



OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND KEROSENE FOR COOKING IN ETHIOPIA



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WONDOGENT, ETHIOPIA

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OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA

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MANAGEMENT

JUNE, 2018

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND KEROSENE
FOR COOKING IN ETHIOPIA**

APPROVAL SHEET-1

This is to certify that the thesis entitled “optimization of Jatropha oil blended with ethanol and kerosene for cooking in Ethiopia” submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Renewable energy utilization and management, the Graduate Program of the School of natural resources and environmental studies, and has been carried out by Lake Belete Adamu Id. No MSc. /ReUm/R008/09 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Kamil Dino Adem (PhD)

Name of major advisor



Signature


14 June 2018

Date

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APPROVAL SHEET-2

We, the undersigned, members of the Board of Examiners of the final open defense by Lake Belete Adamu have read and evaluated his thesis entitled “ Optimization of Jatropha oil blended with ethanol and kerosene for cooking in Ethiopia ” , and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Renewable energy utilization and management.

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DECLARATION

I hereby declare that this thesis my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis has been duly acknowledge.

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ACRONYMS

CCT	controlled cooking Test
CO	carbon monoxide
CO ₂	Carbon dioxide
CRGE	Climate Resilient Green Economy
GTP	Growth and Transformation Plan
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
IAP	Indoor air pollution
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
IWA	International Workshop Agreement
MME	Ministry of Mines and Energy
MWE	Ministry of water and energy
MWIE	Ministry of water irrigation and electricity
WBT	Water Boiling Test

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ABSTRACT

Ethiopia has declared a national biofuel production and utilization strategy in the GTP to assure energy security and minimize the risks associated with deforestation and GHG emission. The objective of this study was evaluating the utilization of jatropha oil blended with ethanol and kerosene for cookstove utilization. The study were assessed (a) the effect of temperature and addition of ethanol or kerosene on the viscosity of jatropha oil (b)The thermal efficiency, SFC and CO emissions of ethanol and jatropha oil stoves operated with ethanol- jatropha oil and kerosene - jatropha oil blended fuels respectively. The viscosity data were collected using Brookfield viscometer model DV2T from 20 °c to 100 °c and at 10, 20, 30 and 40 % jatropha blended with ethanol and kerosene fuels. Thermal efficiency, SFC and CO emissions data were collected using Water Boiling Test protocol (WBT version 4.2.2) at 10, 20 and 40 % jatropha oil blended with ethanol and kerosene fuels. The results show that viscosity of jatropha oil was significantly reduced on heating ($p < 0.01$) and on blended with ethanol ($p < 0.018$) and kerosene ($p < 0.023$).The performance test result showed Ethanol and Jatropha oil stoves thermal efficiency was above 50% up to 40% jatropha oil .SFC and CO of the stoves increases as the ratio of the Jatropha oil increases in the blend. The maximum ratio of Jatropha oil blended with Ethanol and Kerosene was 40 % and shows above 50% thermal efficiency while improved biomass cook stoves such as traditional charcoal stoves, Tikikil and Lakech cook stoves has 23, 26 and 38 % thermal efficiencies, respectively .CO emission of jatropha oil stove and ethanol stove up to 40% jatropha oil showed below 36 grams of CO emission to boil 2.5liters of water while improved cookstoves such as Merchaye, Lakech and traditional cookstoves has 66, 79 and 92 grams of CO emission to boil 2.5 liters of water. Since utilization of Jatropha oil up to 40% blended with ethanol or kerosene fuels on ethanol and jatropha oil stoves have higher thermal efficiency and lower CO emission than other improved cook stoves ,it can be used to reduce deforestation and CO emissions over the existing cook stoves, further improvement of the Jatropha oil stove still needed.

Key words: - Viscosity, Thermal efficiency, Blending, specific fuel consumption, emission

CHAPTER 1: INTRODUCTION

1.1 Background

Sustainable social and economic development requires secured and affordable energy resources provided with low environmental impacts and low greenhouse gas (GHG) emissions. The energy crisis is the main problem to globe facing today as non-renewable energy like coal, oils, and natural gases are often scarce due to rapid depletion of resources. The current global energy supply and consumption primarily is based on fossil fuels which added considerable CO and CO₂ in the earth's atmosphere. Most scientists agree that combustion of fossil fuels has contributed significantly to the greenhouse effect, creating the conditions for climatic changes that threaten life on earth. This threatens climate change can be mitigated if the efficiency of energy supply and consumption improved or renewable energy utilization and development increases. According to IPCC (2012) fourth assessment report, fossil fuels delivered about 85% of the global total energy from 2004 to 2008 and caused for 57% of GHG emissions.

There are multiple ways reducing GHG emissions such as improving supply side efficiency (energy conversion, transmission and distribution, including combined heat and power).Improving demand side efficiency in the respective sectors and applications (buildings, industrial and agricultural processes, transportation, heating, cooling and lighting).Shifting from high-GHG energy carriers to lower-GHG energy carriers such as natural gas, nuclear fuels and renewable energy sources. Utilizing CO₂ capture and storage (CCS) to prevent post-combustion or industrial process CO₂ from entering the atmosphere Changing behavior to better manage energy use or to use fewer carbon- and energy-intensive goods and services (IPCC,2012).

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In East African countries, population growth and rapid urbanization are rising the energy challenges of the region in which the energy consumption highly reliance on traditional fuels. Solid biomass currently accounts for about 80% of final energy consumption in the region which leads to deforestation and land degradation. Thus, the development of alternative energy for households gets focused since it represents the largest share of final energy consumption and contributor to deforestation (REN21, 2016). In Ethiopia, which is one of the East African countries, about 80% household's energy consumption depends on forests and an agricultural residue that causes the country's forest resource to fall under risky. The Ethiopian climate resilient green economy (CRGE) prioritized usage of alternative fuels for cooking and baking as an immediate solution to reducing fuelwood demand and forest degradation. Large-scale promotion of advanced rural cooking technologies is one of the fast track implementation of the CRGE. At country level, about 81.4 % of the households use firewood, 11.5% cook with dung and 2.4 % use kerosene for cooking (MWE, 2012). Development programs can't be achieved without secured energy, thus utilization of locally produced fuels such as biofuels may be the only choice to save foreign currency and reduce greenhouse gases emissions (CRGE, 2012). To ensure the country's sustained development and national fuel security, utilization and substituting the energy demand by locally produced fuels such as biofuel is very important. The Ethiopian biofuel development and utilization strategy targeted to produce locally biofuels without affecting food self-sufficiency. The strategy identified *Jatropha curcas*, castor crop and palm tree as the main feedstock for biodiesel production. Biofuel production and utilization become essential to resist the challenges of unpredicted fossil fuel price escalation, enhancing rural development by providing support and creating employment opportunities,

Supporting soil and water conservation programs and Implementing environmental protection programs and measures (MME, 2007).

The Ethiopian energy policy regarding household's energy focused on energy development and utilization to increase the reliability of energy supply, to halt deforestation and to control environmental pollution resulting from energy use (MWE, 2012). Risks associated to deforestation and emission from combustion of fossil fuels with the escalating price of fossil fuels initiated the search for alternative energy sources such as biofuel which is a promising renewable energy source with comparable energy content with the fossil fuel (Nrel *et al.*, 2010).

The CRGE strategy aimed to reduce emission from fuel wood consumption through efficient stoves .Since fuelwood is largest source of rural energy, efficient stoves can have massive benefits. The CRGE targeted to reduce 30 Mt CO₂ eq in 2030 by disseminating fuelwood efficient cooking stoves and 6 Mt CO₂ eq. by utilizing alternative fuels stoves.

The analysis conducted on rural energy and focused on both the impact of improved cooking/baking technologies on rural energy and on the choice of technology, current and improved dissemination approaches, and financing options (CRGE, 2012).

1.2 Statement of problem

Combustion of fossil fuels is the cause of most of the emission of greenhouse gas (IPCC, 2012).Therefore; the search for viable alternative fuel, which is more environmentally friendly, has become highly important. In Ethiopia, about 85% of the country's population is living in rural areas engaged in the small-scale agricultural sector and can be benefited by cultivation of indigenous energy resources (MME, 2007).Biofuel development and utilization strategy have been developed for utilizing various types of plant species including jatropha plant and castor seed which are important feed-stock for bio-diesel

generation. In Ethiopia Jatropha and castor oil cost is estimated from 0.45 to 0.76 USD /L but in Germany costs about 1.3 USD. So, if the oil is transported to Germany the cost of transportation is estimated 0.575 to 0.885 USD. Therefore, export of Jatropha or castor oil to Europe is competitive in terms of cost. However, in Ethiopia, some barriers such as technical, technological and awareness gaps hinder the utilization of plant fuels such as jatropha as sources of energy beyond fence (Asmare and Gabbiye, 2014) and (Kamil, 2013) .The jatropha oil has comparable energy content with kerosene fuel and it has more energy content than ethanol fuel (Roden *et al.*, 2006). However, its higher viscosity is an existing major problem for utilization of vegetable oils (Yadav and Jha, 2013). Thus reducing the viscosity of vegetable oils is the most important task in the utilization of these plant oils. Blending plant oils with alcohol or diesel and heating plant oil shows reduction the viscosity of plant oils (Pramanik *et al.*, 2003 and Chalatlou *et al.*, 2011) reported the engine performance test using jatropha oil blended with diesel fuel. Jatropha oil (5% blend with diesel) showed slightly higher thermal efficiency than diesel and at 10 and 20 %, jatropha oil showed comparable thermal efficiency with diesel fuels. However, 50% and higher jatropha oil blends showed 3 to 5% less thermal efficiency than diesel fuel. The aim of the present study was reducing viscosity of Jatropha oil through blended with ethanol and kerosene and heating the oil. Thermal efficiencies and emission of ethanol and Jatropha oil stove tested using water boiling test (Roden *et al.*, 2006).

1.3 objectives

1.3.1 General objective

The general objective of the present study was to assess the effects of ethanol and kerosene addition on jatropha oil viscosity, testing the thermal and emission of ethanol and Jatropha oil stoves using blended fuels.

1.3.2 Specific objectives

The specific objectives of this study include

- Evaluating the effect of ethanol and kerosene addition on viscosity of Jatropha oil.
- Evaluating the effect of temperatures on the viscosity of Jatropha oil.
- Determining the performance and emissions of ethanol and Jatropha oil stoves with blended fuels.

1.4 Significance of the Study

Most scientists believed that the rise of the observed increase in global average temperature since the mid-20th century mainly due to the observed increase in anthropogenic GHG concentrations and arguing that it can be reduced through improving energy efficiency and utilizing of renewable energy such as biofuels (IPCC,2012). Ethiopian biofuel development and utilization strategy targeted to produce locally biofuels from Jatropha curcas, castor crop, and palm tree without affecting food self-sufficiency. However, some barriers such as technical limitations, low awareness about utilization of plant oils and technological weakness for the transition towards biofuels the use of jatropha plant can't go beyond the purposes fences in Ethiopia (kamil, 2013) and (Asmare and Gabbiye, 2014). The finding of this study reflected the benefit of jatropha oil through blended with kerosene and ethanol for cooking. The present study evaluated thermal efficiency, specific fuel consumption and emissions of Ethanol and Jatropha oil stoves with blended fuels using standardized water boiling test (Roden *et al.*, 2006).

CHAPTER 2: LITERATURE REVIEW

2.1 Biofuels and Global Climate Change

Global energy consumption is highly dependent on the polluted petroleum energy resource which is found in some parts of the world. According to IPCC, 2012 most of the observed average temperature increased in the globe since the mid-20th century due to the anthropogenic greenhouse gas concentrations increase. For these reasons, alternative energy sources which available locally considered as the best solutions to substitute limited fossil fuels and to reducing emissions of greenhouse gas from combustion of these fuels. Biofuels mostly classified as bioethanol or biodiesel have potential to substitute's fossil fuels. Bioethanol is produced from a wide range of feedstock, primarily from maize and sugarcane. Biodiesel can be produced by converting raw vegetable oils such as and fats to esters. Biofuel can play a significant role in reducing GHG emission which has positive effects on the global climate (Sims *et al.*, 2010) and (Abreham B. and Belay Z.,2015).

2.2 Biofuel Development Debate

Debate on biofuels is between promoters and opponents of the biofuel technology. Promoters arguing that biofuel have a potential for economic growth and has positive carbon balance and believe it is the only solution to overcome the fossil fuel dependency. On the other hand, Opponents concluded that biofuel development has impacts on the environment and food security. They assume that increasing the demand and production of biofuels causes the rise of food prices. Despite this argumentative debate, biofuel

cultivation is a growing branch of agriculture and it is assumed that the demand for biofuels will further increase in the next few years at global scale.

This demand will also stay high because many countries promoting cultivation of biofuel crops with subsidies to improve their carbon balance and reduce dependency on fossil fuel. According to Rosegrand, (2008) recent increases in food-price caused not only by biofuel production but also due to bad weather in crop production, higher oil prices for the production of inputs, transportation and poor government policies such as export sanctions.

2.3 Knowledge Gaps on Biofuels potentials

The debates on biofuels come from knowledge gaps concerning the potential of biofuels for economic development, their likely impacts on rural incomes, food security and environmental balance of biofuel value chains. Hence, more objective and precise information on biofuel development and utilization issues are needed to lead the development strategies and policies, especially in developing countries. Based on the fact that *Jatropha curcas* grows in wide range of climatic conditions, it gets high attention as sustainable biofuel source or unproductive marginal and degraded. Therefore, biofuel production would not compete with food production and does not caused influence on food security in degraded and marginal areas (Henning, 2008).

2.4 Overview of *Jatropha curcas*

Jatropha curcas grouped in the genus Euphorbiaceous and has the scientific denomination of *Jatropha curcas* Linnaeus. It has common names such as a physic nut, pignut, purging nut or wild oil nut. It is a large shrub or a small tree which has the maximum height not exceeding 6 meters. It is monocious and succulent plant that sheds its leaves during the dry (Gerpen *et al.*, 2004).

2.5 Oil Extraction

The ripe fruits are plucked from trees and dried to decorticate seeds. The seeds subjected to dry either in sunlight or roasting pan to accelerate the oil extraction. The heating process helps to breakdowns the cells that contain the oil and liquefy the oil which improves the extraction process. The oil extraction can be done by mechanical expeller and chemical extraction methods. Mechanical expeller is a method for extracting oils from seeds by hand or electrical expeller. Chemical extractions extract the oil from oils seeds using common solvents such as hexane, petroleum distillates, alcohol, and ester. Solvent extracting plants are expensive and only suitable for large volumes (Halder *et al.*, 2012). Mechanical oil expellers can extract 28.4% to 42.3% of the oil from plant seeds (Heller, 1999).

2.6 Oil Purification

The vegetable oil can be purified by the following common methods

A) Sedimentation

Sedimentation is the easiest way of oil purification method. However, sedimentation takes about a week until 20-25% of the raw oil is separated from the sediment.

B) Boiling in water

Boiling the oil in water can accelerate purification process. In this purification method boiling continues until all water has evaporated (until bubbles of water vapor removed).

C) Filtration

Filtration is a very slow process of oil purification method. It takes several weeks to separate the oil from the residues.

2.7 Calorific values of jatropha oil

The energy content of jatropha oil is a promising energy source (Chalatlon *et al.*,2011). The following table shows energy contents of biofuels and kerosene fuels .The Jatropha oil has comparable energy content of kerosene and it is higher than ethanol fuels.

Table 1: Calorific values of some fuels

Fuel	Calorific value (MJ/kg)	Source
Kerosene	43.3	(Zhang <i>et al.</i> , 2000)
Jatropha oil	37.65	(Chalatlon <i>et al.</i> , 2011)
Ethanol	26.8	(Roden <i>et al.</i> , 2006)

2.8 Modification of plant oils

The use of vegetable oils in diesel engines begun in the 1930s and 1940s when vegetable oils were used as diesel substitutes (Boonmee *et al.*, 2010). Currently, because of increase in fossil fuel prices, limited resources of fossil fuel and environmental concerns developing and utilizing alternative fuels such vegetable oils get attention in many countries. However, higher viscosity of plant oils which leads to problems in pumping and atomization characteristics is an existing major problem in utilizing vegetable oils. The combination of high viscosity and low volatility character of vegetable oils causes poor cold starting and high carbon deposit formation. Thus, to utilize vegetable oils it must be chemically modified to a more suitable and compatible form of fuel (Kanpur and engineering, 2015).

A) Blending

Blending is the process of mixing of vegetable oils with other fuels such as petroleum and alcohol fuels to reduces the viscosity of the vegetable oil and make it suitable for easy combustion (Henning, 2008).

B) Micro-emulsion

Micro-emulsion is scattering of optically isotropic fluid formed from two immiscible liquids. It improves spray characteristics by explosive vaporization of the low boiling constituents in the micelles (Henning, 2008) .

C) Pyrolysis

Pyrolysis is chemical conversion of one substance into another through heat with presence of a catalyst. Pyrolysis of vegetable oils keeps acceptable amounts of sulfur and sediment (Henning, 2008).

D) Transesterification

Transesterification is the reaction of fat or oil with alcohol to form esters and glycerol as a by-product. Methanol and ethanol are added most frequently due to their low cost and chemical advantages .Catalyst such as sodium hydroxide and potassium added to allow the reaction to proceed at a reasonable rate (Freedman *et al.*, 2001).

2.9 Plant oil cook stoves

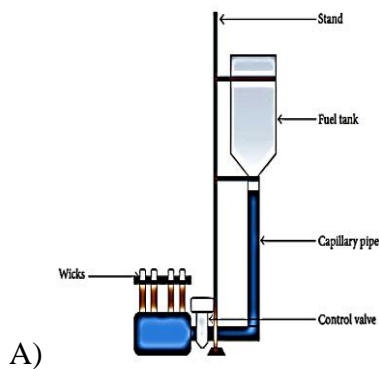
High ignition points of plant oils related to its high viscosity require special adaptation mechanism of the cooking stoves. Only a few attempts have been made to develop cooking stoves which utilize plant oils. Since the viscosity of plant oil is many times higher than a viscosity of kerosene, common wick type cookstoves are not suitable for the utilization of plant oils. Therefore, researchers have been focused on utilization of plant oils on gravity and pressure stoves (Yadav and Ashok, 2013); (Stumpf, 2007(pic.B)).

a) Gravity stove

Gravity stove has a fuel tank separate from the stove and the stove fueled by gravity force. The fuel tank placed at a height at least longer than height of upper wick and the stove consumes the fuel by capillary action.

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The height produces a required force to overcome the resistance encountered by the fuel during flow through wicks. A control valve used to control fuel flow (Halder *et al.*, 2012(pic.A) .



B) Figure 1: Gravity and

Pressure cook stoves (A&B) respectively

b) Pressure stove

Pressure plant oil cook stove has induced pressure in a tank through the application of pump. The liquid evaporates in the vaporizer made of a stainless steel tube and exits through a nozzle into a combustion area, where it mixes with ambient air and burns. The power is adjusted with a valve by regulating the fuel flow. The stove needs a small amount of ethanol added to a pre-heating plate below the vaporizer (Stumpf, 2002) .

2.10 Viscosity

Viscosity is the internal friction of fluids caused by molecular attraction or internal interaction of fluid and resists fluid flow. Fluids with higher viscosity required the greater amount of force (shear) to cause this movement. Shearing occurs whenever the fluid physically distributed as pouring, spreading, spraying and mixing. In determination viscosity of liquid the sample placed in the concentric cylinder and viscosity measured on a viscometer. Viscometer measures the torque required to rotate the spindle which is driven by a motor through calibrated spring. Viscosity is the most important characteristic that influences the degree of pre-heat required for handling and atomization.

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Temperature has known having high influences on viscosity of fluids. Generally the viscosity of a fluid decreased as temperature increased (Brookfield engineering, 2014).

Table 2: viscosity of some plant oils at different temperatures

Oil	Temperature (°C)	Absolute viscosity (Pa·s)	r^2
Avocado	26	0.0576 ± 0.0002	0.9996-1.0000
	38	0.0364 ± 0.0003	0.9996-1.0000
	50	0.0287 ± 0.0006	0.9997-1.0000
Canola	30	0.0462 ± 0.0005	0.9997-1.0000
	50	0.0245 ± 0.0002	0.9993-0.9998
	90	0.0108 ± 0.0004	0.9952-0.9982
Grape seed	26	0.0466 ± 0.0003	0.9997-1.0000
	38	0.0311 ± 0.0001	0.9999-1.0000
	50	0.0227 ± 0.0000	0.9995-1.0000
Macadamia nut	26	0.0583 ± 0.0003	0.9998-0.9998
	38	0.0394 ± 0.0002	0.9816-1.0000
	50	0.0272 ± 0.0012	0.9997-0.9998
Olive	26	0.0562 ± 0.0003	0.9997-1.0000
	38	0.0341 ± 0.0005	0.9994-1.0000
	50	0.0261 ± 0.0003	0.9997-1.0000
	70	0.0157 ± 0.0001	0.9990-0.9992
Peanut	26	0.0574 ± 0.0007	0.9992-0.9996
	38	0.0380 ± 0.0002	0.9999-1.0000
	54	0.0236 ± 0.0003	0.9998-0.9999
Rapeseed	26	0.0592 ± 0.0011	0.9998-0.9999
	38	0.0376 ± 0.0001	1.0000-1.0000
	50	0.0305 ± 0.0001	0.9972-0.9998
Rice bran	26	0.0593 ± 0.0006	0.9996-0.9997
	38	0.0398 ± 0.0001	0.9999-1.0000
	50	0.0280 ± 0.0000	0.9997-0.9999
Safflower	26	0.0445 ± 0.0003	0.9998-1.0000
	38	0.0299 ± 0.0000	0.9989-1.0000
	50	0.0239 ± 0.0005	0.9992-0.9996
Sesame	26	0.0525 ± 0.0007	0.9999-0.9999
	38	0.0351 ± 0.0002	1.0000-1.0000
	50	0.0251 ± 0.0002	0.9995-0.9999
Soybean	30	0.0405 ± 0.0003	0.9993-1.0000
	50	0.0232 ± 0.0001	0.9996-0.9998
	90	0.0098 ± 0.0003	0.9905-0.9980
Sunflower	26	0.0488 ± 0.0002	0.9998-0.9999
	38	0.0323 ± 0.0005	0.9998-0.9999
	50	0.0234 ± 0.0001	0.9975-0.9993
Walnut	26	0.0429 ± 0.0003	0.9998-0.9999
	38	0.0296 ± 0.0002	0.9989-1.0000
	50	0.0212 ± 0.0001	0.9975-0.9972

(Diamante and Lan, 2014)

2.10.1 Viscosity Measurement Techniques

Viscosity measures the torque required to rotate an immersed spindle in a fluid. The spindle is driven by a motor through a calibrated spring; deflection of the spring is indicated by a pointer and dial. For a given viscosity, the viscous drag, or resistance to flow is proportional to the spindle's speed of rotation and is related to the spindle's size and shape. The drag will increase as the spindle size and/or rotational speed increase. It follows that for a given spindle geometry and speed, an increase in viscosity will be indicated by an increase in deflection of the spring. For any Viscometer model, the minimum range is obtained by using the largest spindle at the highest speed; the maximum range by using the smallest spindle at the slowest speed.

I) Record

For Viscosity measurement; viscometer model, spindle, rotational speed, container size or dimensions, sample temperature, time of spindle rotation, sample preparation procedure, and whether or not the spindle guard leg was used should be recorded

I) The Spindle and the Guard leg

To avoid damage to the instrument's pivot point and jewel bearing always lift up on the spindle coupling when attaching a spindle. A good procedure to follow is to immerse and position the spindle in the sample fluid.

II) Selecting a Spindle Speed

When conducting an original test, the best method for spindle and speed selection is trial and error. The goal is to obtain a Viscometer dial or display (% torque) reading between 10 and 100. If the reading is over 100, a slower speed and/or a smaller spindle are selected to correct the problem and if the reading is under 10, a higher speed and/or a larger spindle are selected to correct the reading.

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For given spindle/speed combination, the maximum range is equal to the spindle factor multiplied by 100. The minimum recommended range equals the factor multiplied by 10.

III) Sample Container Size

Standard Viscometer models use a container with an inside diameter of 3 1/4 inches (83 mm) or larger. The usual vessel for this purpose is a 600 cm³. Smaller containers result in an increase in viscosity readings.

IV) Sample Conditions

The sample fluid should be free from entrapped air and at a constant and uniform temperature. Temperature uniformity can often be maintained by agitation prior to a measurement. Factors used to calculate viscosity values from the viscometer readings are independent of temperature. A constant temperature water bath is used to maintain the desired temperature. Homogeneity of the sample is quite important, especially in dispersed systems where settling can occur. In many cases, simple stirring just prior to the test will keep the components dispersed.

V) Spindle Immersion

The spindle should be immersed up to the middle of the shaft indentation. In some cases the sample fluid may change its rheological structure during the act of spindle immersion.

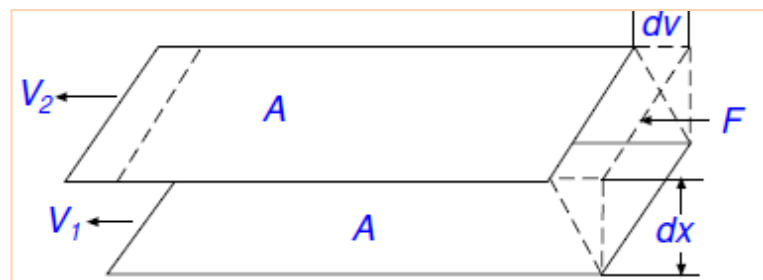
VI) Obtaining a Viscometer Reading

Turn the Viscometer on and allow it to run until a constant reading is obtained. Some overshoot since momentum gained by the spindle during acceleration may cause the reading to initially oscillate about the final equilibrium value.

A number of procedures can be employed to obtain a satisfactory reading. In some cases, as much as 5 minutes must be allowed for the reading to reach equilibrium.

2.10.2 Viscosity Basics

Viscosity is the measure of the internal friction of a fluid. This friction becomes apparent when a layer of fluid is made to move in relation to another layer. The greater the friction, the greater the amount of force required to cause this movement, which is called shear. Shearing occurs whenever the fluid is physically moved or distributed, as in pouring, spreading, spraying and mixing. Highly viscous fluids, therefore, require more force to move than less viscous materials.



$\frac{F}{A} = \mu \frac{dv}{dx}$, μ is constant for each material and called its viscosity. The velocity gradient $\frac{dv}{dx}$ is a measure of the change in speed at which the intermediate layers move with respect to each other. It describes the shearing that the liquid experiences and is thus called Shear rate and symbolized as γ (sec^{-1}).

The term F/A indicates the force per unit area required to produce the shearing action. It is referred to as “shear stress” and will be symbolized by τ (dynes/cm²) or (N/m²).

Using these terms, viscosity defined mathematically by formula

$$\mu = \frac{\tau}{\gamma} = \text{viscosity} = \frac{\text{shear stress}}{\text{shear rate}}$$

The fundamental unit of viscosity measurement is poise. A material requiring a shear stress of one dyne per square centimeter to produce a shear rate of one reciprocal second has a viscosity of 1 poise, or 100 centipoise. Viscosity measurements can be expressed in Pascal-seconds (Pa•s) or milli-Pascal-seconds (mPa•s).

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A) For cylindrical spindles on Brookfield Viscometer

$$\text{Shear rate (sec}^{-1}\text{)} = \gamma = 2\omega R_c^2 R_b^2 / X^2 (R_c^2 - R_b^2)$$

$$\text{Shear stress (dynes/cm}^2\text{)} = \tau = M / 2\pi R_b^2 L$$

$$\text{Viscosity } (\mu) = \frac{\tau}{\gamma}$$

ω =angular velocity of spindle (rad/sec)

R_c =radius of container (cm) ,

R_b =radius of spindle (cm)

X =radius at which shear rate is being calculated (cm)

M =torque input by instrument (dyne-cm),

L =effective length of spindle (cm)

B) Temperature Dependence of Viscosity

The viscosity of most fluids decreases with an increase in temperature. By measuring viscosity at two temperatures (using a single spindle and speed), it is possible to predict a flow curve representing the temperature dependence of the viscosity of a fluid according to the following relationships using the equations:

$$\mu = A . e . power \left(\frac{B}{T} \right)$$

$$B = \left(\frac{T_2 * T_1}{T_2 - T_1} \right) . \text{Ln} \left(\frac{\mu_2}{\mu_1} \right)$$

$$A = \mu_1 . e . power \left(\frac{-B}{T_1} \right)$$

T_1 = Temperature at which viscosity η_1 was measured

T_2 = Temperature at which viscosity η_2 was measured

2.11 Cook stove performance

A) Thermal Efficiency

Cookstove efficiency is the ratio of the work done by heating and evaporating water to the energy consumed by burning fuel. It estimates the total energy produced by the fire used to heat the water in the pot. A higher thermal efficiency of cooking stoves indicates a greater ability to transfer the heat produced by the burning to the cooking pot. The thermal efficiency of cook stove is determined using standardized water boiling test, which divided into three testing phases cold start high power test, hot start high power test and low power (simmering) test (Roden *et al.*, 2006). The cold start high power test phase begins with the pot, stove, and water at room temperature while hot start high power test phase begins immediately after cold start high power test phase is completed. The stove is then adjusted to a low power (simmering) test about 3°C below boiling point for 45 minutes. Water boiling test is used to determine the thermal efficiency, specific fuel consumption, firepower and other performance indicators of the cooking stove. Thermal efficiency, Specific fuel consumption, and firepower of the cook stove are calculated using the following equations ,

$$\text{Eff (\%)} = \frac{\left(\frac{4.186 \text{ kJ}}{\text{kg}\cdot\text{K}}\right) \cdot (p_i - p) \cdot T_f - T_i + 2260 \text{ kJ/kg} \cdot w_v}{(\text{fuel mass}(f_m) \cdot \text{LHV})} \quad (1) \text{ (Roden } et al., 2006)$$

Where P_i = weight of pot with water before (g)

P = weight of the empty pot (g)

T_i (°C) = water temperature before test

T_f (°C) = water temperature after

WV = water vaporized (g) f_m = mass of fuel (g),

LHV (J/g) = lower heating value for fuel.

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B) Specific fuel consumption

Specific consumption is the parameter that calculates fuel required producing a unit output. Specific fuel consumption is a measure of the amount of fuel required to produce one liter of boiled water starting with cold stove.

$$\text{Specific fuel consumption (g/L)} = \frac{\text{mass of fuel(gm)}}{\text{mass of boild water(L)}} \quad (2) \quad (\text{Roden } et \text{ al., 2006})$$

C) Fire power

Fire power is a measure of the fuel energy consumed to boil the water divided by the time to boil it .firepower tells the average power output of the stove (in Watts).

$$\text{Fire power (w)} = \frac{\text{mass of fuel(kg)} \times \text{LHV} \left(\frac{\text{kJ}}{\text{kg}} \right)}{\text{time to boil(sec)}} \quad (3) \quad (\text{Roden } et \text{ al,2006})$$

Table 3: performance of some improved cookstoves in Ethiopia

Stove type	Test method	Efficiency (%)	Specific fuel consumption (g/ L)
open fire	WBT	11	160
Tikikil	WBT	26	75
Lakech	WBT	38	290
Tradition	WBT	23	550
Ethanol(double burner) stove	WBT	65	----

(GIZ-SUN:energy, 2007) :(Stokes, 2007)

2.12 Cook stove emission measurement

There are two types of cook stove emission known as total and indoor emissions. Indoor emissions are measured only from the stove excluding emissions from the chimney while total emissions measured by capturing emissions from the stove and from the chimney through the hood and duct system.

A) Direct stack sampling method

Direct stack sampling method measures emissions by draws sample directly from the chimney. It doesn't work for stoves without a chimney (Roden *et al.*, 2006).

B) Room method

Room method is a simple setup of emission measurement if a suitable room is available. It needs extra equations to infer emission rate (Roden *et al.*, 2006). In Room method emission measuring set up gas analyzer puts in some place in the room related to the position of the stove.

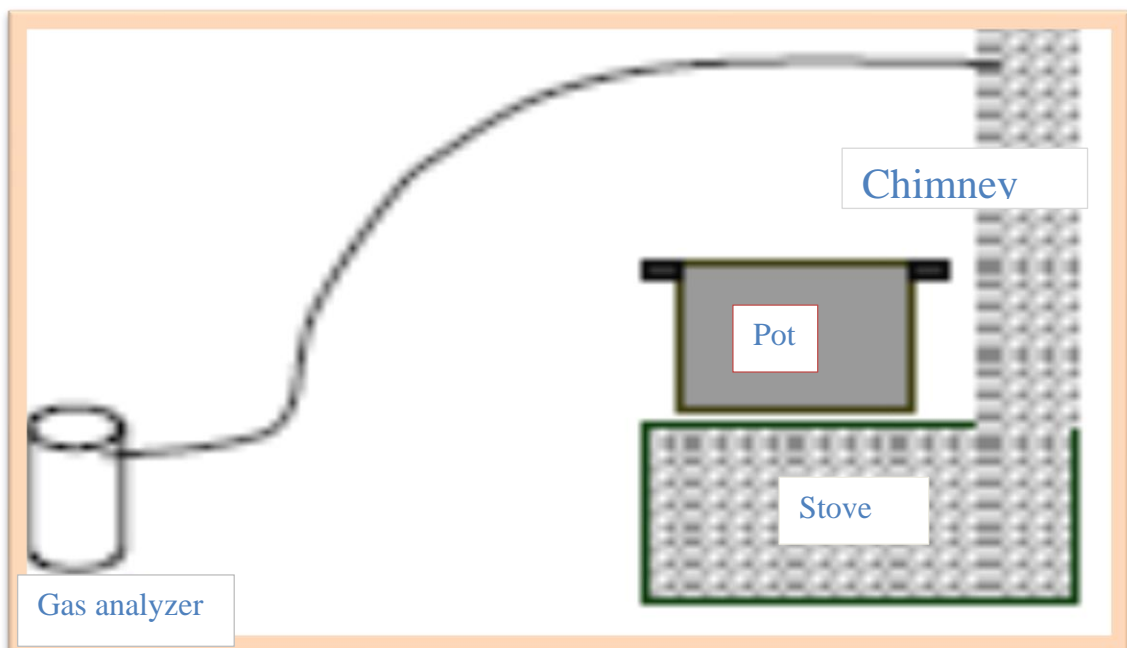


Figure 2: direct stack emission measuring set up

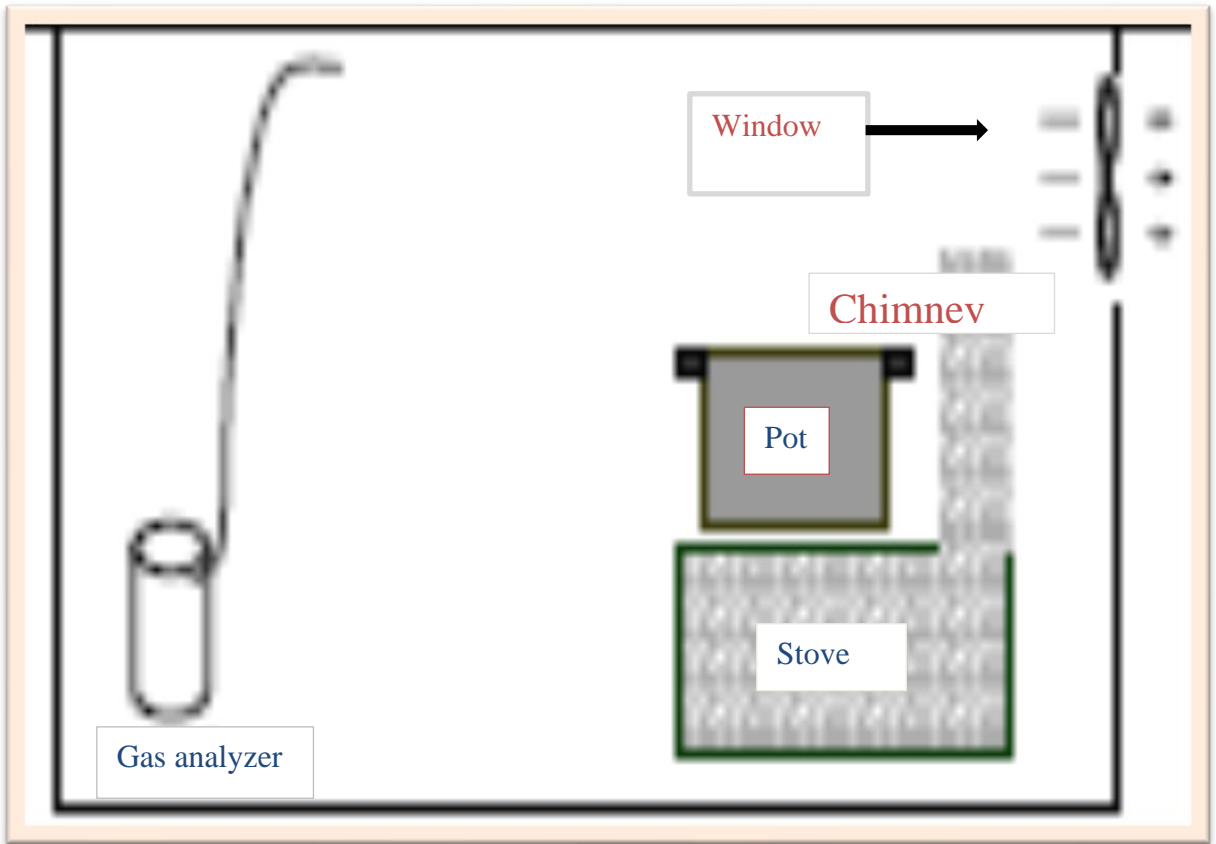


Figure 3: Room method emission measuring set up

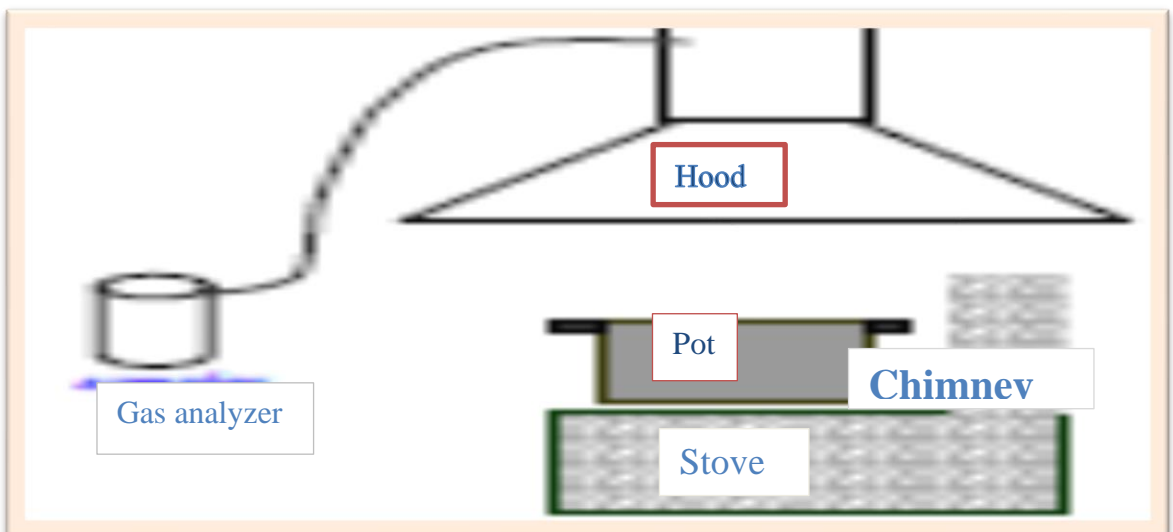


Figure 4: Hood method emission measuring set up

C) Hood method

The Hood method emission measurement shows instantaneous changes in combustion and used to measure flow rate of the flue gas in the duct .It is the most accurate method but difficult to build an exhaust hood and is less portability (Roden *et al.*, 2006).

Table 4: Emission of some improved cook stoves in Ethiopia

Stoves	Test method	CO emission (g/2.5 L)	CO ₂ emission (g/2.5 L)
Lakech	WBT	79	531
Merchaye	WBT	66	625
Tradition	WBT	92	681

Source (Fikadu *et al.*, 2017)

IWA Guidelines for evaluating performance of Cookstoves

The International Standards Organization with collaborate (IWA) Global Alliance for Clean Cookstove approved performance evaluation tiers (Dean Still *et al.*, 2014).

Table 5: IWA tiers description (IWA/ISO: 2012)

Tiers	Description
0	No improvement over the open fire/baseline
1	Measurable improvement over baseline
2	Substantial improvement over baseline
3	Currently achievable technology for biomass stoves
4	Stretch goals for targeting ambitious health and environmental outcome

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Table 6: Tiers for selection and ranking of stoves (adapted from ISO/IWA: 2012)

Tiers	Fire power (watt)	Low power specific consumption (MJ/min/L)
0	<500	>0.050
1	≥500	≤0.050
2	≥750	≤0.039
3	≥1000	≤0.028
4	≥1500	≤0.017

CO emission		
Tiers	High power CO (g/MJd)	Low power CO (g/min/L)
0	>16	> 0.20
1	≤ 16	≤ 0.20
2	≤ 11	≤ 0.13
3	≤ 9	≤ 0.10
4	≤ 8	≤ 0.09

PM2.5 emissions		
Tiers	High power PM2.5 (mg/MJd)	Low power PM2.5 (mg/min/L)
0	>979	>8
1	≤979	≤8
2	≤386	≤4
3	≤168	≤2
4	≤41	≤1

Indoor emissions		
Tiers	Indoor emissions CO (g/min)	Indoor emissions PM2.5 (mg/min)
0	0.97	40
1	0.97	40
2	0.62	17
3	0.49	8
4	0.42	2

Characteristics of tested cook stoves

Kerosene stove

The kerosene stove is barrel-shaped steel constructed with a series of vertical slots on its sides. It has adjustable textile which allow for power adjustments during operation. This stove has a potholder with three pot stands mounted on top. It has power control knob to increase and decrease power by adjusting upwards and downwards movement of the textile wicks (Makonese *et al.*, 2012).

Ethanol stove

The ethanol stove is made of stainless steel constructed in cylindrical shape and has a pot seat on top. It has cylindrical fuel holder with air supply holes around in the middle part of the stove. The bottom of the stove contains a black plastic plate with four feet to support the stove. The stove refueled through the combustion opening, refueling during operation is not possible. The stove has a lever to regulate the intake of primary air aiding in controlling the power level (MWE, 2012).

Jatropha oil stoves

Kakute and protos plant oil stoves are developed for utilizing plant oils but the functional didn't verify to be a competitive alternative to existing systems. Studies reported that the viscous plant oil cannot use in common wick stoves and therefore researchers focused on pressure and gravity stoves to utilize plant oils. The gravity plant oil stove is described by (Halder *et al.*, 2012) needs fuel tank separated from the stove and stands to hold the fuel tank at least at a height above the wicks. Pressure plant oil stove described by (Stumpf, 2007) needs fuel tank with induced pressure and pump to push fuel to stoves. Both the pressure and gravity plant oil stoves described needs extra section other than the stove. In present study, a simple jatropha oil cook stove has been constructed stove without wicks.

CHAPTER 3: MATERIALS AND METHODS

3.1 Materials and Equipment

The material and equipment used to conduct this study includes stoves (kerosene, ethanol Jatropha oil stove) ,fuels (ethanol, kerosene and jatropha oil) ,water, Brookfield DV2T viscometer, Bielenberg Ram oil extracting press, balance, measuring cylinders, thermocouple, gas analyzer, emission hood, aluminum pots ,stopwatch and others.



Figure 5: some of the materials used for the study

3.2 Experimental Methods

3.2.1 Study area description

The Viscosity, performance and emission tests are carried out in the laboratory of section of alternative energy technology development and promotion directorate under Ministry of Water, Irrigation and electricity, Addis Ababa, Ethiopia.

3.2.2 Experimental framework of the study

The studies were categorized into viscosity, performance and emission measurement subgroups. Viscosity was measured at temperatures 20, 30,40,50,60,70,80,90 & 100 °c and at 10, 20, 30 and 40 % jatropha oil blended with kerosene and ethanol. Thermal efficiency, Specific fuel consumption, and CO emission tests were conducted on kerosene, ethanol and Jatropha oil stoves.

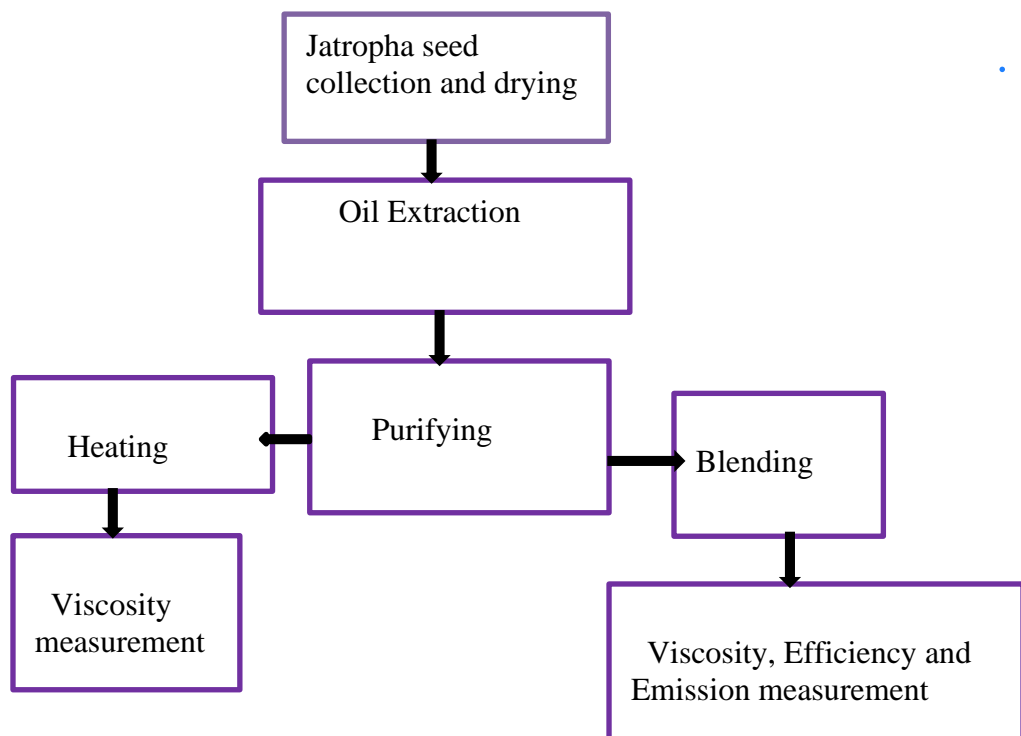


Figure 6: General framework of the study

The framework of this the study was categorized into groups: 1) Viscosity tests, 2) performance and emission testing.

The collected jatropha seed was dried using sunlight to accelerate its oil extraction then the extracted oil purified through sedimentation and filtration to remove residues. Dependency of viscosity of jatropha oil and temperature or on blended with Ethanol and Kerosene was analyzed by linear regression analysis was done using linear regression test. A two-tailed T-test and one way ANOVA analysis was applied to test the difference in thermal efficiency and CO emission characteristics of Ethanol and kerosene stoves with blended fuels. All analysis was done at 95% confidence level by SPSS software version 20.

3.2.3 Materials Preparation

Jatropha seed and ethanol was supplied by the alternative energy technology development and promotion laboratory. The commercial kerosene fuel was purchased from a nearby petroleum station. Bielenberg ram press was used to extract oil from the seeds. The crude oil was allowed to settle and decant to remove residues.

3.3 Viscosity test

About 300 cm³ of Jatropha oil was taken to 600 cm³ volumetric glass to measure the viscosity using Brookfield viscometer model DV2T. The spindle screwed into the underside of the viscometer, the cup containing sample was carefully locked into position so that the spindle cone would be completely immersed in the sample, the machine was switched on and readings of viscosity, torque, and speed of rotation of the spindles were observed after about ten seconds rotation of the spindle in the container viscosity data recorded when the torque is between 10 % and 100 % if the torque is out of this value the spindle type or speed of rotation of the spindle is adjusted to correct the reading. Brookfield Viscometers has the accuracy to within ± 1 m.pa.s of the spindle/speed combination in use (Brookfield engineering, 2014).



Figure 7: viscosity measurement set up (Lake B.,2018)

3.4 Water boiling test

The Water Boiling Test (WBT) which is used for clean cook stove performance evaluation protocol was applied to measure the performance and emissions of the kerosene, ethanol and jatropha oil stoves. The test was conducted three times on each type of fuel on the same stove. Two high power testes and one low power test were done on the stoves. However analysis was done only on data collected from high power water boiling tests. Parameters on lower power test are not indicating the real performance of the stove sine it allowed to operate on lower energy consumption.

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Table 7: Experimental layout of WBT

Tests	Fuel type	Stove type	Emissions recorded
Test-1			
Test-2	Ethanol	Ethanol	CO and CO ₂
Test-3			
Test-1			
Test-2	J10E90	Ethanol	CO and CO ₂
Test-3			
Test-1			
Test-2	J20E80	Ethanol	CO and CO ₂
Test-3			
Test-1			
Test-2	J40E60	Ethanol	CO and CO ₂
Test-3			
Test-1			
Test-2	Kerosene	Kerosene	CO and CO ₂
Test-3			
Test-1			
Test-2	J10K90	Jatropha oil stove	CO and CO ₂
Test-3			
Test-1			
Test-2	J20K80	Jatropha oil stove	CO and CO ₂
Test-3			
Test-1			
Test-2	J40K60	Jatropha oil stove	CO and CO ₂
Test-3			

3.5 Emission tests

The Hood method described by (Roden *et al.*, 2006) was used for determining the emissions of cooking stoves using water boiling test protocol. However, due to the absence of test setting hood in the laboratory, hood settings have been constructed based on the Indian standard for testing biomass cookstoves. CO and CO₂ were measured continuously with a Testo 330-LL flue gas analyzer. The analyzer has an accuracy of ± 20 ppm CO with measuring range (0 to 4000 ppm CO) and 1ppm resolution. The reaction time for the analyzer is approximately 40s. The analyzer is automatically calibrated daily at start-up through its zero calibration function (Testo, 2010). The stove to be tested is placed under a natural draft ventilation hood and duct and the gas sample probe is placed inside a hood exhaust duct. Since a high extraction rate may influence the thermal characteristics of the stove an extractor fan was not used for drawing air through the hood and duct. The hood method of determining emissions can be used simultaneously for the determination of performance in a systematic and standard manner (Roden *et al.*, 2006).

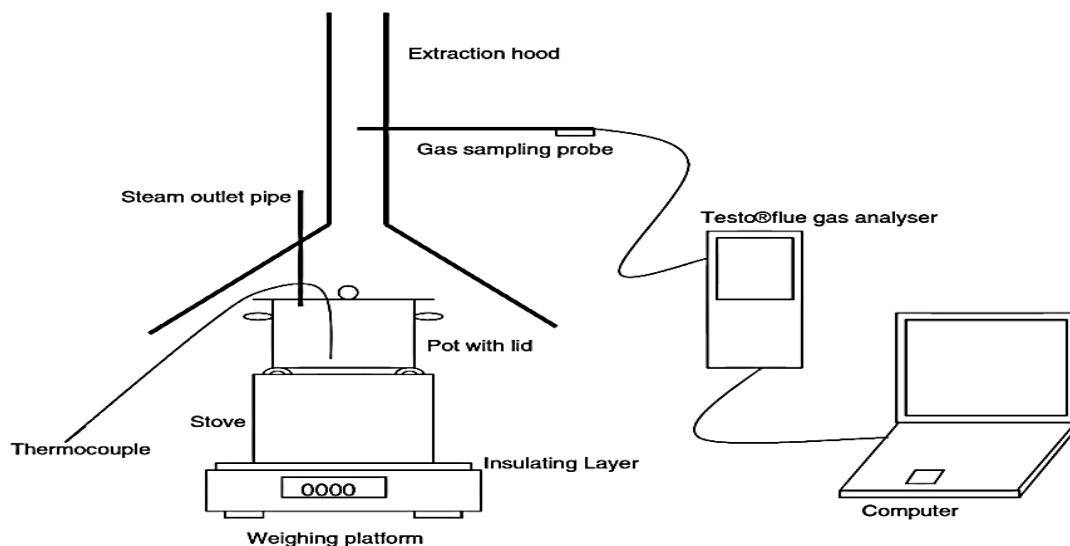


Figure 8: Emission test set up

(Makonese *et al.*, 2012)

During emission testing cooking stoves placed inside the hood .The following set up shows test set up of emission testing using hood system and gas analyzer. The analyzer inserted to the hood after the probe is coupled with the analyzer.



Figure 9: Emission test set up (Lake B., 2018)

3.6 Statistical data analysis

Linear regression test at the 95% level of confidence ($p < 0.05$) was used to evaluate the temperature-viscosity relationship of jatropha oil and kerosene/ethanol-blended fuels. A two-tailed student T-test and one way ANOVA at the 95% confidence level ($p < 0.05$) statistical test were used to evaluate of the differences in thermal efficiency, specific fuel consumption, firepower and CO emissions between the blended and base fuels.

CHAPTER 4: RESULT AND DISCUSSION

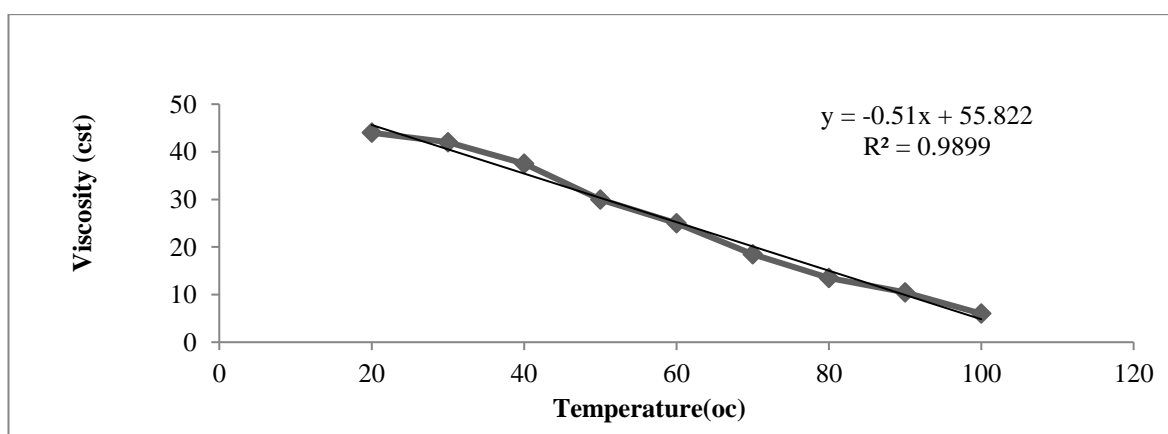
4.1 Extraction of jatropha oil

In present study, Bielenberg Ram Press mechanical expeller was used to extract the jatropha oil from dried Jatropha seeds. Twenty-kilograms of dry jatropha seed were pressed by Bielenberg Ram Press and it gave 5.2 kg of crude oil. The extraction shows that 26% of the jatropha seed is crude oil by weight. (Chalatlon *et al.*, 2011) reported that extraction with Bielenberg rams press, thirty-two-kilograms and forty two-kilograms of Jatropha seed yield 6.88kg and 11.71kg crude oil by weight respectively. The first extraction shows 21% of the dried jatropha seed by weight is crude oil while the second shows 28% of the dried jatropha seed is crude oil by weight. The maximum amount of oil that can be extracted from jatropha seeds depends on method of extraction (mechanical or chemical) and the quality of the seed.

4.2 Viscosity reduction methods

According to (Pramanik *et al.*, 2003) heating and blending of plant oils with alcohol and petroleum fuels help to reduce the viscosity.

A) Effect of temperature on viscosity of jatropha oil.



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Figure 10: Approximate linear graph for temperature -viscosity relationships

The statistical analysis of viscosity of the jatropha oil shows significant reduction ($p < 0.01$) on heating. Diamante and Lan, (2014) reported that of the viscosity values of all the tested vegetable oils decrease with increasing temperature. According to Diamante and Lan, (2014) the r^2 values above 0.9 shows a presence of a very strong relationship between viscosity of plant oils and temperature.

B) Effect of ethanol addition on viscosity of jatropha oil

The viscosity of blended fuels at 10, 20, 30 and 40 % jatropha oil with ethanol were measured using calibrated viscometer model DVT2. The viscosity of the Jatropha oil significantly decreased through blending with ethanol ($p < 0.018$) with r^2 value 0.9834.

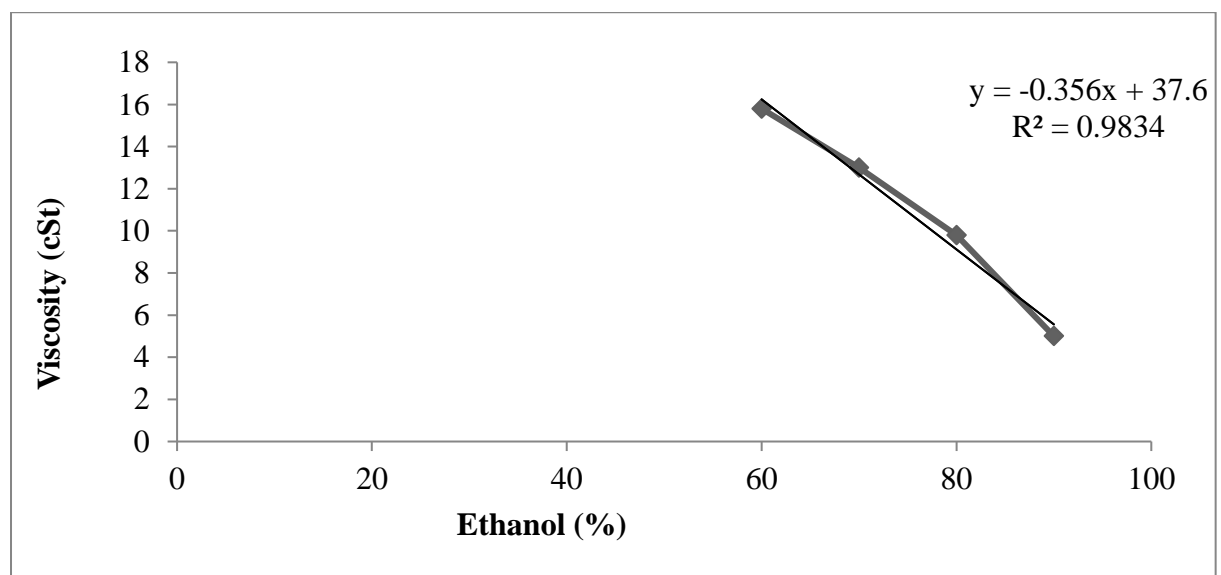


Figure 11: Viscosity of the ethanol-Jatropha oil blended fuels

According to Diamante and Lan, 2014 the slope of the regression (r^2) values above 0.9 shows a presence very strong relationship between tested variable. The coefficient of regression of the viscosity to addition of jatropha oil showed 0.9834 indicated presence of a strong relationship between viscosity and amount of jatropha oil addition in the blend.

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The viscosity of blended fuels increased with increased of jatropha oil. Prbakaran and Dinoop Viswanathan, (2018) reported ethanol addition on cotton oil reduced its viscosity.

C) Effect of kerosene addition on viscosity of jatropha oil

The viscosity of blended fuels at 10, 20, 30 and 40 % jatropha oil with kerosene are shown in table 10. Viscosities of blended fuels significantly increased with increased of jatropha oil ($p < 0.023$). The slope of regression (r^2) of the viscosity to addition of jatropha oil showed 0.9754, which indicated presence of a strong relationship between viscosity and jatropha oil addition .A viscosity of blended fuels increased with jatropha oil increased Chalatlou *et al*, (2011) reported that addition of diesel reduced viscosity of jatropha oil.

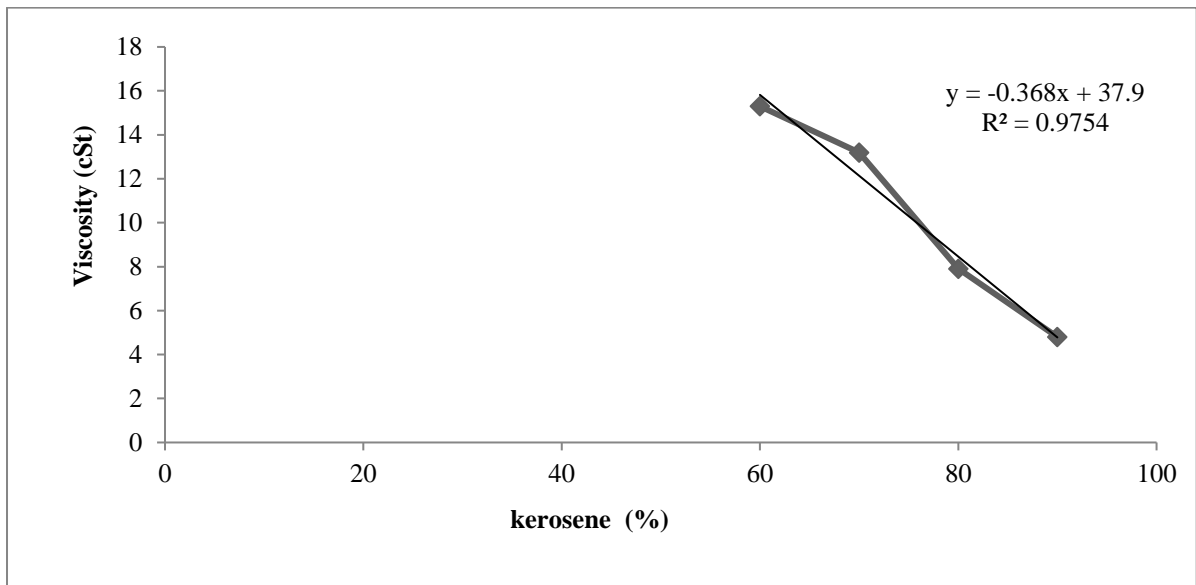


Figure 12: Viscosity of jatropha oil-kerosene blended fuels

4.3 Development of modified jatropha oil stove

The gravity plant oil stove developed by (Halder *et al.*, 2012) and pressure plant oil stove developed by (Stumpf, 2007) for utilization of plant oil in cookstoves.

In the present study, a simple jatropha oil cookstove has been constructed based these plant oils without and pressure tank.

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The stove is cylindrical in shape, constructed from stainless steel and has pot seats on the top. To control the combustion of the stoves allowed operates limited amount since no controlling valve for the entrance of the fuel to the stove. The stove is constructed based on designs given below.

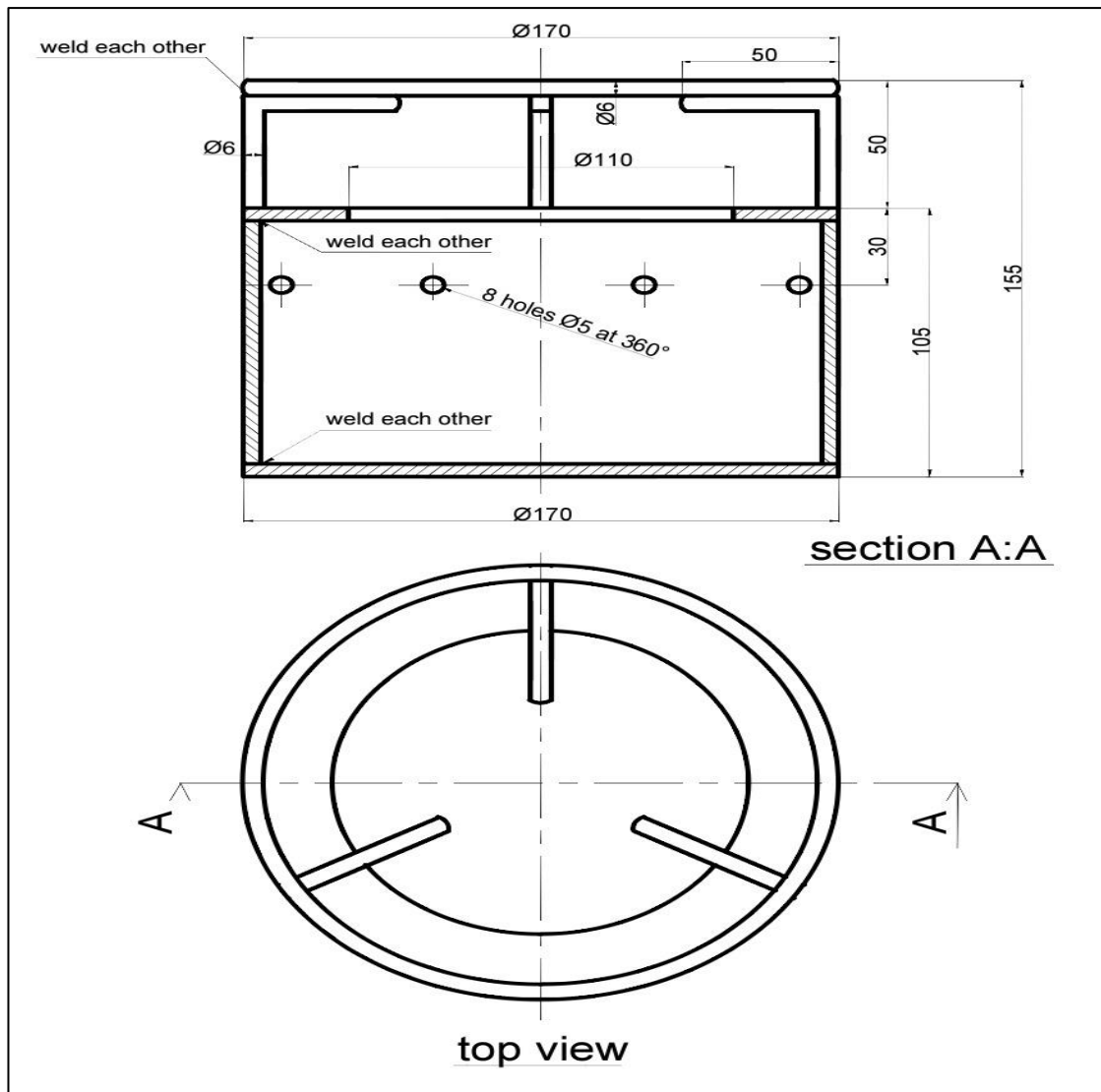


Figure 13: Top view of the Jatropha oil stove

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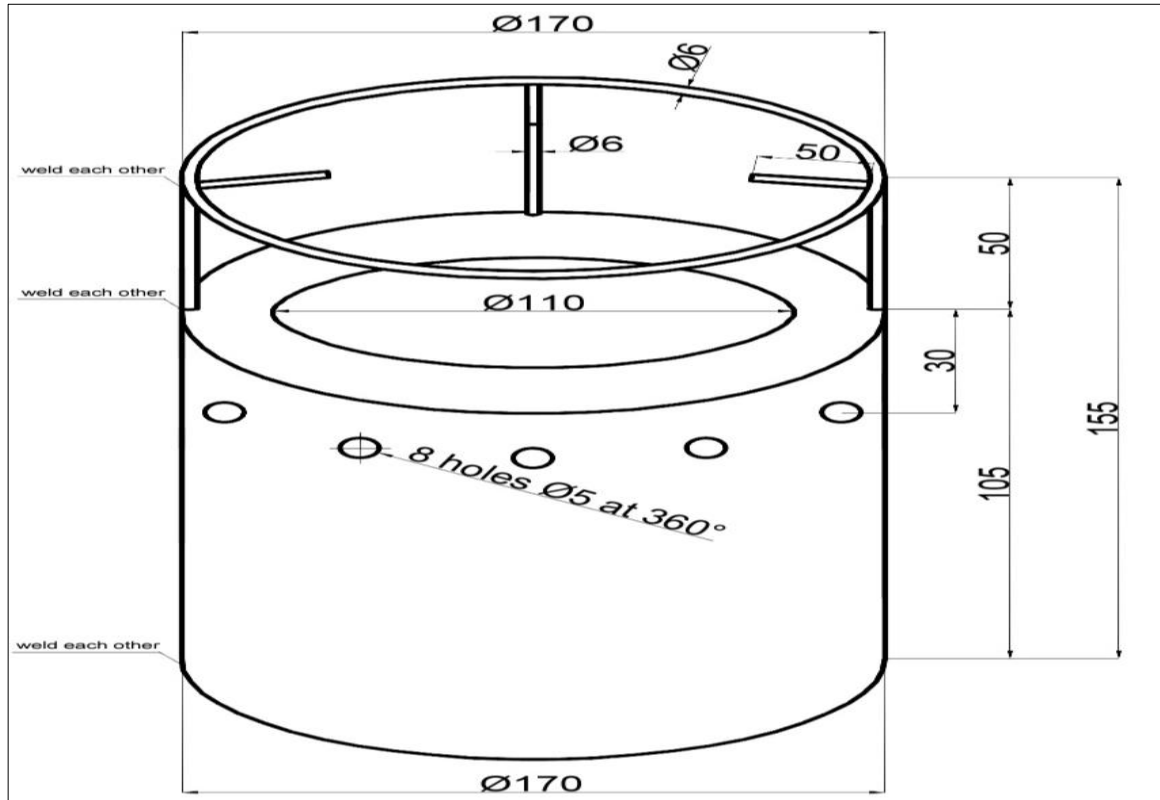


Figure 14: Complete design the stove



Figure 15: Jatropha oil stove (Lake B., 2018)

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4.4 construction of emission testing hood

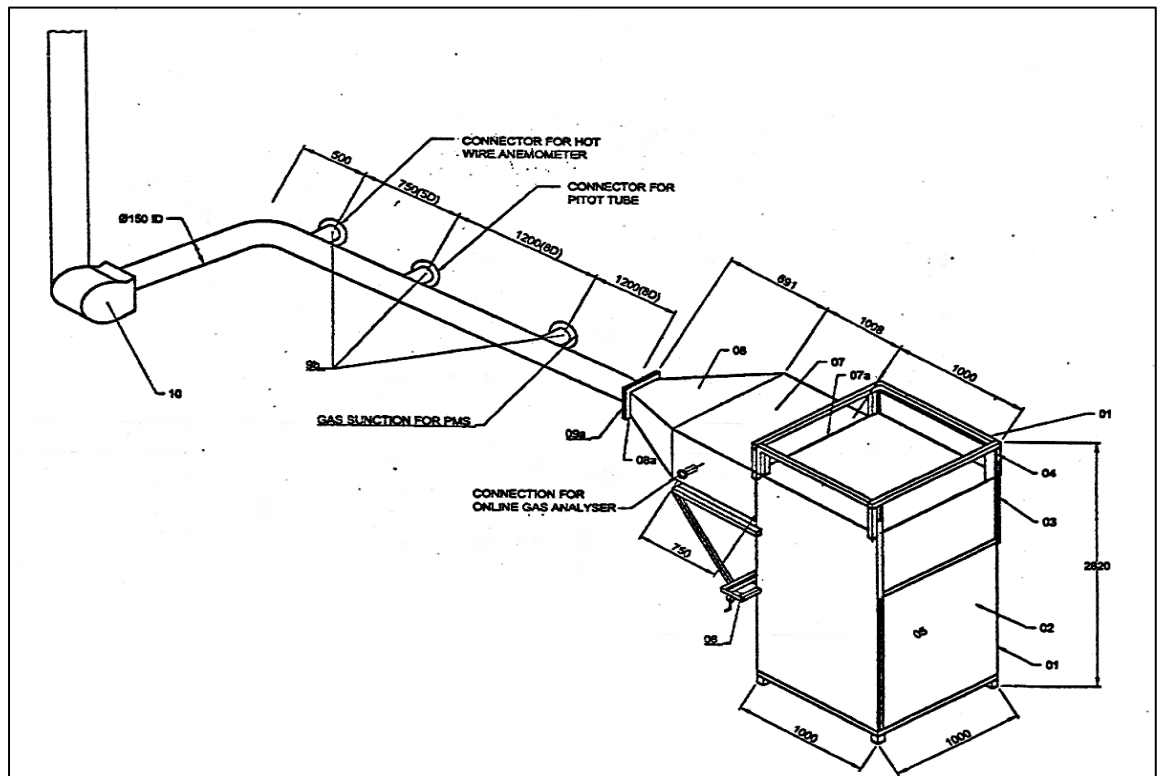


Figure 16: Complete design of the emission testing Hood

10	Suction blower	Fitted with FVD / Damper Max. delivery 1500 cu. M / hr.		1 Set
06b	Connector for fixing instruments with gas duct	As per drawing	M.S.	3 Set
09a	Flange of gas discharge duct	As per drawing	M.S.	1 Set
09	Gas discharge duct	Ø 150 mm LD, x 2 mm thick	S.S.	1 Set
06a	Flange of convergent Nozzle	As per drawing	M.S.	1 Set
06	Convergent Nozzle	As per drawing	M.S.	1 Set
07a	Flange of gas mixing chamber	As per drawing	M.S.	3 Set
07	Gas mixing chamber	As per drawing	M.S.	1 Set
06	drum arrangement for hoisting of door of hood	As per drawing	M.S.	1 Set
05	Toughen glass of door	As per drawing	Glass	1 Set
04	Hoisting arrangement of door hold	As per drawing	M.S.	1 Set
03	Guide for vertical movement of door	As per drawing	M.S.	1 Set
02	Sliding door with roller arrangement	As per drawing	M.S.	1 Set
01	Chassis of hood	50 x 60 x 2.9 Sq. hollow sec.	M.S.	1 Set
Part No.	Part name	Description	MAT.	Nos. Reqd.

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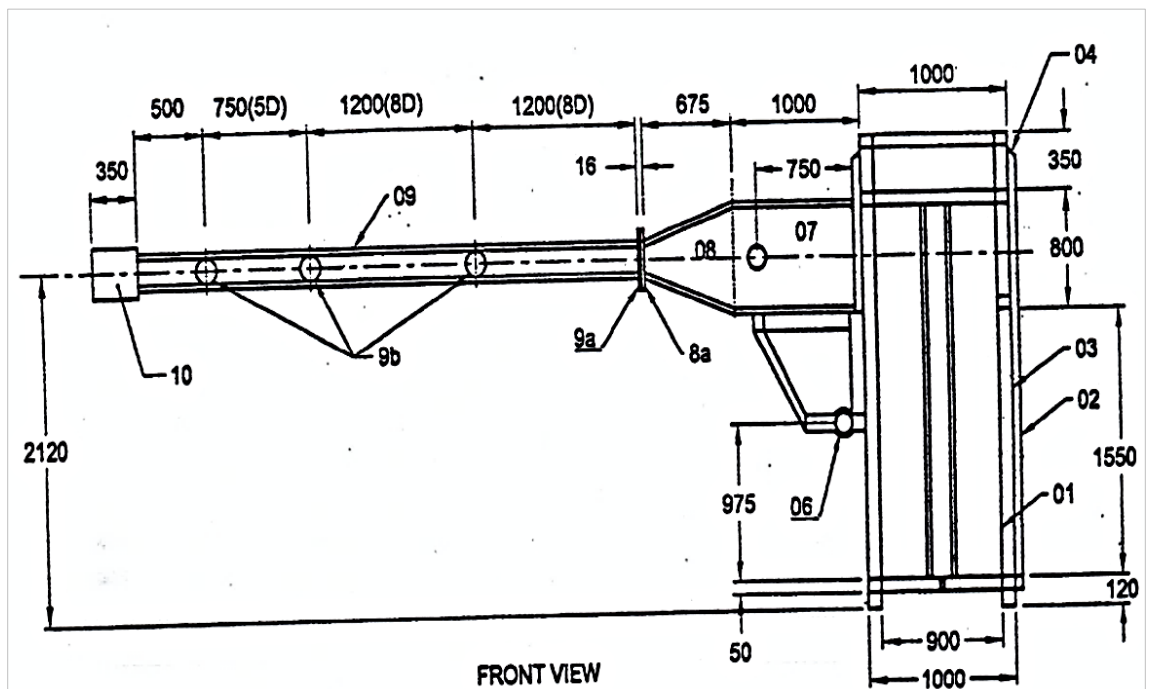
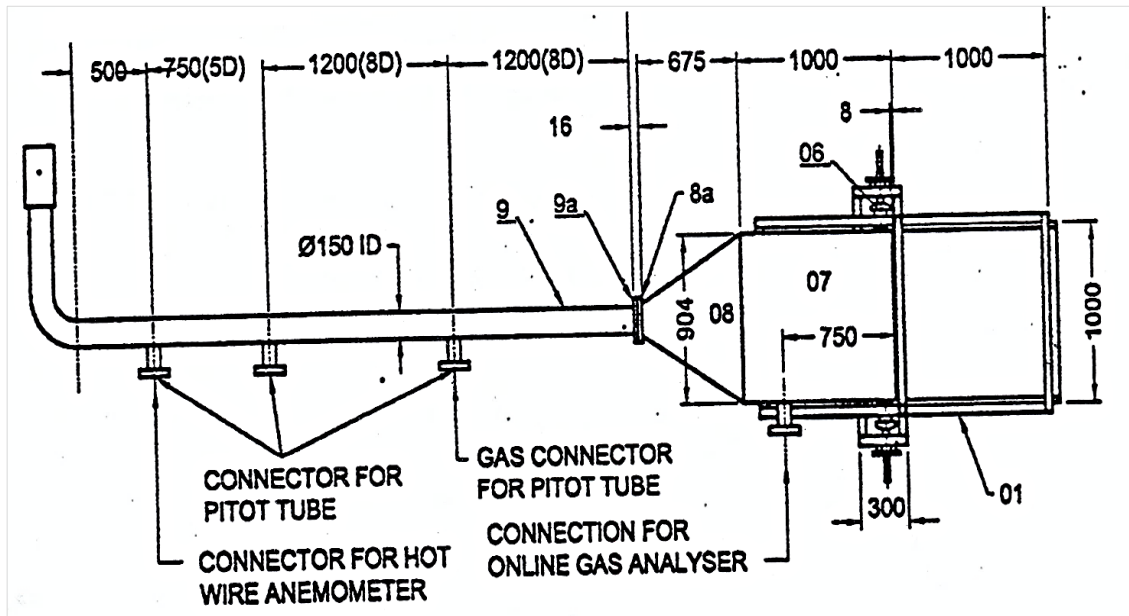


Figure 17: Emission hood design

The Emission hood was constructed from stainless steel to protect the hood from rust and corrosion materials emitted from flue gases in the exhaust. The hood has a glass door to monitor the combustion of the stove during Water Boiling Test.

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The hood has four holes that used to measure the flue gas concentration, particulate matter, flow rate of the flue gas and fluid temperature. The concentration of CO and CO₂ are measured at the mixing chamber part of the hood and the other three are measured at gas discharging duct on different positions. The design of the hood constructed here is adopted from Indian standards for cooking stoves efficiency and emission measurement (Indian Standard for stove testing, 1991).



Figure 18: Emission testing set up (Lake B., 2018)

4.5 Performance and emission test results

In this study thermal efficiency (eff), specific fuel consumption (SFC), firepower (FP) and CO emissions parameters are selected to evaluate ethanol, kerosene, and Jatropha oil stoves on blended fuels.

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All these parameters are tested at high power water boiling test. In blending of 5% jatropha oil very small amount of oil is utilized and therefore the present study started blending from 10% .On the other hand, viscous plant oil cannot be used in common wick stoves, so this study does not used the oil for cooking stoves.

4.5.1 Performance and emission of ethanol stove

Table 8: High power WBT test results of ethanol stove with ethanol

COLD START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Thermal efficiency	%	0.72	0.69	0.7	0.7	0.02	0.03
SFC	g/liter	42	40	43	41.5	1.2	0.03
Firepower	watts	1407	1335	1310	1351	50.2	0.04
HOT START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Thermal efficiency	%	0.73	0.72	0.73	0.73	0.01	0.01
SFC	g/liter	37	39	37	37.5	1	0.03
Firepower	watts	1325	1271	1203	1266	61.1	0.05

Table 9: High power WBT results of ethanol stove with J10E90

COLD START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Thermal efficiency	%	0.72	0.68	0.73	0.71	0.03	0.04
SFC	g/liter	41	41	41	41	0.4	0.01
Firepower	watts	1266	1351	1341	1319	46.2	0.04
HOT START	Units	Test 1	Test 2	Test 3	Mean	St. Dev	COV
Thermal efficiency	%	0.74	0.67	0.75	0.72	0.04	0.06
SFC	g/liter	36	39	37	37.3	1.5	0.04

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Firepower	watts	1097	1199	1378	1225	142.2	0.12
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Table 10: High power WBT results of ethanol stove with J20E80

COLD START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.69	0.7	0.65	0.68	0.03	0.04
SFC	g/liter	43	40	42	41.9	1.8	0.04
Firepower	Watts	1136	1069	1136	1114	38.4	0.03
HOT START	Units	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.69	0.66	0.67	0.67	0.02	0.02
SFC	g/liter	39	39	40	39.4	0.9	0.02
Firepower	Watts	1018	1396	1187	1200	189.2	0.16

Table 11: High power WBT results of ethanol stove with J40E60

COLD START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.59	0.65	0.69	0.64	0.05	0.08
SFC	g/liter	51	43	43	45.6	4.4	0.1
Firepower	Watts	1364	1116	1074	1185	156.5	0.13
HOT START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.69	0.67	0.68	0.68	0.01	0.01
SFC	g/liter	40	41	43	41.6	1.5	0.03
Firepower	Watts	1211	1242	1046	1166	105.4	0.09

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A) Thermal efficiency of ethanol stove on blended fuels

Table 12 shows thermal efficiencies for ethanol stove with J0E100, J10E90, J20E80 and J40E60 fuels. The thermal efficiency of ethanol stove with the given fuels was 71.5 ± 2 , 71.5 ± 0.7 , 68 ± 0.7 and 66 ± 2.8 % respectively. The results show that there is no difference in thermal efficiency of Ethanol stove with ethanol and J10E90 fuels. The stove is more efficient with ethanol than with 20% J and 40%J. The stove with J10E90 is more efficient than with 20% J and 40 %. In addition, the stove is more efficient with J20E80 than with J40E60. Ethanol stove with all the tested blended fuels could be considered good thermal efficiency which has above 66 %. IWA/ISO: 2012 cookstove performance evaluation tiers, Ethanol stove under blended fuels ranked as Tier 4 in terms of efficiency.

Table 12 Statistical analysis thermal efficiencies of ethanol on blended fuels

Fuel	Eff (%) (mean \pm SD)	Statistical analysis			
		T-test	P value	Sig.@95%	% diff
J0E100	71.5 ± 2				
vs J10E90	71.5 ± 0.7	97	0.007	Yes	0
J0E100	71.5 ± 2				
vs J20E80	68 ± 0.7	25	0.025	Yes	4.0
J0E100	71.5 ± 2				
vs J40E60	66 ± 2.8	18.6	0.034	Yes	5.5
J10E90	71.5 ± 0.7				
vs J20E80	68 ± 0.7	35	0.018	Yes	4
J10E90	71.5 ± 0.7				
vs J40E60	66 ± 2.8	23	0.028	Yes	5.5
J20E80	68 ± 0.7				
vs J40E60	66 ± 2.8	67	0.01	Yes	1.5

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B) Specific fuel consumptions of ethanol stove on blended fuels

Table 13 shows specific fuel consumptions of ethanol stove at J0E100, J10E90, J20E80 and J40E60 fuels were 39.5 ± 2.8 , 39 ± 2 , 40.65 ± 1.7 and 43.6 ± 2.8 g/L respectively. The stove with J0E100 has 0.05 % more consumption than J10E90. However the stove with J0E100 has 1.15 % and 4.1 % lower consumption than with J20E80 and J40E60 respectively. Stove with J10E90 has 4.1% and 1.2 % lower consumption than J20E80 and J40E60 fuels respectively. J20E80 has 2.95 % lower SFC than J40E60. Ethanol stove with blended fuels up to 40% Jatropha oil has SFC than improved cookstoves.

Table 13: Statistical analysis of SFC of Ethanol stove on blended fuels

Fuel	SFC (g/L) (mean \pm SD)	Statistical analysis			
		T-test	P value	Sig.@95%	% diff
J0E100 vs J10E90	39.5 ± 2.8 39 ± 2	40	0.016	yes	0.05
J0E100 vs J20E80	39.5 ± 2.8 40.65 ± 1.7	27	0.024	yes	-1.15
J0E100 vs J40E60	39.5 ± 2.8 43.6 ± 2.8	16.6	0.038	yes	-4.1
J10E90 vs J20E80	39 ± 2 40.65 ± 1.7	28	0.022	yes	-1.2
J10E90 vs J40E60	39 ± 2 43.6 ± 2.8	21.5	0.03	yes	-4.15
J20E80 vs J40E60	40.65 ± 1.7 43.6 ± 2.8	22	0.029	yes	-2.95

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C) Fire power of Ethanol stove on blended fuels

Table 14 shows fire-power of the stove under J0E100, J10E90, J20E80 and J40E60 fuels which show 1.3 ± 0.06 , 1.27 ± 0.06 , 1.15 ± 0.06 and 1.17 ± 0.01 KW firepower respectively. Results show that the ethanol stove with J0E100 shows a 0.036, 0.51 and 0.133KW higher firepower than J10E90, J20E80 and J40E60 fuels respectively. Ethanol stove under J10E90 has 0.115 and 0.096 KW higher firepower than the stove with J20E80 and J40E60 fuels respectively. According to IWA/ISO cookstove , performance evaluation tires the ethanol stove under the four fuel types ranked as tire 3 (Dean Still *et al.*, 2014) .

Table 14: Statistical analysis fire power of Ethanol stove on blended fuels

Fuel	FP(kw)mean \pm SD)	Statistical analysis			
		T-test	P value	Sig.@95%	% diff
J0E100 vs J10E90	1.3 ± 0.06 1.27 ± 0.06	85.6	0.007	Yes	0.036 %
J0E100 vs J20E80	1.3 ± 0.06 1.15 ± 0.06	16.3	0.039	Yes	0.151%
J0E100 vs J40E60	1.3 ± 0.06 1.17 ± 0.01	19	0.033	Yes	0.133%
J10E90 vs J20E80	1.27 ± 0.06 1.15 ± 0.06	20	0.032	Yes	0.115%
J10E90 vs J40E60	1.27 ± 0.06 1.17 ± 0.01	24.4	0.026	Yes	0.096%
J20E80 vs J40E60	1.15 ± 0.06 1.17 ± 0.01	116	0.005	Yes	-0.018%

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Table 15: Thermal efficiency and SFC of some cookstoves in Ethiopia

Stove	Eff (%)	SFC (g/L)	Remark
Open fire	11	160	GIZ- SUN energy, 2007
Traditional	23	550	GIZ- SUN energy, 2007
Tikikil	26	75	GIZ- SUN energy, 2007
Lakech	38	290	GIZ- SUN energy, 2007
Jatropha oil stove with 40 % jatropha oil	52	37.4	Experimental
Ethanol stove (single burner) with jatropha oil stove	66	43	Experimental

Table 16: CO emission of some improved cookstoves

Stove	CO (g/2.5L)	Remark
Lakech	79	(Fikadu <i>et al.</i> , 2017)
Merchaye	66	(Fikadu <i>et al.</i> , 2017)
Traditional	92	(Fikadu <i>et al.</i> , 2017)
Jatropha oil stove	34	40% jatropha oil in kerosene
Ethanol stove	36.5	40% jatropha oil in ethanol

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D) Emissions of Ethanol stove on blended fuels

Carbon monoxide emission (EFCO) is the average grams of CO emitted per kilogram of fuel burned (Zhang *et al.*, 2000).

Table 17: CO Emissions and fuel consumption of ethanol stove on blended fuels

Fuel type	Parameters	Test-1	Test-2	Test-3	Mean
Ethanol	CO (ppm)	249	203	273	241.6
	CO ₂ (%)	0.79	0.75	0.84	0.79
	Fuel consumed (gm)	105	100	107	104
	COEF (g/kg)	26.14	20.3	29.2	25.2
	CO ₂ EF (g/kg)	829.5	750	898.8	826.1
J10E90	CO (ppm)	252	240	265	252.3
	CO ₂ (%)	0.82	0.8	0.85	0.82
	Fuel consumed (gm)	103	106	109	106
	COEF (g/kg)	26	25.4	28	26.46
	CO ₂ EF (g/kg)	844	848	927	873
J20E80	CO (ppm)	266	316	279	287
	CO ₂ (%)	0.77	0.85	0.86	0.82
	Fuel consumed (gm)	113	100	109	107.3
	COEF (g/kg)	30	31.6	30.4	30.6
	CO ₂ EF (g/kg)	870	850	937	885.6
J40E60	CO (ppm)	292	309	271	290.6
	CO ₂ (%)	0.68	0.75	0.7	0.71
	Fuel consumed (gm)	125	118	133	125.3
	COEF (g/kg)	36.5	36.5	36	36.3
	CO ₂ EF (g/kg)	850	885	931	888.6

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Table 18: Statistical analysis of CO emission of ethanol stove on blended fuels

Fuel	CO(g/2.5L) (mean± SD)	Statistical analysis			
		T-test	P value	Sig.@95%	% diff
J0E100	25.2±4.5	26	0.024	Yes	-1.45
vs J10E90	26.6±3.5				
J0E100	25.2±4.5	13.5	0.047	Yes	-5.32
vs J20E80	30.5±0.92				
J0E100	25.2±4.5	7.25	0.049	Yes	-11.12
vs J40E60	36.3±6				
J10E90	26.6±3.5	14	0.045	Yes	-3.8
vs J20E80	30.5±0.92				
J10E90	26.6±3.5	8.429	0.075	No	-9.6
Vs J40E60	36.3± 6				
J20E80	30.5±0.92	21	0.03	Yes	-5.8
Vs J40E60	36.3± 6				

E) CO emission of Ethanol stove on blended fuels

Table 18 shows that J0E100, J10E90, J20E80 and J40E60 have 25, 26, 30 and 36 grams of CO emission to boil 2.5 L of water (CO g/2.5 L). The result shows Ethanol stove with J0E100 has 1.45%, 5.32 % and 11.12 % lower CO emissions than with J10E90, J20E80 and J40E60 respectively. The stove with J10E90 has 3.8% and 9.6 % lower CO emissions than the stove with J20E80 and J40E60 fuels respectively. Ethanol stove with J20E80 has 5.8 % lower CO emissions than J40E60.

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Ethanol stove under blended fuels up to 40% jatropha oil shows lower CO emission. Utilization of jatropha oil up to 40% jatropha oil has lower CO emission than the improved biomass cookstoves.

4.5.2 Performance kerosene stove

Table 19 : High power WBT test results of kerosene stove

COLD START	unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.7	0.73	0.72	0.72	0.02	0.02
SFC	g/liter	29	27	26	27.2	1.5	0.06
Firepower	watts	1429	1286	1048	1254	192.5	0.15
HOT START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.68	0.67	0.73	0.69	0.03	0.04
SFC	g/liter	29	29	27	28.4	1.4	0.05
Firepower	watts	1452	1238	1244	1312	121.9	0.09

4.5.3 Performance of jatropha oil stove

Table 20: High power WBT test results of Jatropha oil stove with J10K90 fuel

COLD START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Eff	%	0.65	0.69	0.59	0.65	0.05	0.08
SFC	g/liter	31	28	32	30.4	2.1	0.07
Firepower	Watts	1398	1357	1276	1344	61.9	0.05
HOT START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.69	0.68	0.6	0.66	0.05	0.07
SFC	g/liter	29	29	31	29.8	1.4	0.05
Firepower	Watts	1538	1452	1571	1521	61.8	0.04

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Table 21: High power WBT test results of Jatropha oil stove with J20K80 fuel

COLD START	unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.57	0.53	0.55	0.55	0.02	0.04
SFC	g/liter	33	34	36	34.4	1.4	0.04
Firepower	watts	1111	1403	1316	1277	150	0.12
HOT START	unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.55	0.55	0.59	0.57	0.02	0.04
SFC	g/liter	36	35	32	34.7	1.9	0.06
Firepower	watts	1667	1507	1417	1530	126.6	0.08

Table 22: High power WBT test results of Jatropha oil stove with J40K60

COLD START	unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.52	0.53	0.47	0.51	0.03	0.06
SFC	g/liter	38	36	40	38.3	2.2	0.06
Firepower	watts	1404	1316	1619	1446	156.1	0.11
HOT START	Unit	Test 1	Test 2	Test 3	Mean	St Dev	COV
Efficiency	%	0.54	0.5	0.51	0.52	0.02	0.05
SFC	g/liter	36	37	36	36.5	0.6	0.02
Firepower	watts	1250	1335	1467	1351	109.2	0.08

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I) Thermal efficiency of jatropha oil stove on blended fuels

Table 23: shows the thermal efficiencies Jatropha oil stove with blended fuels (J10K90, J20K80 and J40K60) fuels. The Jatropha oil stove shows 65.6 ± 0.7 , 56 ± 1.4 and $51.5 \pm 5.5\%$ for J10K90, J20K80 and J40K60 fuels respectively. Jatropha oil stove with J10K90 is 9.5% and 14 % more efficient than the stove with J20K80 and J40K60 fuel respectively. The stove with J20K80 is 4.5 % more efficient than with J40K60. Jatropha oil stove shows above 50 % thermal efficiency with blended fuels .Jatropha oil stove with 40% jatropha oil has higher thermal efficiency than improved biomass cookstoves.

Table 23: Statistical analysis of thermal efficiency of Jatropha oil stove

Fuel	Eff (%) (mean \pm SD)	Statistical analysis			
		T-test	P value	Sig.@95%	% diff
J10K90 vs J20K80	65.5 ± 0.7 56 ± 1.4	13.211	0.048	Yes	9.50%
J10K90 vs J40K60	65.5 ± 0.7 52 ± 5.5	8.31	0.076	No	14%
J20K80 vs J40K60	56 ± 1.4 51.5 ± 5.5	22.2	0.029	Yes	4.50%

II) Specific fuel consumptions of jatropha oil stove on blended f fuels

Table 24 shows specific fuel consumptions Jatropha oil stove with J10K90, J20K80 and J40K60 fuels which were 30.1 ± 0.42 , 34.5 ± 0.2 and 37.4 ± 1.2 g/L. Jatropha oil stove with a J10K90 fuel consumption lower by 4.45 and 7.3 % than the stove with J20K80 and J40K60 respectively. Jatropha oil stove with J20K80 fuel consumption lower by 2.85 % than J40K60. Kerosene stoves fuel consumption is about 27.8 g/L.

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Result shows Jatropha oil stove up to 40 % Jatropha oil shows lower fuel consumptions than improved biomass cook stoves available in Ethiopia.

Table 24: Statistical analysis of SFC of Jatropha oil stove on blended fuels

Fuel	SFC (g/L) (mean±SD)	Statistical analysis			
		T·test	P value	Sig.@95%	% diff
J10K90 vs J20K80	30.1 ± 0.42 34.5 ± 0.2	16	0.04	yes	-4.45
J10K90 vs J40K60	30.1 ± 0.42 37.4 ± 1.2	11	0.058	no	-7.3
J20K80 vs J40K60	34.5 ± 0.2 37.4 ± 1.2	35	0.018	yes	-2.85

III) Fire power of jatropha oil stove on blended fuels

Table 25: shows fire-power of jatropha oil stove with J10K90, J20K80 and J40K60 which were 1.43 ± 0.12 , 1.4 ± 0.178 and 1.39 ± 0.06 KW respectively. Jatropha oil stove with J10K90 shows 0.029% and 0.034 % higher firepower than the stove with J20K80 and J40K60 fuel respectively. The stove with J20K80 has 0.005% higher firepower than with J40K60 fuel. Kerosene stove has 1.28KW According to ISO/IWA cookstove performance evaluation tier kerosene and Jatropha oil stoves rated as tier 3 (Dean Still *et al.*, 2014)

Table 25: Statistical analysis of fire power of jatropha oil stove.

Fuel	FP(KW) (mean±SD)	Statistical analysis			
		T·test	P value	Sig.@95%	% diff
J10K90 vs J20K80	1.43 ± 0.12 1.4 ± 0.178	0.094	0.007	Yes	0.029
J10K90 vs J40K60	1.43 ± 0.12 1.4 ± 0.178	0.07	0.009	Yes	0.034
J20K80 vs J40K60	1.43 ± 0.12 1.39 ± 0.06	0.279	0.002	Yes	0.005

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IV) CO emission of Jatropha oil stove on blended fuels

Table 26: CO emissions and fuel consumption Jatropha oil stove on blended fuels

Fuel	Parameters	Test_1	Test_2	Test_3	Mean
Kerosene	CO (ppm)	340	293	409	347
	CO ₂ (%)	0.93	0.88	1.06	0.95
	Fuel consumed (gm)	72.5	67.5	65	68.3
	COEF (g/kg)	24.65	19.7	26	23.45
	CO ₂ EF (g/kg)	674.25	594	689	652.4
	CO (ppm)	368	378	298	348
J10K90	CO ₂ (%)	0.97	1.07	1.25	1.1
	Fuel consumed (gm)	76	68	78	74
	COEF (g/kg)	28	26	24	26
	CO ₂ EF (g/kg)	737	728	975	813
	CO (ppm)	478	362	326	388
	CO ₂ (%)	1.35	1.07	1.03	1.15
J20K80	Fuel consumed (gm)	82.5	85	90	85.8
	COEF (g/kg)	39.43	30.77	29.34	33
	CO ₂ EF (g/kg)	1113.8	909.5	927	983.4
	CO (ppm)	429	341	307	359
	CO ₂ (%)	1.23	1.14	0.91	1.09
	J40K60	Fuel consumed (gm)	95	90	100
COEF (g/kg)		40.75	30.69	30.7	34
CO ₂ EF (g/kg)		1168.5	1026	910	1034.8

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V) Carbon monoxide emission of Jatropha oil stove on blended fuels

Table 27 shows CO emissions of Jatropha oil stove with J10K90, J20K80 and J40K60 which were 26 ± 2 , 33 ± 5.5 and 34 ± 5.8 grams of CO to boil 2.5 liters of water.

Jatropha oil with J10K90 has 7.2 % and 8.05% lower CO emissions than the stove with J20K80 and J40K60 fuel respectively .The stove with J20K80 shows 0.87% lower CO emission than the stove with J40K60 fuel. Kerosene stove shows 23 grams of carbon monoxide emissions to boil 2.5 litre of water. Jatropha oil stove with 40% Jatropha oil showed lower CO emissions than improved cookstoves available in Ethiopia.

Table 27: Statistical analysis of CO emission of jatropha oil stove on blended fuels

Fuel	COEF (g/2.5L) (mean \pm SD)	Statistical analysis			
		T-test	P value	Sig.@95%	% diff
J10K90	26 ± 2				
vs J20K80	33 ± 5.5	53	0.012	Yes	-7.2
J10K90	26 ± 2				
vs J40K60	34 ± 5.8	27	0.024	Yes	-8.05
J20K80	33 ± 5.5				
vs J40K60	34 ± 5.8	28	0.023	Yes	-0.87

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- ✓ Figure 10 represents the dependency viscosity of jatropha oil on temperature. From the result 99% of the reduction in viscosity of jatropha oil is attributing due to temperature. Figure 11 and figure 12 represent reduction of viscosity jatropha oil due to addition of ethanol and kerosene.
- ✓ Table 12, 13, 14 and 18 shows the thermal efficiency, Specific fuel consumption, and firepower and CO emission of Ethanol stoves using blended fuels. Generally, the stove's thermal efficiency, SFC, firepower is decreased while CO Emission increased on addition of jatropha oil in the blend.
- ✓ Table 23, 24, 25 and 27 showed thermal efficiency, SFC, firepower and CO emission of jatropha oil stove on Jatropha oil- kerosene blended fuels. Generally, thermal efficiency, SFC, firepower reduced and CO emission is increased when more jatropha blended with kerosene.

5.2 Recommendations

With respect to this study, such things are recommended for further study

- More than 40% oil can be blended with ethanol and kerosene for cooking with better thermal efficiency and lower CO emission using ethanol and jatropha oil stoves, the jatropha oil stove still needed improvement to reduce soot formation when more oil is added to the blend.
- Life cycle assessment of jatropha oil production and utilization should be studied to develop clear biofuel development and utilization strategy.
- Other Physical and Chemical characteristics of kerosene -Jatropha Oil and Ethanol-Jatropha oil blended fuels should be studied.

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**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Appendix A: Water Boiling Test result

Annex 1: Water boiling test result Ethanol stove

Stove type/model: Ethanol stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: Ethanol
 Wind conditions: No wind; No wind; Light breeze
 Ambient temperature: 22, 22, 24

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	27	30	30	29.0	1.7	6%
Temp-corrected time to boil Pot # 1	min	28	30	30	29.6	1.3	4%
Burning rate	g/min	3	3	3	3.0	0.2	6%
Thermal efficiency	%	72%	69%	70%	70%	2%	3%
Specific fuel consumption	g/liter	42	40	43	41.5	1.2	3%
Temp-corrected specific consumption	g/liter	43	41	43	42.5	1.3	3%
Temp-corrected specific energy cons.	kJ/liter	1,146	1,171	1,147	1154.7	14.1	1%
Firepower	watts	1,407	1,335	1,310	1351	50.2	4%
2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	26	30	29	28.3	2.1	0.07347
Temp-corrected time to boil Pot # 1	min	27	31	30	29.3	1.8	6%
Burning rate	g/min	3	3	3	2.8	0.2	6%
Thermal efficiency	%	73%	72%	73%	73%	1%	1%
Specific fuel consumption	g/liter	37	39	37	37.5	1.0	3%
Temp-corrected specific consumption	g/liter	38	40	38	38.8	0.8	2%
Temp-corrected specific energy cons.	kJ/liter	1,017	1,134	1,013	1054.8	69.0	7%
Firepower	watts	1,325	1,271	1,203	1266	61.1	5%
3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	1	1	2	1.5	0.1	4%
Thermal efficiency	%	73%	69%	69%	70%	2%	3%
Specific fuel consumption	g/liter	41	41	43	41.4	1.1	3%
Temp-corrected specific energy cons.	kJ/liter	1,077	1,168	1,128	1124.4	45.4	4%
Firepower	watts	638	667	667	658	17.0	3%
Turn down ratio	--	2.14	1.95	1.88	1.99	0.1	7%
BENCHMARK VALUES (for 5L)							
Fuel Use Benchmark Value	g	407	406	417	410	6.0	1%
Energy Use Benchmark Value	kJ	10,793	11,602	11,042	11,146	414.0	4%

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Annex 2: Water boiling test result Ethanol stove

Stove type/model: Ethanol stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: J10E90
 Wind conditions: No wind; Light breeze, Light breeze
 Ambient temperature: 23, 19, 24

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	30	30	28	29.3	1.2	4%
Temp-corrected time to boil Pot # 1	min	31	30	28	30.0	1.5	5%
Burning rate	g/min	3	3	3	2.9	0.1	4%
Thermal efficiency	%	72%	68%	73%	71%	3%	4%
Specific fuel consumption	g/liter	41	41	41	41.0	0.4	1%
Temp-corrected specific consumption	g/liter	43	41	41	42.0	1.1	3%
Temp-corrected specific energy cons.	kJ/liter	1,145	1,183	1,095	1140.9	44.3	4%
Firepower	watts	1,266	1,351	1,341	1319	46.2	4%

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	31	33	25	29.7	4.2	0.14034
Temp-corrected time to boil Pot # 1	min	32	32	26	30.1	3.8	13%
Burning rate	g/min	2	3	3	2.7	0.4	13%
Thermal efficiency	%	74%	67%	75%	72%	4%	6%
Specific fuel consumption	g/liter	36	39	37	37.3	1.5	4%
Temp-corrected specific consumption	g/liter	38	38	38	37.9	0.1	0%
Temp-corrected specific energy cons.	kJ/liter	1,004	1,088	1,001	1030.9	49.5	5%
Firepower	watts	1,097	1,199	1,378	1225	142.2	12%

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	2	1	1	1.5	0.0	2%
Thermal efficiency	%	69%	67%	71%	69%	2%	3%
Specific fuel consumption	g/liter	43	43	41	42.3	0.8	2%
Temp-corrected specific energy cons.	kJ/liter	1,127	1,227	1,097	1150.0	68.0	6%
Firepower	watts	667	699	648	671	25.9	4%
Turn down ratio	--	1.77	1.82	2.10	1.90	0.2	9%

BENCHMARK VALUES (for 5L)

Fuel Use Benchmark Value	g	415	413	405	411	5.6	1%
Energy Use Benchmark Value	kJ	11,006	11,811	10,722	11,179	564.7	5%

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Annex 3: Water boiling test result Ethanol stove

Stove type/model: Ethanol stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: J20E80
 Wind conditions: No wind; No wind; Light breeze
 Ambient temperature: 19, 22, 23

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	35	37	35	35.7	1.2	3%
Temp-corrected time to boil Pot # 1	min	36	38	35	36.5	1.0	3%
Burning rate	g/min	3	2	3	2.5	0.2	8%
Thermal efficiency	%	69%	70%	65%	68%	3%	4%
Specific fuel consumption	g/liter	43	40	42	41.9	1.8	4%
Temp-corrected specific consumption	g/liter	45	41	43	42.9	2.4	5%
Temp-corrected specific energy cons.	kJ/liter	1,199	1,160	1,137	1165.3	31.4	3%
Firepower	watts	1,136	1,069	1,136	1114	38.4	3%

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	36	28	32	32.0	4.0	0.125
Temp-corrected time to boil Pot # 1	min	38	29	33	33.1	4.5	14%
Burning rate	g/min	2	3	3	2.6	0.3	12%
Thermal efficiency	%	69%	66%	67%	67%	2%	2%
Specific fuel consumption	g/liter	39	39	40	39.4	0.9	2%
Temp-corrected specific consumption	g/liter	41	40	42	40.7	0.9	2%
Temp-corrected specific energy cons.	kJ/liter	1,085	1,137	1,101	1107.5	26.4	2%
Firepower	watts	1,018	1,396	1,187	1200	189.2	16%

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	2	2	2	1.5	0.0	2%
Thermal efficiency	%	71%	66%	73%	70%	3%	5%
Specific fuel consumption	g/liter	45	45	43	44.4	0.9	2%
Temp-corrected specific energy cons.	kJ/liter	1,187	1,287	1,147	1206.8	71.9	6%
Firepower	watts	687	741	667	699	38.4	5%
Turn down ratio	--	1.57	1.66	1.74	1.66	0.1	5%

BENCHMARK VALUES (for 5L)

Fuel Use Benchmark Value	g	439	426	428	431	7.5	2%
Energy Use Benchmark Value	kJ	11,645	12,174	11,329	11,716	427.0	4%

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Annex 4: Water boiling test result Ethanol stove

Stove type/model: Ethanol stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: J40E60
 Wind conditions: No wind; No wind, Light breeze
 Ambient temperature: 20.5, 22, 24

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	34	38	37	36.3	2.1	6%
Temp-corrected time to boil Pot # 1	min	35	39	38	37.1	1.6	4%
Burning rate	g/min	3	2	2	2.6	0.4	16%
Thermal efficiency	%	59%	65%	69%	64%	5%	8%
Specific fuel consumption	g/liter	51	43	43	45.6	4.4	10%
Temp-corrected specific consumption	g/liter	53	44	44	46.7	5.3	11%
Temp-corrected specific energy cons.	kJ/liter	1,398	1,245	1,159	1267.0	121.1	10%
Firepower	watts	1,364	1,116	1,074	1185	156.5	13%

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	31	33	38	34.0	3.6	0.10605
Temp-corrected time to boil Pot # 1	min	32	34	39	35.1	3.5	10%
Burning rate	g/min	3	3	2	2.6	0.2	7%
Thermal efficiency	%	69%	67%	68%	68%	1%	1%
Specific fuel consumption	g/liter	40	41	43	41.6	1.5	3%
Temp-corrected specific consumption	g/liter	42	43	44	43.1	1.1	3%
Temp-corrected specific energy cons.	kJ/liter	1,119	1,218	1,176	1170.9	50.0	4%
Firepower	watts	1,211	1,242	1,046	1166	105.4	9%

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	2	2	2	1.6	0.1	4%
Thermal efficiency	%	67%	66%	70%	67%	2%	3%
Specific fuel consumption	g/liter	49	46	45	46.7	1.7	4%
Temp-corrected specific energy cons.	kJ/liter	1,288	1,323	1,198	1269.6	64.8	5%
Firepower	watts	736	741	697	725	24.4	3%
Turn down ratio	--	1.75	1.59	1.52	1.62	0.1	7%

BENCHMARK VALUES (for 5L)

Fuel Use Benchmark Value	g	480	447	446	458	19.6	4%
Energy Use Benchmark Value	kJ	12,731	12,774	11,824	12,443	536.4	4%

Annex 5: water boiling test result kerosene stove

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Stove type/model: kerosene stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: kerosene
 Wind conditions: No wind; Light breeze, Light breeze
 Ambient temperature: 19, 20, 22

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	28	30	35	31.0	3.6	12%
Temp-corrected time to boil Pot # 1	min	28	30	35	31.0	3.9	13%
Burning rate	g/min	2	2	2	1.8	0.3	15%
Thermal efficiency	%	70%	73%	72%	72%	2%	2%
Specific fuel consumption	g/liter	29	27	26	27.2	1.5	6%
Temp-corrected specific consumption	g/liter	29	26	26	27.2	1.5	6%
Temp-corrected specific energy cons.	kJ/liter	1,159	1,104	1,060	1107.4	49.7	4%
Firepower	watts	1,429	1,286	1,048	1254	192.5	15%

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	28	34	30	30.7	3.1	0.09962
Temp-corrected time to boil Pot # 1	min	29	34	31	31.0	2.4	8%
Burning rate	g/min	2	2	2	1.9	0.2	11%
Thermal efficiency	%	68%	67%	73%	69%	3%	4%
Specific fuel consumption	g/liter	29	29	27	28.4	1.4	5%
Temp-corrected specific consumption	g/liter	30	29	28	28.8	1.3	5%
Temp-corrected specific energy cons.	kJ/liter	1,209	1,207	1,104	1173.2	59.7	5%
Firepower	watts	1,452	1,238	1,244	1312	121.9	9%

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	1	1	1	1.0	0.0	2%
Thermal efficiency	%	68%	67%	69%	68%	1%	1%
Specific fuel consumption	g/liter	30	29	29	29.1	0.6	2%
Temp-corrected specific energy cons.	kJ/liter	1,190	1,206	1,156	1184.1	25.5	2%
Firepower	watts	681	686	667	678	10.1	1%
Turn down ratio	--	2.11	1.84	1.72	1.89	0.2	11%

BENCHMARK VALUES (for 5L)

Fuel Use Benchmark Value	g	297	280	280	286	9.6	3%
Energy Use Benchmark Value	kJ	11,869	11,806	11,190	11,622	375.3	3%

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Annex 7: water boiling test result Jatropha oil stove
 Stove type/model: Jatropha oil stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: J20K80
 Wind conditions: No wind; No wind; Light breeze
 Ambient temperature: 19, 22, 23

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	42	36	38	38.7	3.1	8%
Temp-corrected time to boil Pot # 1	min	42	36	39	38.7	3.2	8%
Burning rate	g/min	2	2	2	1.9	0.2	10%
Thermal efficiency	%	57%	53%	55%	55%	2%	4%
Specific fuel consumption	g/liter	33	34	36	34.4	1.4	4%
Temp-corrected specific consumption	g/liter	33	34	37	34.5	1.8	5%
Temp-corrected specific energy cons.	kJ/liter	1,330	1,414	1,460	1401.7	65.8	5%
Firepower	watts	1,111	1,403	1,316	1277	150.0	12%

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	30	34	32	32.0	2.0	0.0625
Temp-corrected time to boil Pot # 1	min	31	34	33	32.4	1.4	4%
Burning rate	g/min	3	2	2	2.3	0.2	9%
Thermal efficiency	%	55%	55%	59%	57%	2%	4%
Specific fuel consumption	g/liter	36	35	32	34.7	1.9	6%
Temp-corrected specific consumption	g/liter	37	35	33	35.1	1.9	5%
Temp-corrected specific energy cons.	kJ/liter	1,486	1,468	1,335	1429.6	82.8	6%
Firepower	watts	1,667	1,507	1,417	1530	126.6	8%

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	1	1	1	1.3	0.0	3%
Thermal efficiency	%	56%	52%	59%	56%	4%	6%
Specific fuel consumption	g/liter	38	37	36	36.9	1.2	3%
Temp-corrected specific energy cons.	kJ/liter	1,523	1,562	1,426	1503.8	70.3	5%
Firepower	watts	859	889	815	854	37.2	4%
Turn down ratio	–	1.62	1.64	1.68	1.64	0.0	2%

BENCHMARK VALUES (for 5L)

Fuel Use Benchmark Value	g	366	357	353	359	7.0	2%
Energy Use Benchmark Value	kJ	14,658	15,019	14,116	14,597	454.5	3%

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Annex 8: water boiling test result Jatropha oil stove

Stove type/model: Jatropha oil stove
 Location: Addis Ababa, MWIE laboratory
 Fuel description: J40K60
 Wind conditions: No wind; No wind; Light breeze
 Ambient temperature: 19, 20, 22

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	38	40	35	37.7	2.5	7%
Temp-corrected time to boil Pot # 1	min	38	39	35	37.6	2.0	5%
Burning rate	g/min	2	2	2	2.1	0.3	13%
Thermal efficiency	%	52%	53%	47%	51%	3%	6%
Specific fuel consumption	g/liter	38	36	40	38.3	2.2	6%
Temp-corrected specific consumption	g/liter	38	36	41	38.3	2.7	7%
Temp-corrected specific energy cons.	kJ/liter	1,535	1,498	1,642	1558.1	74.6	5%
Firepower	watts	1,404	1,316	1,619	1446	156.1	11%

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Time to boil Pot # 1	min	40	41	35	38.7	3.2	0.08313
Temp-corrected time to boil Pot # 1	min	41	40	36	39.2	2.8	7%
Burning rate	g/min	2	2	2	2.0	0.2	9%
Thermal efficiency	%	54%	50%	51%	52%	2%	5%
Specific fuel consumption	g/liter	36	37	36	36.5	0.6	2%
Temp-corrected specific consumption	g/liter	37	37	37	37.0	0.3	1%
Temp-corrected specific energy cons.	kJ/liter	1,479	1,547	1,497	1507.6	35.1	2%
Firepower	watts	1,250	1,335	1,467	1351	109.2	8%

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV
Burning rate	g/min	2	2	2	1.7	0.1	5%
Thermal efficiency	%	49%	50%	47%	49%	1%	3%
Specific fuel consumption	g/liter	52	48	53	50.7	2.5	5%
Temp-corrected specific energy cons.	kJ/liter	2,065	2,012	2,104	2060.0	46.3	2%
Firepower	watts	1,111	1,091	1,156	1119	32.8	3%
Turn down ratio	--	1.19	1.21	1.34	1.25	0.1	6%

BENCHMARK VALUES (for 5L)

Fuel Use Benchmark Value	g	446	420	459	442	20.1	5%
Energy Use Benchmark Value	kJ	17,858	17,670	18,366	17,965	360.1	2%

Appendix B: Emission test results

Annex 9: Emission data of ethanol stove with ethanol



Flue gas measurement

Location



Measurement

Time 3/12/2018 12:38:59 AM
Instrument testo 330-2 LL

3/12/2018 12:38:59 AM	Date / time
32.5	°C Tstack
0.79	% CO ₂
0.64	l/min Pump
1,655.74	λ
19.8	% O ₂
249	ppm CO
-0.384	mbar Draft
4372	ppm CO AF
-	% Eff gr.
34.8	°C Tinst.
32.5	°C DewPt
0	ppm NO

Figure 19: Emission data Test -1



Flue gas measurement

Location



Measurement

Time 3/12/2018 4:21:03 AM
Instrument testo 330-2 LL

3/12/2018 4:21:03 AM	Date / time
34.6	°C Tstack
0.84	% CO ₂
0.65	l/min Pump
1,544.03	λ
19.7	% O ₂
273	ppm CO
0.242	mbar Draft
4488	ppm CO AF
88.6	% Eff gr.
31.8	°C Tinst.
31.2	°C DewPt
2	ppm NO

Figure 20: Emission data Test -2

**OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND
KEROSENE FOR COOKING IN ETHIOPIA**

Annex 10: Emission test results of ethanol stove with 40E60 fuel



Flue gas measurement

Location



Measurement

Time 3/13/2018 11:04:09 PM
Instrument testo 330-2 LL

3/13/2018 11:04:09 PM	Date / time
24.8	°C Tstack
0.68	% CO ₂
0.66	l/min Pump
1,937.43	λ
20.0	% O ₂
292	ppm CO
0.090	mbar Draft
5949	ppm CO AF
-	% Eff gr.
28.2	°C Tinst.
24.8	°C DewPt
0	ppm NO

Figure 21: Emission data test-1



Flue gas measurement

Location



Measurement

Time 3/13/2018 11:07:46 PM
Instrument testo 330-2 LL

3/13/2018 11:07:46 PM	Date / time
25.3	°C Tstack
0.69	% CO ₂
0.66	l/min Pump
1,894.72	λ
19.9	% O ₂
309	ppm CO
0.075	mbar Draft
6164	ppm CO AF
-	% Eff gr.
28.4	°C Tinst.
25.3	°C DewPt
0	ppm NO

Figure 22: Emission data test-2

Annex 11: Emission test results of kerosene stove



Flue gas measurement

Location



Measurement

Time 3/14/2018 4:35:24 AM
Instrument testo 330-2 LL

3/14/2018 4:35:24 AM	Date / time
26.6	°C Tstack
0.93	% CO ₂
0.63	l/min Pump
1,561.08	λ
19.7	% O ₂
340	ppm CO
0.030	mbar Draft
5648	ppm CO AF
-	% Eff gr.
32.8	°C Tinst.
26.6	°C DewPt
0	ppm NO

Figure 23: Emission data test-1



Flue gas measurement

Location



Measurement

Time 3/14/2018 5:27:11 AM
Instrument testo 330-2 LL

3/14/2018 5:27:11 AM	Date / time
29.6	°C Tstack
1.06	% CO ₂
0.63	l/min Pump
1,354.46	λ
19.6	% O ₂
409	ppm CO
-0.005	mbar Draft
5949	ppm CO AF
-	% Eff gr.
33.4	°C Tinst.
29.6	°C DewPt
0	ppm NO

Figure 24: Emission data test-2

Annex 12: Emission test results of Jatropha oil stove with J40K60 fuel



Flue gas measurement

Location



Measurement

Time 3/16/2018 12:56:29 AM
Instrument testo 330-2 LL

3/16/2018 12:56:29 AM	Date / time
40.1	°C Tstack
0.91	% CO ₂
0.52	l/min Pump
1,585.13	λ
19.8	% O ₂
307	ppm CO
-0.052	mbar Draft
5173	ppm CO AF
86.6	% Eff gr.
32.0	°C Tinst.
29.8	°C DewPt
2	ppm NO

Figure 25: Emission data test -1



Flue gas measurement

Location



Measurement

Time 3/16/2018 12:28:47 AM
Instrument testo 330-2 LL

3/16/2018 12:28:47 AM	Date / time
35.1	°C Tstack
1.23	% CO ₂
0.53	l/min Pump
1,150.54	λ
19.3	% O ₂
429	ppm CO
-0.048	mbar Draft
5365	ppm CO AF
89.7	% Eff gr.
31.6	°C Tinst.
30.5	°C DewPt
2	ppm NO

Figure 26: Emission data test -2

OPTIMIZATION OF JATROPHA OIL BLENDED WITH ETHANOL AND KEROSENE FOR COOKING IN ETHIOPIA

Annex 13: Water boiling test data sheet

Water Boiling Test - Test Entry Form Version 4.2.3															
These values are not linked to the Test sheets. This sheet is provided so you can print an easy data entry form. You will have to enter these values in each Test sheet to obtain the calculations.															
Air Temperature <input style="width: 100%;" type="text"/> Wind Conditions <input style="width: 100%;" type="text"/> Fuel Dimensions <input style="width: 100%;" type="text"/> Moisture Content (wet basis) <input style="width: 100%;" type="text"/> Dry Weight Pot 1 <input style="width: 100%;" type="text"/> Dry Weight Pot 2 <input style="width: 100%;" type="text"/> Dry Weight Pot 3 <input style="width: 100%;" type="text"/> Dry Weight Pot 4 <input style="width: 100%;" type="text"/> Weight Container for Char <input style="width: 100%;" type="text"/> Local Boiling Point * <input style="width: 100%;" type="text"/> <small>* enter on General Information</small> Background CO2 (ppm)** <input style="width: 100%;" type="text"/> Background CO (ppm)** <input style="width: 100%;" type="text"/> Background PM (ug/m3)** <input style="width: 100%;" type="text"/> <small>** For emission testing only</small>	Name of Testers Date Stove Type/Model Test Number Location Fuel Type Notes														
	<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th></th> <th colspan="2" style="text-align: center;">Cold Start</th> <th colspan="2" style="text-align: center;">Hot Start</th> <th colspan="2" style="text-align: center;">Simmer</th> </tr> <tr> <th></th> <th style="text-align: center;">Start</th> <th style="text-align: center;">End</th> <th style="text-align: center;">Start</th> <th style="text-align: center;">End</th> <th style="text-align: center;">Start</th> <th style="text-align: center;">End</th> </tr> </thead> </table>		Cold Start		Hot Start		Simmer			Start	End	Start	End	Start	End
	Cold Start		Hot Start		Simmer										
	Start	End	Start	End	Start	End									
Time	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Weight of Fuel	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Water Temperature, Pot 1	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Water Temperature, Pot 2	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Water Temperature, Pot 3	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Water Temperature, Pot 4	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Weight of Pot 1 with water	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Weight of Pot 2 with water	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Weight of Pot 3 with water	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Weight of Pot 4 with water	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>	<input style="width: 100%;" type="text"/>									
Fire Starting Materials	<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>										
Average CO2 (ppm)		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>									
Average CO (ppm)		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>									
Average PM (ug/m3)		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>									
Average Duct Temperature		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>		<input style="width: 100%;" type="text"/>									

