	16355

But with varying moisture contents these calorific values vary too. The moisture content of a wood species can be expressed as a function of calorific value. This relation can be showed through the following table. In the below case the wood specimen has a calorific value of **18500 KJ/Kg** having 0% Moisture content. [17]

Table 4.3: Moisture Content of a wood specimen [17]

MC (%)	**KJ PER KG**
15	15306
16	15150
17	14940
18	14730
19	14520
20	14310
21	14100
22	13890
23	13680
24	13470
25	13270
26	13060
27	12850
28	12640
29	12430
30	12220

Using this relation, the changed calorific values of the three types of biomass fuel having varying moisture content can be determined.

4.3.2.3 Change of calorific value of Mango wood with varying moisture content

Calorific value for 0% moisture: 6150 KJ/Kg. **[14]**

Table 4.4: Change of calorific value of Mango wood with varying moisture content

MOISTURE CONTENT (%)	CALORIFIC VALUE (KJ/KG)
11.37	5359
14.76	5123
20.86	4734

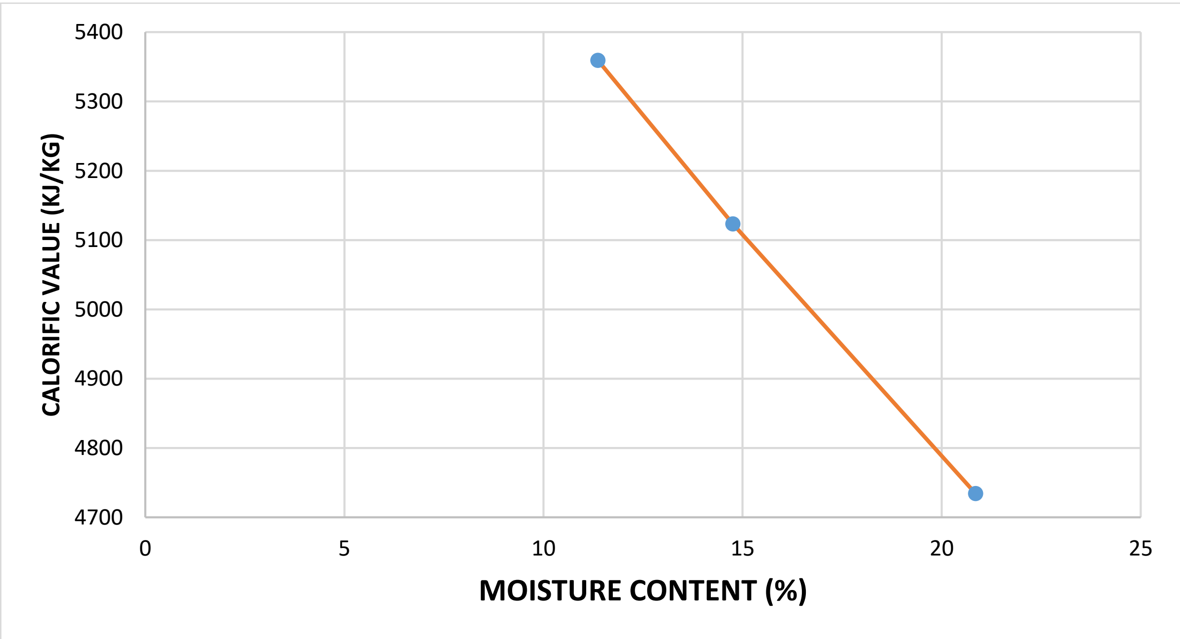

Figure 4.13: Calorific Value Vs Moisture Content of Mango Wood

4.3.2.4 Change of calorific value of Raintree wood with varying moisture content

Calorific value for 0% moisture: 23400 KJ/Kg. **[15]**

Table 4.5: Change of calorific value of Raintree wood with varying moisture content

MOISTURE CONTENT (%)	CALORIFIC VALUE (KJ/KG)
12.3	20141
15.18	19378
19.14	18328

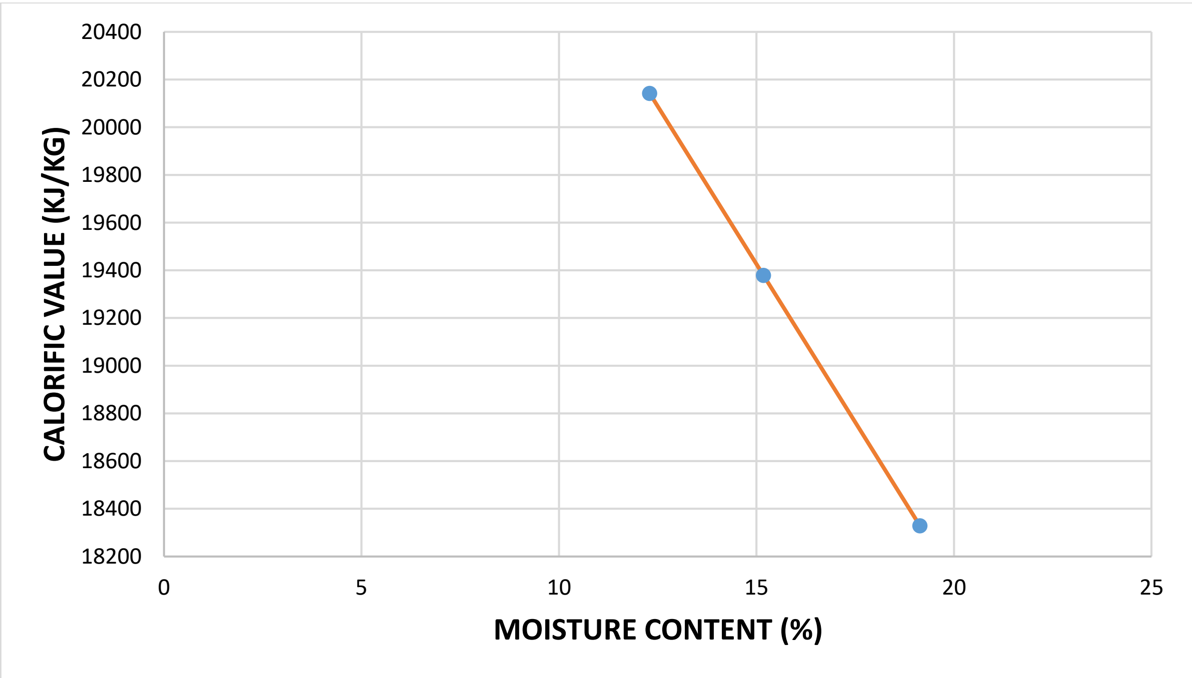

Figure 4.14: Calorific Value Vs Moisture Content for Raintree Wood

4.3.2.5 Change of calorific value of Jackfruit wood with varying moisture content

Calorific value for 0% moisture: 16355 KJ/Kg. **[16]**

Table 4.6: Change of calorific value of Jackfruit wood with varying moisture content

MOISTURE CONTENT (%)	CALORIFIC VALUE (KJ/KG)
9.66	14567
13.53	13850
17.03	13202

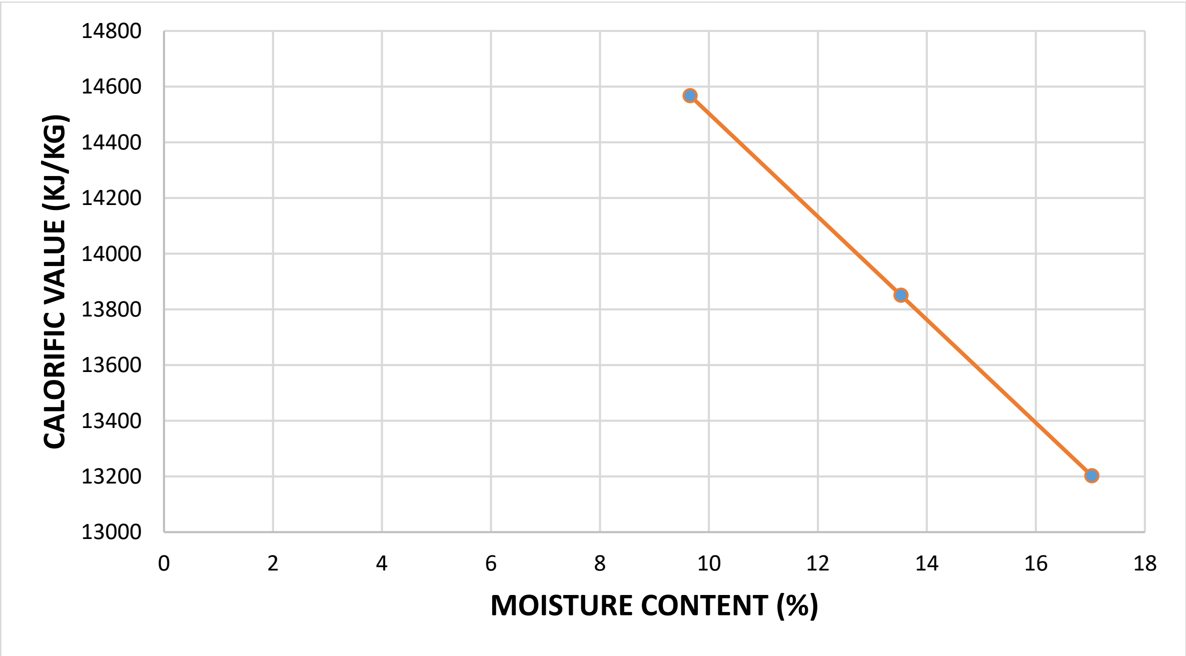

Figure 4.15: Calorific Value Vs Moisture Content for Jackfruit Wood

Chapter Five:

Experimental Data,

Calculations & Graphs

5.1 Experimental data

5.1.1 Mango Tree Wood

		Sample-01 (20.86% M.C.)		Sample-02 (14.76% M.C.)		Sample-03 (11.37% M.C.)	
		Traditional	Improved	Traditional	Improved	Traditional	Improved
1	Initial temperature of water	26.4°C	26.1°C	25.2°C	25.9°C	25.6°C	26.1°C
2	Final temp of water	84.1°C	100°C	82.5°C	100°C	79.3°C	100°C
3	Weight of fuel before burning	0.758 Kg	1.16 Kg	0.85 Kg	0.68 Kg	0.55 Kg	0.91Kg
4	Weight of fuel after burning	0.288 Kg	0.21 Kg	0.45 Kg	0.16 Kg	0.27 Kg	0.32 Kg
5	Weight of fuel burnt	0.47 Kg	0.95 Kg	0.40 Kg	0.52 Kg	0.28 Kg	0.59 Kg
6	Weight of kerosene burnt	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg
7	Initial weight of water	1 Kg	1 Kg	1 Kg	1 Kg	1 Kg	1 Kg
8	Final weight of water	1 Kg	0.76 Kg	1 Kg	0.87 Kg	1 Kg	0.8 Kg
9	Water evaporated	-	0.24 Kg	-	0.13 Kg	-	0.2 Kg
10	Weight of pot	0.4012 Kg	0.558 Kg	0.4012 Kg	0.558 Kg	0.4012 Kg	0.558 Kg

Table 5.1: Experimental data of Mango Tree wood

5.1.2 Raintree wood

		Sample-01 (19.14% M.C.)		Sample-02 (15.18% M.C.)		Sample-03 (12.3% M.C.)	
		Traditional	Improved	Traditional	Improved	Traditional	Improved
1	Initial temperature of water	27.1°C	27°C	26.9°C	26.2°C	26.4°C	26.3°C
2	Final temp of water	83°C	100°C	80.5°C	100°C	87.2°C	100°C
3	Weight of fuel before burning	0.41 Kg	.64 Kg	0.56 Kg	0.39 Kg	0.4 Kg	0.51Kg
4	Weight of fuel after burning	0.29 Kg	0.45 Kg	0.46 Kg	0.26 Kg	0.3 Kg	0.33 Kg
5	Weight of fuel burnt	0.12 Kg	0.19 Kg	0.10 Kg	0.13 Kg	0.10 Kg	0.18 Kg
6	Weight of kerosene burnt	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg
7	Initial weight of water	1 Kg	1 Kg	1 Kg	1 Kg	1 Kg	1 Kg
8	Final weight of water	1 Kg	0.83 Kg	1 Kg	0.89 Kg	1 Kg	0.76 Kg
9	Water evaporated	-	0.17 Kg	-	0.11 Kg	-	0.24 Kg
10	Weight of pot	0.4012 Kg	0.558 Kg	0.4012 Kg	0.558 Kg	0.4012 Kg	0.558 Kg

Table 5.2: Experimental data of Raintree wood

5.1.3 Jackfruit tree wood

		Sample-01 (17.03% M.C.)		Sample-02 (13.53% M.C.)		Sample-03 (9.66% M.C.)	
		Traditional	Improved	Traditional	Improved	Traditional	Improved
1	Initial temperature of water	27.5°C	27.5°C	27.2°C	27.3°C	26.6°C	26.3°C
2	Final temp of water	79.2°C	100°C	86.2°C	100°C	86.5°C	100°C
3	Weight of fuel before burning	0.29 Kg	.47 Kg	0.30 Kg	0.51 Kg	0.27 Kg	0.41Kg
4	Weight of fuel after burning	0.16 Kg	0.21 Kg	0.16 Kg	0.22 Kg	0.15 Kg	0.21 Kg
5	Weight of fuel burnt	0.13 Kg	0.26 Kg	0.14 Kg	0.29 Kg	0.12 Kg	0.20 Kg
6	Weight of kerosene burnt	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg	0.01 Kg
7	Initial weight of water	1 Kg	1 Kg	1 Kg	1 Kg	1 Kg	1 Kg
8	Final weight of water	1 Kg	0.81 Kg	1 Kg	0.74 Kg	1 Kg	0.79 Kg
9	Water evaporated	-	0.19 Kg	-	0.26 Kg	-	0.21 Kg
10	Weight of pot	0.4012 Kg	0.558 Kg	0.4012 Kg	0.558 Kg	0.4012 Kg	0.558 Kg

Table 5.3: Experimental data of Jackfruit wood

5.2 Calculations

5.2.1 Mango

<u>**Sample: 01 (Moisture Content = 20.86%)**</u>

1) <u>Efficiency of Traditional cook stove:</u>

$$\frac{1\times4.187\times(84.1-26.4)}{(0.47\times4734)+(0.01\times35000)} = \mathbf{9.4\%}$$

2) <u>Efficiency of Improved Cook Stove (ICS):</u>

$$\frac{1\times4.187\times(100-26.1)+(0.24\times2260)}{(0.95\times4734)+(0.01\times35000)} = \mathbf{17.6\%}$$

<u>**Sample: 02 (Moisture Content = 14.76%)**</u>

1) <u>Efficiency of Traditional cook stove:</u>

$$\frac{1\times4.187\times(82.5-25.2)}{(0.40\times5123)+(0.01\times35000)} = \mathbf{10\%}$$

2) <u>Efficiency of Improved cook Stove (ICS):</u>

$$\frac{1\times4.187\times(100-25.9)+(0.13\times2260)}{(0.52\times5123)+(0.01\times35000)} = \mathbf{20\%}$$

Sample: 03 (Moisture Content = 11.37 %)

1) Efficiency of Traditional cook stove:

$$\frac{1 \times 4.187 \times (79.3 - 25.6)}{(0.28 \times 5359) + (0.01 \times 35000)} = \mathbf{12.15\%}$$

2) Efficiency of Improved Cook Stove (ICS):

$$\frac{1 \times 4.187 \times (100 - 26.1) + (0.20 \times 2260)}{(0.59 \times 4734) + (0.01 \times 35000)} = \mathbf{21.7\%}$$

5.2.2 RainTree

Sample: 01 (Moisture Content = 19.14 %)

1) Efficiency of Traditional cook stove:

$$\frac{1\times4.187\times(83-27.1)}{(0.12\times18328)+(0.01\times35000)} = \mathbf{9.2\%}$$

2) Efficiency of Improved Cook Stove (ICS):

$$\frac{1\times4.187\times(100-27)+(0.17\times2260)}{(0.19\times18328)+(0.01\times35000)} = \mathbf{18\%}$$

Sample: 02 (Moisture Content = 15.18 %)

1) Efficiency of Traditional cook stove:

$$\frac{1\times4.187\times(80.5-26.9)}{(0.10\times19378)+(0.01\times35000)} = \mathbf{9.8\%}$$

2) Efficiency of Improved Cook Stove (ICS):

$$\frac{1\times4.187\times(100-26.2)+(0.11\times2260)}{(0.13\times19378)+(0.01\times35000)} = \mathbf{19.4\%}$$

Sample: 03 (Moisture Content = 12.13 %)

1) Efficiency of Traditional cook stove:

$$\frac{1\times4.187\times(87.2-26.4)}{(0.10\times20141)+(0.01\times35000)} = \mathbf{10.7\%}$$

2) Efficiency of Improved cook Stove (ICS):

$$\frac{1\times4.187\times(100-26.3)+(0.24\times2260)}{(0.18\times20141)+(0.01\times35000)} = \mathbf{21.4\%}$$

5.2.3 JackFruit

Sample: 01 (Moisture Content = 17.03 %)

1) Efficiency of Traditional cook stove:

$$\frac{1\times4.187\times(79.2-27.5)}{(0.13\times13202)+(0.01\times35000)} = \mathbf{10.5\%}$$

2) Efficiency of Improved cook Stove (ICS):

$$\frac{1\times4.187\times(100-27.5)+(0.19\times2260)}{(0.26\times13202)+(0.01\times35000)} = \mathbf{19.4\%}$$

Sample: 02 (Moisture Content = 13.53 %)

1) Efficiency of Traditional cook stove:

$$\frac{1\times4.187\times(86.2-27.2)}{(0.14\times13850)+(0.01\times35000)} = \mathbf{10.8\ \%}$$

2) Efficiency of Improved cook Stove (ICS):

$$\frac{1\times4.187\times(100-27.3)+(0.26\times2260)}{(0.29\times13850)+(0.01\times35000)} = \mathbf{20.4\ \%}$$

Sample: 03 (Moisture Content = 9.66 %)

1) Efficiency of Traditional cook stove:

$$\frac{1\times4.187\times(86.5-26.6)}{(0.12\times14567)+(0.01\times35000)} = \mathbf{11.9\%}$$

2) Efficiency of Improved Cook Stove (ICS):

$$\frac{1\times4.187\times(100-26.3)+(0.21\times2260)}{(0.20\times14567)+(0.01\times35000)} = \mathbf{24\%}$$

5.3 Graphs

5.3.1 Traditional Cooking Stove

Data Table

MANGO WOOD		RAINTREE WOOD		JACKFRUIT WOOD	
MOISTURE CONTENT (%)	EFFICIENCY (%)	MOISTURE CONTENT (%)	EFFICIENCY (%)	MOISTURE CONTENT (%)	EFFICIENCY (%)
11.37	12.15	12.3	10.7	9.66	11.9
14.76	10	15.18	9.8	13.53	10.8
20.86	9.4	19.14	9.17	17.03	10.5

Table 5.4: Efficiency of Traditional Cooking Stove for various biomass fuel (wood)

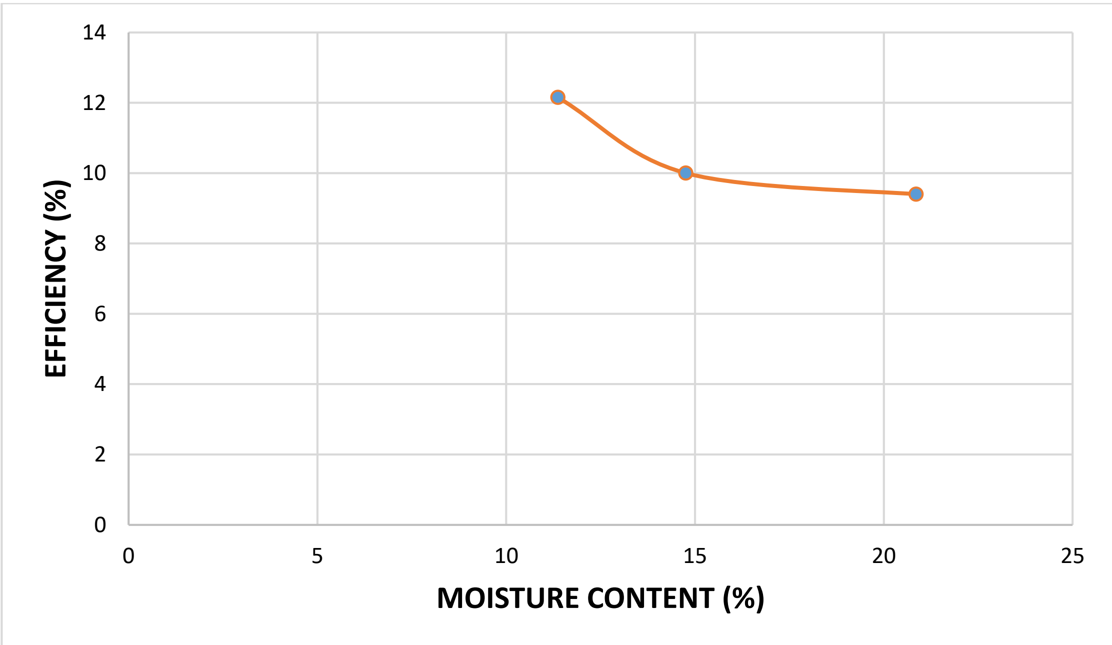

Figure 5.1: Efficiency Vs Moisture Content for Mango Wood

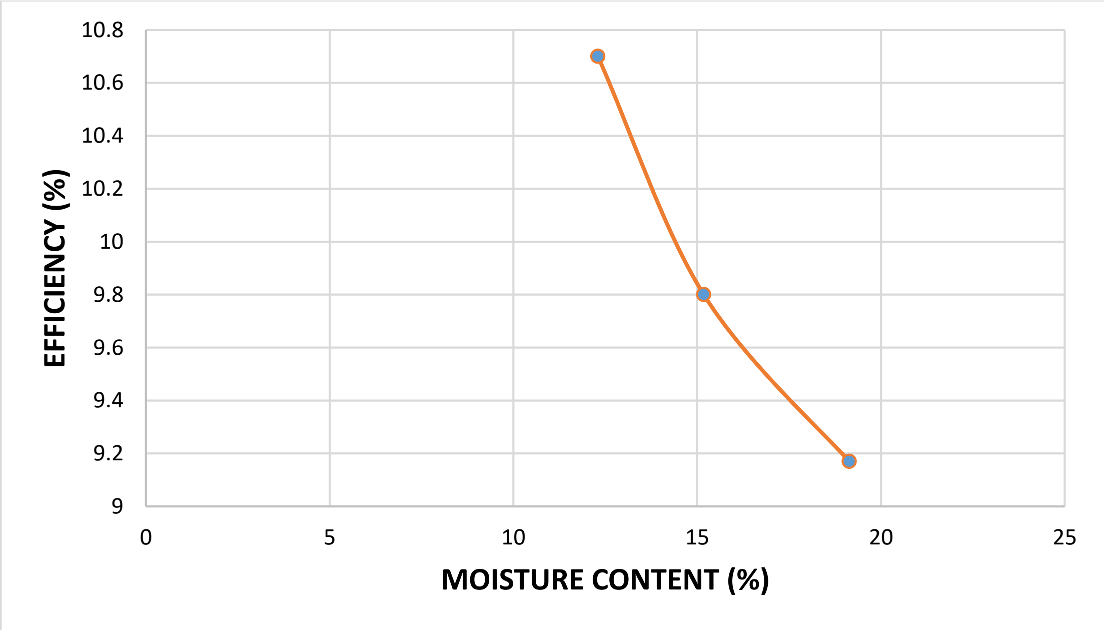

Figure 5.2: Efficiency Vs Moisture Content for Raintree Wood

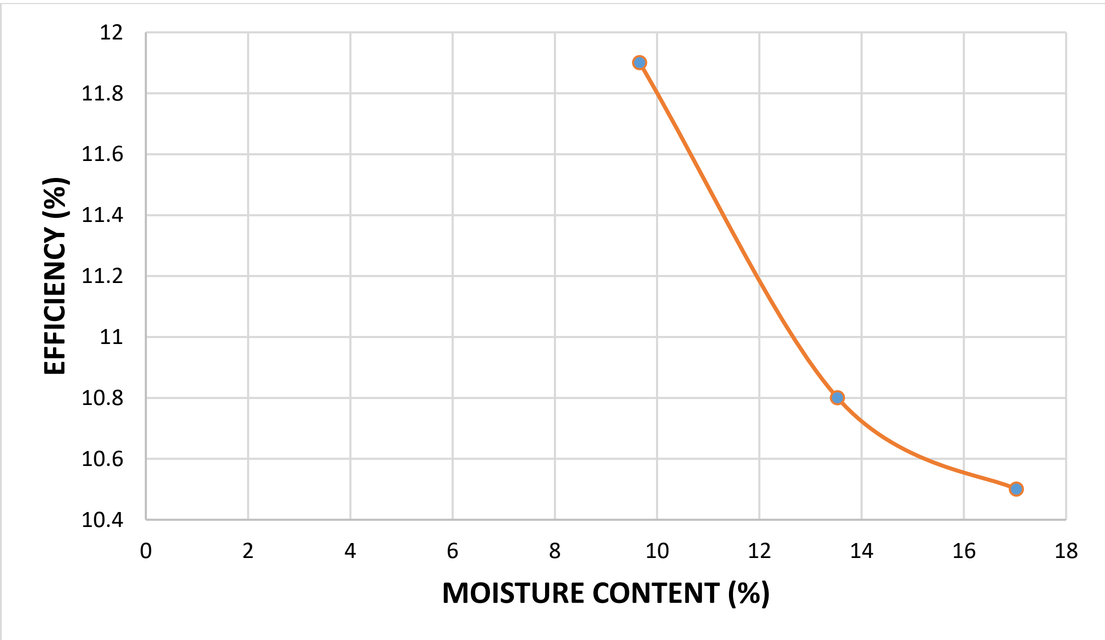

Figure 5.3: Efficiency Vs Moisture Content for Jackfruit Wood

5.3.2 Improved Cooking Stove

Data Table

MANGO WOOD		RAINTREE WOOD		JACKFRUIT WOOD	
MOISTURE CONTENT (%)	EFFICIENCY (%)	MOISTURE CONTENT (%)	EFFICIENCY (%)	MOISTURE CONTENT (%)	EFFICIENCY (%)
11.37	21.7	12.3	21.31	9.66	24
14.76	20	15.18	19.4	13.53	20.4
20.86	17.6	19.14	18	17.03	19.4

Table 5.5: Efficiency of Improved Cooking Stove for various biomass fuel (wood)

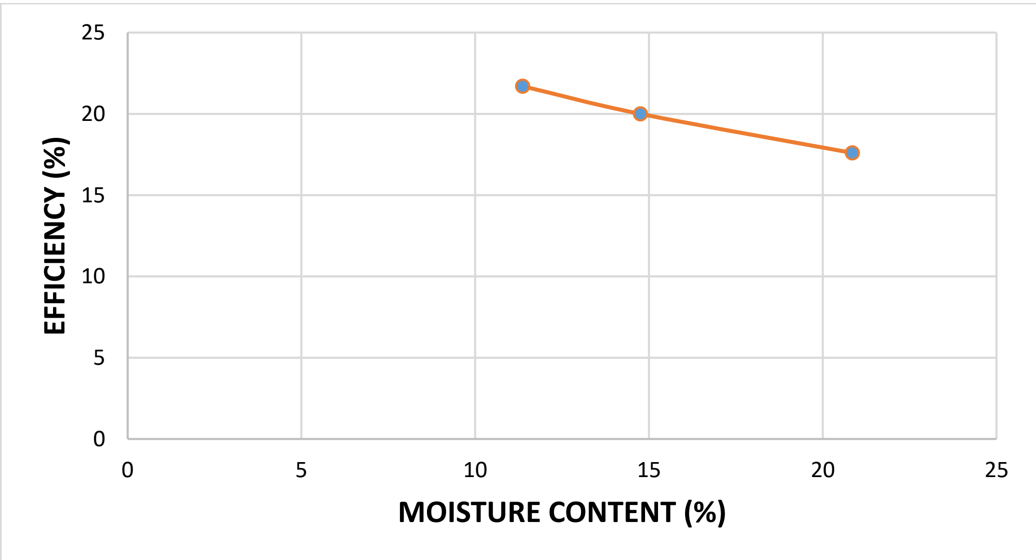

Figure 5.4: Efficiency Vs Moisture Content for Mango Wood

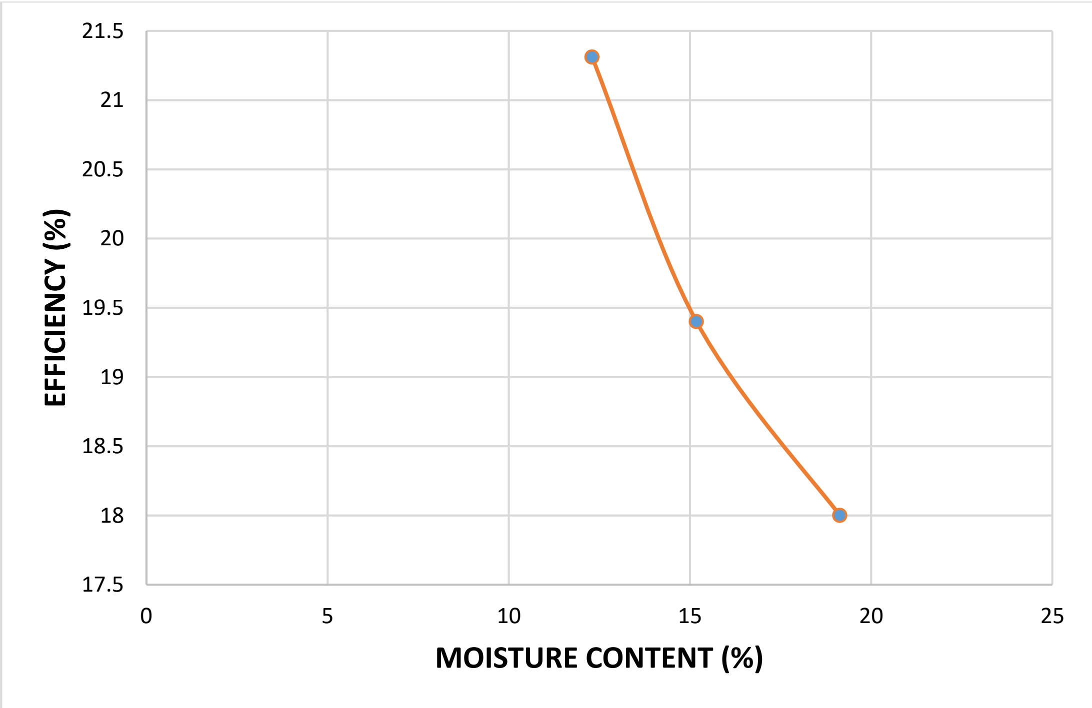

Figure 5.5: Efficiency Vs Moisture Content for Raintree Wood

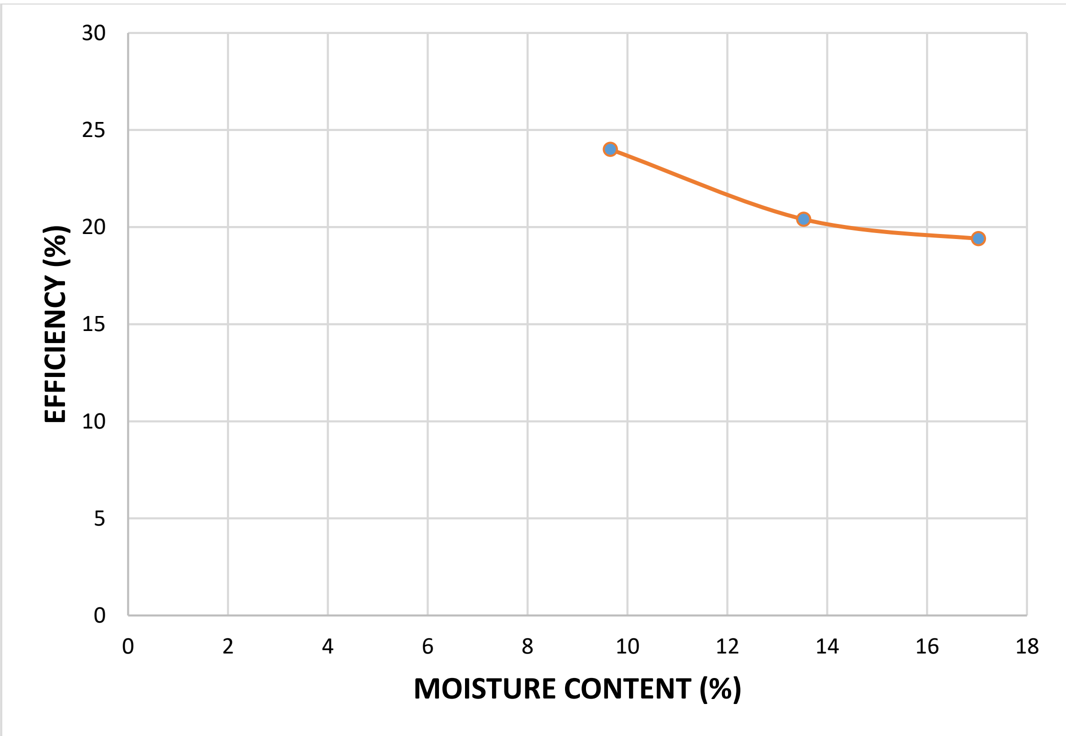

Figure 5.6: Efficiency Vs Moisture Content for Jackfruit Wood

Chapter Six:

Broad Context Discussion of Result and Relevance

6.1 Findings

6.1.1 Thermal Efficiency

- The average thermal efficiency of improved cook stove was 20.21% and maximum efficiency was seen for jackfruit wood which was 24% at 9.66% moisture content. The minimum efficiency observed for ICS was with mango wood which was 17.6 % at 20.86% moisture content.

- The average thermal efficiency of traditional cook stove was 10.49% and maximum efficiency was seen for mango wood which was 12.15% at 11.37% moisture content. The minimum efficiency observed for traditional stove was raintree mango wood which was 9.17 % at 19.14% moisture content.

6.1.2 Evaporation of water for ICS in 20 minutes

- The average amount of water evaporated in 20 minutes in ICS was 0.19 Kg of water. The maximum amount of evaporation occurred using mango wood of 13.53% moisture content which was 0.26 Kg of water. The minimum was 0.11 Kg which was with raintree of 15.18% moisture content.
- The traditional cook stove was not efficient enough to achieve the boiling state at 20 minutes.

6.1.3 Rise of temperature of water in traditional cook stove in 20 minutes

- The average temperature rise of traditional cook stoke was 59.54℃. The maximum temperature rise occurred with raintree of 12.3% moisture content which was 60.4℃. The minimum temperature rise occurred with Jackfruit tree wood of moisture content 17.03% that was 51.7℃.

6.1.4 Fuel burnt

- The average fuel burnt in ICS was 0.37 Kg. Maximum fuel burnt occurred with mango tree of 20.86% moisture content which was 0.95 Kg. Minimum fuel burnt occurred with raintree of 15.18% moisture content which was 0.13 Kg.
- The average fuel burnt in traditional cook stove was 0.21 Kg. Maximum fuel burnt occurred with mango tree of 20.86% moisture content which was 0.47 Kg. Minimum fuel burnt occurred with raintree of 12.3% moisture content which was 0.10 Kg.

6.2 Discussion

- The moisture content was varied using a handheld bottle sprayer which was done considering approximation of the naked eye and the spraying was initiated as uniformly possible.
- The reason for using household electric oven for determining the moisture content was it provided sufficiently reliable results.
- The average efficiency of the ICS was almost double of that of traditional cook stove. This was due to the smart construction and insulating boundaries of the ICS. The airflow inside the traditional stove was poor, whereas air channels below the ICS provided sufficient airflow for better fuel combustion.
- The amount of kerosene used was kept as minimum as possible to assure that the core objective of the experiment remained sustained.
- Boiling state of water could not be achieved in traditional cook stove in 20 minutes due to waste heat loss and slow burning rate of wood fuel inside the stove.
- The temperature data collected from the digital thermometer was taken through a thermocouple which was directly submerged in water. This was done to ensure the complete wetting of the thermocouple tip which maximized the possibility of acquiring accurate reading.

Chapter Seven:

Conclusion &

Recommendation

7.1 Conclusion

The use of biomass, as a traditional energy source for the third world, can play a pivotal role in helping the developed world reduce the environmental impact of burning fossil fuels to produce energy. Using an improved cook stove in house hold use can tackle the aforesaid problem in the most efficient way. The effect of moisture content plays a vital role in the cook stove efficiency, which also can directly impact the amount of wood fuel being used. Improved cook stove (ICS) has interesting advantages compared with traditional clay cook stoves due to the higher burning rates, the increased power dynamic range and the low emissions of pollutants. There is a vast opportunity of development in the field of Improved Cook Stove (ICS) in the near future and has a brighter side of research development.

7.2 Recommendations

The efficiency of the improved cook stove can be increased and it may be made more fuel saving by improving the following areas:

1. Instead of using natural draft operation characteristics, forced draft can be used by implementing a small induction fan on the sidewalls of the stove.
2. More type of biomass fuels is recommended to be used, having smaller log size or wood chips.
3. More drying time for the firewood is recommended to achieve better burning rate.
4. The ICS can be subjected to insulation of any sort to trap the waste heat being escaped.
5. The ICS can be further studied for improvement using computerized flow simulation.
6. The ICS can be redesigned using same concept for mass cooking application.
7. Vessels made of different materials rather than aluminum can be used to study the different effects it has on the ICS efficiency.

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