ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES ENERGY TECHNOLOGY DEPARTMENT

PERFORMANCE OF ETHANOL WATER MIXTURE AS FUEL FOR HOUSEHOLD STOVE

By
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A thesis submitted to the School of Graduate Studies Addis Ababa University in partial fulfilment of the requirements of the Degree of Master of Science in Energy Technology

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"I declare that this thesis entitled "Performance of Ethanol water Mixture as a fuel for Household Stove" is the result of my own research except as cited in the references."

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ABSTRACT

Ethiopia is one of the world's least developed countries where population pressures and an over reliance on traditional biomass fuels have led to deforestation. The combustion of unsustainably harvested biomass releases large quantities of greenhouse gases into the atmosphere and when burnt indoors has been strongly linked to acute respiratory infections and a major cause of death in developing countries. In order to protect the environment, it is urgently required to substitute the utilization of firewood for cooking purposes. Ethanol-water mixture oil, as one of the best solutions, is a promising alternative energy source offering a variety of economical and ecological advantages.

A new pressurized cooking stove was developed according to the principles of the appropriate technology that can be operated on ethanol-water mixture. According to the chemical, physical and combustion properties of fuel oil, a new nozzle socket, a new burner head and a new tank as well as a hand pump device were designed and manufactured.

The stove was evaluated by varying ethanol concentration by water boiling test and also was evaluated against wheel brand stove, a typical example of an adapted kerosene stove. The procedure followed for the test is in accordance with the standard test methods recommended by Volunteers in Technical Assistance (VITA).

A pressurized-ethanol stove running on 40 % (w/w) ethanol concentration (40% ethanol and 60% water) has been developed. Based on one litre boil of water, it showed no significant difference in performance; its efficiency as high as 29.5% as compared to 33% with that of conventional kerosene stove was observed.

However, the pressurized-ethanol stove had advantages over kerosene in that it produced smokeless burning and no irritating smells. Thus, the prototype stove was found to be potentially appropriate for use.

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LIST OF SYMBOLS

A	Cross sectional area
d_e	External diameter
d_i	Inside diameter of shell
E_{in}	Energy content of fuel consumed during high and low Power Phase
E_{lout}	Energy gained by water during High Power Phase
E_{2out}	Energy gained by water during Low Power Phase,
E_{vess}	Energy gained by vessel
f	Allowed value of the nominal design stress for normal
F	Force exerted
H	Convective heat transfer coefficient
h	Height of shell
h_i	Inside height of torispherical end
k_B	Boltzmann’s constant
L_i	Inside length of torispherical end
m_{eva}	Mass of water evaporated during test
m_{fuel}	Mass of ethanol-water mixture consumed during test
m_w	Mass of water remaining at the end of the period
N_i	Initial number of gas particles
N_f	Final number of gas particles
P	Absolute Pressure
T_a	Ambient temperature
T_{gas}	Flue gas temperature
t_s	Minimum shell thickness
V_e	Volume of end
V_i	Inside volume of shell

V_T	Total volume
V_{ip}	Initial volume of pump
z	Weld joint efficiency

Abbreviations

CCT	Controlled Cook Test
CO_2	Carbon Dioxide
GHG	Green House Gas
KPT	Kitchen Performance Test
KW	Kilowatt (1,000 W)
LHV	Lower Heating Value
LPG	Liquid Petroleum Gas
MW	Megawatt (1,000,000 W)
NGO	Non-Governmental Organization
SFC	Specific Fuel Consumption
WBT	Water Boiling Test

Greek letters

μ	Viscosity
ρ	Density
η	Efficiency

CHAPTER 1

INTRODUCTION

1.1. General Background

Most of the rural households in Ethiopia and other developing countries cook food on inefficient and smoky biomass cook stoves. Besides creating environmental pollution, these stoves create health problems for the cookers and are based on biomass, which is not easily accessible and tedious to collect. Biomass which includes wood, charcoal, animal waste and agricultural residue is the most widely used form of energy in Ethiopia. Nearly 90% of Ethiopia’s current total energy demand is met using biomass fuels. Within household sector, the contribution of biomass fuel is close to 97% [12]. Given the fact that rural incomes are generally low and biomass fuels are collected ‘freely’ in most rural areas, it would be very difficult to switch to modern fuels.

Collection of firewood is a drudgery work mainly carried out by women and children. This often causes severe health problems, especially for children. With less wood available, collecting firewood becomes increasingly difficult and time spent for collection and transportation rises. As a consequence, families have less time for generating income and for household as well as field work, or they must pay steadily rising prices for wood. In many cases the wood necessary for cooking is more expensive than the food itself. Such economic trends lead to a decline in living standards and to increasing malnutrition.

Due to shortage of firewood, dung and plant residues are used more widely as cooking fuel. However, burning these organic materials disturbs the natural nutrient cycle and soils become impoverished and less fertile [8].

The currently predominant open fire cooking is desperately in need of improvement or even replacement. A more intensive utilization of cooking stoves using fossil fuels like gas or kerosene as energy source can economically and ecologically hardly be recommended. Moreover, Ethiopia is already dependent on fossil fuel imports. This often burdens the foreign currency reserves to a great extent. Due to difficult distribution fossil fuels are very expensive especially in remote areas. Since fossil fuels become scarce in the future, it can be expected that prices will rise furthermore.

Thus this current situation urgently requires introduction of alternative ways of cooking. Fuel-efficient wood stoves can significantly reduce the firewood consumption but the decrease in consumption will soon be compensated by the fast growing population. Therefore, ethanol-water mixture is a promising alternative energy source offering a variety of economical and ecological advantages. Utilization as cooking fuel will assure a sustainable energy supply for numerous communities in developing countries and will secure an adequate food preparation.

Moreover to overcome the current firewood problems it is an urgent need to develop an alternative cooking method. The use of ethanol-water mixture oil as fuel for cooking stoves presents a promising alternative. This fuel oil provides some additional services; in terms of health, by reducing indoor air pollution; as well as environmental, by running on a locally produced, carbon-neutral fuel.

1.2 Problem Statement

Bio-diesel and bio-fuel production has attracted great interest around the world because of developments on the economic, social, environmental, institutional and political fronts. On one hand, high oil prices mean that countries that are not self-sufficient in fossil fuels must spend a portion of their foreign exchange earnings on imports of hydrocarbons.

At the same time, there is the social aspect of diversifying energy sources by using local resources and generating employment through greater demand for labour to produce those resources. These types of fuel, which are ethanol-water mixture is also less polluting and have less impact on climate change than fossil fuels. The fact is that every increase in oil prices sparks concerns over its impact on overall economic growth**.** Moreover, the persistent hike in global prices of crude oil is becoming the major issue in every country. The situation was exacerbated, owing to ever increasing demand; in the face of continued decline in quantity of crude petroleum, dwindling production rate, and the instabilities in the centres of petroleum production [4].

This inevitably, reflected an adverse impact on the local economy of many countries, especially the oil importing countries, by posing a severe burden on their foreign exchange [6]. Therefore, increasing non-renewable energy costs, environmental impacts of fossil fuels, uncertainties regarding future energy supply, the need to reduce energy import bills have given incentives to encourage the production of petroleum substitutes from agricultural commodities [1] and there by the need for such alternatives has been driven worldwide by economic, environmental, political and social factors [3].

The current energy crisis has beckoned upon us to look towards an energy alternative that is feasible and sustainable in the long run. Being a direct solution to the current shortage of liquid fuel, bio-diesel and bio-fuel is one of the most popular alternatives of all time. Even so, we need to look towards feedstock that will be suitable for Ethiopia, as well as sustainable and economical in the long run.

1.3 Objective

This work has the objective of investigating the use of ethanol-water mixture as fuel for cooking in order to substitute unsustainably produced charcoal, fuel wood and kerosene, already produced ethanol from sugar industry. This should result in lower levels of GHG emissions and considerable benefits to public health, the environment and also to the local economy by using local resource and existing technology. The work is based around the stove which, although at a prototype stage.

1.3.1 General objective

The overall objective of this paper was to:

- Assess the suitability of ethanol-water mixture as an alternative source of energy for cooking; using self designed and manufactured stove which, although at a prototype stage.

1.3.2 Specific objective

The specific objectives of the study were to:

- Determine the time taken to boil 1litre of water using new stove and compare the efficiency with low-income households currently used kerosene wick fuel stove,
- Determine the specific fuel consumption of stove using, ethanol-water mixture as a fuel,
- Determine the efficiencies of ethanol-water mixture in cooking various dishes,
- Determine the suitability of ethanol-water mixture by varying the concentration.

1.4 Methodology

The methods to be employed to achieve the objective of the research are

- Literature review: - reviewing the importance of ethanol as fuel for house hold stoves.
- Data collection:- The information collected from many sources will be used as an input for comparison analysis.
- Design and manufacture a household stove.
- Experimental analysis and interpretation of the results.

1.5 Over view of Traditional and Modern Cooking Fuel

1.5.1 Traditional cooking fuels

It is already being used by the rural people as a major source of energy, mainly in cooking food, which constitutes almost over 90% of the total energy consumption [10]. Assuming that the population of Ethiopia are about 82 million in Ethiopia, 90% of the population in Ethiopia lives in rural area [7], and assuming that each family consists of five persons and uses annually about 3 tones of biomass as fuel, one comes to the figure of about 44.28 million tones of biomass utilized annually only for domestic cooking in rural areas only. The urban populations of Ethiopia (10%) are also uses biomass and assuming that 78% of the urban population uses this biomass as a fuel, one comes to the figure of 3.84 million tonnes of biomass as fuel. There is also a third dimension to fuel use, and that is the pollution arising due to burning of biomass.

a. Firewood

In Ethiopia, as in most developing countries, firewood is the predominant energy source, as are other traditional fuels such as cow dung, and agricultural residues. These are usually free, multiple-purpose fuels, providing much service such as heating and lighting. In terms of energy for cooking, 85% of the population on average relies on wood, with an even larger reliance in rural regions and less so in urban regions.

In rural settings, the proportion of the population that uses firewood is fairly consistent across countries a result of its low cost and the lack of available alternatives. In urban areas, use of firewood as the primary fuel varies according to factors such as differences in price and availability of alternatives. Firewood is often burned in open stoves resulting in low energy density and low total energy efficiency on combustion, often between 10% and 20% [2].

b. Charcoal

Wood charcoal has been the primary fuel for cooking in Ethiopia because it is cheap and easily available. However, using wood charcoal has consequences on health and pollution because of smoking.

Charcoal is another important fuel currently used for household cooking in developing nations. While its role in meeting the energy needs of rural communities is typically small, it is often widely used in urban areas. In many respects its characteristics as a cooking fuel make it more desirable for household use than firewood as it emits fewer pollutants, has higher energy content and is simpler to transport. Because of its advantages over firewood there have been a number of efforts to promote its use; nonetheless, in comparison to clean cooking fuels it remains inefficient and less than ideal for household cooking.

The processes involved in producing charcoal and using it as a cooking fuel is tremendously inefficient and resource intensive. Charcoal is often manufactured in rural areas where wood is more accessible. Wood is heated in earth kilns that restrict air flow, resulting in a product with a high carbon density that can be used as a cooking fuel. During the conversion process up to three quarters of the energy in the original biomass is lost.

The efficiency of charcoal stoves commonly found in urban households is approximately 25%, so the overall system efficiency is quite low: about 5% of the energy in the original biomass is converted to useful energy for cooking [5]. As a result, large quantities of biomass must be used to manufacture enough fuel to meet the energy demand of the urban population.

1.5.2 Modern cooking fuels

Modern cooking fuels are considered to be those that have a high energy density, high combustion efficiency and high heat-transfer efficiency with sufficient heat control characteristics. Biogas and LPG are commonly used gaseous fuels, and ethanol, kerosene and Jatropha oil are the more familiar liquid cooking fuels.

a. Kerosene

Kerosene is a petroleum-based fuel produced in oil refineries. It is used almost exclusively in urban areas of Africa, though its level of urban use varies greatly across national borders. When burned, it produces soot and other particulates, and together with fire hazard risks, it is not an ideal cooking fuel. However, it is quite often used in developing countries where it is burned in wick stoves or fairly efficient pressurized stoves. While mainly used for lighting, kerosene has a market as a cooking fuel, especially in the urban regions of Ethiopia, mainly due to its availability and relatively low cost. It is imported, and distributed at fuelling stations around the country.

Two types of stoves are used for cooking with kerosene: wick stoves and pressurised stoves. Both have high total energy efficiencies of between 40% and 60% and are simple to use [6]. However, there are numerous hazards associated with the household use of kerosene because of its toxicity and flammability.

b. Biogas

Biogas is a clean cooking fuel that is produced through the anaerobic digestion of various organic wastes; the most commonly used feedstock is animal waste. The digestion process, which takes place in sealed airless containers called “digesters”, produces a mixture of methane and carbon dioxide gases from which the carbon dioxide can be separated to further increase the energy density of the gas. The result is a clean fuel that produces no smoke or particulate matter on combustion. With high total energy efficiency on combustion of nearly 60%, biogas is well suited to household cooking [11]. One of the most important advantages of biogas is its feasibility in rural areas where it offers the potential for sustainable development projects. The scale of digesters can vary to suit the energy needs of a household or small community, and the only input required organic waste is readily available in rural areas. Modern biogas digesters designed to produce energy for a household can function on the waste produced by four humans, or one to two cows. Several countries have made efforts to introduce digesters to rural areas, but biogas remains an untapped energy resource.

c. Liquefied petroleum gas (LPG)

LPG is a mixture of propane and butane. Despite the fact that it is a fossil fuel, LPG is considered to be clean because it can be burned very efficiently and emits few pollutants. Its use as a cooking fuel in Africa varies significantly across national borders and is highly dependent on government policy. Where it is used in household cooking, though, LPG is a popular fuel. It is non-toxic, and the specialised stove required for its combustion is simple and easy to use. The fuel has a high energy density and a total energy efficiency of between 45% and 60% [6].

d. Ethanol

The ethanol produced in Ethiopia from sugar industry is mainly used as an additive in transportation fuels. However, as the industry continues to expand, ethanol could offer the prospect of meeting household cooking needs. Ethanol is produced by fermenting the sugars in various types of biomass feedstock. It can also be produced from starches if they are first converted into sugars. The resulting mixture is then distilled to yield a high concentration of ethanol. There are a wide range of crops that can be used as feedstock, including sugarcane, cassava, sweet sorghum, maize and wheat. The ideal feedstock for the production of ethanol is dependent on regional climate and soil conditions, the crop’s annual cycles, and available technology.

e. Electricity

Although an efficient and clean source of energy, electricity has difficulties in penetrating the cooking market in developing countries. There are many reasons for this, one of which is the grid or lack of it. Electricity constitutes less than 4 percent of the total domestic consumption of urban households, and the current level of electrification is only about 13 percent.

Most of the electricity that is generated in Ethiopia is used for industrial and commercial purposes. Even in urban settings where grid connectivity is substantial, use of electricity for cooking is not feasible because its prices are so high compared with traditional fuels. As a result, only wealthy households benefit. Because of the tremendous capital investment needed to develop grids to the point where a significant number of households could have access to electricity for cooking. Besides the costs of grid connection, further costs would be incurred for many householders because of the building work needed on their homes to make electricity use safe.

CHAPTER 2

LITERATURE REVIEW

2.1 Ethanol as Cooking Fuel

The rise in crude oil price and the associated increase in the price of petroleum products that has occurred since the beginning of 2004 are showing adverse effect on the uses of petroleum products in all countries including Ethiopia. The use of ethanol promotes energy security creates jobs, prevent local pollution and contribute to the reduction of green house gas emissions.

Today a number of countries produce and use a significant amount of ethanol and some countries are busy preparing and approving directives and programs to produce and use renewable energy sources. Household cooking fuel is one of the critical problems in the country. Nearly 90% of Ethiopia’s current total energy demand is met using biomass fuels. Within household sector, the contribution of biomass fuel is close to 97% [12]. The existing households’ energy sources are mostly comes from: the uncontrolled use of wood fuels, and animal dung and agricultural residues.

In many rural areas deforestation and soil impoverishment is mainly happened due to lack of alternative energy sources. In addition to these problems huge amount of kerosene is imported each year with a lot of foreign currency as a household cooking fuel with government subsidies. Efforts have been made by Finchaa Sugar Factory to market ethanol as a cooking fuel. Ethanol can be used in a variety of cooking, heating, and lighting appliances in parallel with utilizing as a blend motor fuel.

Ethanol can be produced locally from a variety of materials that can be classified as sugar-containing, starch-containing and cellulose-containing [36]. Thus, the low cost and abundant availability of raw materials for the production of ethanol will make it very competitive with the other fuels used for cooking.

Ethanol has roughly similar limits of inflammability (limits of fuel-to-air ratio in which combustion will proceed) to those of the component gases of LPG. Due to the extremely low value (4.3 %) of the lower limit of inflammability, the use of pure ethanol for household purposes is dangerous. This problem can be overcome by the use of ethanol mixtures in a suitably designed stove.

Domestic production and use of ethanol for fuel can decrease dependence on foreign oil, reduce trade deficits, create jobs in rural areas, reduce air pollution, and reduce global climate change carbon dioxide build up. Ethanol, unlike gasoline, is an oxygenated fuel that contains 35% oxygen, which reduces particulate and No_x emissions from combustion.

The use of fuel ethanol promotes energy security, creates jobs, prevents local pollution, and contributes to the reduction of the green house effects. Each ton of sugarcane grown for hydrated or anhydrous ethanol production saves 0.17 and 0.25 tons of CO_2 (Carbon dioxide, one of the green house gases) SO_X emission, respectively , including emissions of this and other gases resulting from industrial processing and the burning of ethyl alcohol in vehicles engines

2.1.1 Physical properties of ethanol-water mixture

Ethanol is a straight-chain alcohol, and its molecular formula is C_2H_5OH. Its empirical formula is C_2H_6O. An alternative notation is $CH_3–CH_2–OH$, which indicates that the carbon of a methyl group ($CH_3–$) is attached to the carbon of a methylene group ($–CH_2–$), which is attached to the oxygen of a hydroxyl group (–OH). It is a constitutional isomer of dimethyl ether. Ethanol is a volatile, colorless liquid that has a slight odor. It burns with a smokeless blue flame that is not always visible in normal light.

The physical properties of ethanol stem primarily from the presence of its hydroxyl group and the shortness of its carbon chain. Ethanol's hydroxyl group is able to participate in hydrogen bonding, rendering it more viscous and less volatile than less polar organic compounds of similar molecular weight.

Ethanol is a versatile solvent, miscible with water and with many organic solvents, including acetic acid, acetone, benzene, carbon tetrachloride, chloroform, diethyl ether, ethylene glycol and glycerol. Ethanol's miscibility with water contrasts with that of longer-chain alcohols (five or more carbon atoms), whose water miscibility decreases sharply as the number of carbons increases.

Ethanol-water mixtures have less volume than the sum of their individual components at the given fractions. Because the hydrogen bonding and closer packing of the molecules by the attraction allows a larger number of molecules of the hydrated alcohol to fit into the same space, thus decreasing the overall volume.

Mixtures of ethanol and water that contain more than about 50% ethanol are flammable and easily ignited. Alcoholic proof is a widely used measure of how much ethanol (i.e., alcohol) such a mixture contains. Ethanol-water solutions that contain less than 50% ethanol may also be flammable if the solution is first heated. Some cooking methods call for wine to be added to a hot pan, causing it to flash boil into a vapor, which is then ignited to burn off excess alcohol.

The latent heat of vaporization for ethanol is about 839.686 kJ/kg and water has a latent heat of about 1628.2 kJ/kg. Therefore, if ethanol and water is mixed in the fuel tank the latent heat of the water will cool the mixture and increase volumetric efficiency. In addition, when the low concentration mixture is fired in the burner, the water will turn to high-pressure steam and provide additional power due to the pressure exerted by the steam. There are definite limits, however, to the amount of water that can be mixed. Too much will cause excessive cooling and misfiring. Ethanol and water mix simply by adding the desired amount of water to the alcohol in the fuel tank.

Table 2.1: Properties of ethanol

PROPERTIES					
PHYSICAL		CHEMICAL		THERMAL	
Density	789kg/m^3	Formula	C_2H_5OH	Lower heating value	26.8MJ/kg
Vapour pressure	50mm Hg	Molecular (wt)	46.1	Higher heating value	29.6MJ/kg
Boil temperature	78.5 $^{o}_{C}$	Carbon (wt)	52.2%	Ignition temperature	35$^{o}_{C}$
Solubility in water	∞	Hydrogen (wt)	13.1%	Specific heat	2.5kJ/kg$^{o}_{C}$
		Oxygen (wt)	34.7%	Melting point	-115$^{0}_{C}$

A. *Flash points of ethanol based water solution*

The flash point of a chemical is the lowest temperature at which it will evaporate enough fluid to form a combustible concentration of gas. The flash point is an indication of how easy a chemical may burn.

Table 2.2 : Flash points of ethanol based water solution.

Flash point												
Ethanol Concentration *(%* by volume*)*		5	10	20	30	40	50	60	70	80	90	96
Temperature	°F	144	120	97	84	79	75	73	70	68	63	63
	°C	62	49	36	29	26	24	22	21	20	17	17

Table 2.3: Freezing points of ethanol based water solutio***n.***

Freezing point												
Ethanol Concentration *(%* by volume*)*		0	10	20	30	40	50	60	70	80	90	100
Temperature	°F	32	25	15	5	-10	-25	-35	-55	-75	-110	-175
	°C	0	-4	-9	-35	-23	-32	-37	-48	-59	-73	-115

Source: The engineering toolbox

2.1.2 Overview ethanol production

Ethanol can be produced from any biological feedstock that contains appreciable amounts of sugar or materials that can be converted into sugar such as starch or cellulose. Many different feedstock sources can be used for ethanol production. They can divide into sugary, starchy and cellulosic feedstock.

A. Sugar-to-ethanol process

The simplest way to produce ethanol is the sugar-to-ethanol production. Thereby biomass is used that contains six-carbon sugars which can be fermented directly to ethanol. Examples for typical sugary feedstock types are sugar cane and sugar beets which contain substantial amounts of sugar.

Although fungi, bacteria, and yeast micro organisms can be used for fermentation, the specific yeast is frequently used to ferment glucose to ethanol. Traditional fermentation processes rely on yeasts that convert six- carbon sugars (mainly glucose) to ethanol. Theoretically, 100 grams of glucose will produce 51.4 g of ethanol and 48.6 g of carbon dioxide. In specific case of Finchaa sugar factory fermentation alcohol, substrate glucose is used, in which is obtained from molasses sucrose. This glucose converted into ethanol and CO_2 (Carbon dioxide) by yeast.

Commercial production of ethanol by fermentation is based on the conversion of sugar with six carbon atoms or C_6 sugars, to ethanol by yeast. Fermentation is the decomposition of organic compounds in to simple compounds through catalysts. The commercial production of ethanol as:

$$\underbrace{C_{12}H_{22}O_{11}}_{\text{Sucrose}} + H_2O\ \text{inverted} \rightarrow \underbrace{C_6H_{12}O_6}_{\text{Glucose}} + \underbrace{C_6H_{12}O_6}_{\text{Fructose}}$$

$$\underbrace{C_6H_{12}O_6}_{\text{Glucose}} + \text{Zymase} \rightarrow \underbrace{2C_2H_5OH}_{\text{Ethanol}} + 2CO_2 + E$$

Fig. 2.1: Commercial production of ethanol by fermentation

The whole fermentation process takes 24-30 hrs, with resulting beer (fermented mash) containing 6-12% ethanol by volume. This fermented beer is distilled to draw off ethanol. By conventional distillation processes ethanol can be concentrated to about 96.4% ethanol by volume. Further distillation cannot increase this percentage. The remaining water can be removed by dehydration (Fig.2.1), a step that follows conventional distillation. Therefore aromatic benzene is added to commercial grade ethanol in the dehydration step so that anhydrous alcohol is obtained.

B. Starch-to-ethanol process

Another potential ethanol feedstock is starch. In Europe and in the United states a large portion of bio-ethanol is produced from the starch component of grain crops, primarily corn and wheat in the US and wheat and barley in Europe. Starch molecules are made up of long chains of glucose molecules which have to be broken into simple glucose molecules (saccharification). Therefore starchy materials require a reaction of starch with water (hydrolysis). Typically hydrolysis is performed by mixing the starch with water to form slurry which is then stirred and heated to rupture the cell walls. During the heating cycle, specific enzymes are added, which break the chemical bonds. Organisms and enzymes for starch conversion and glucose fermentation on a commercial scale are readily available.

C. Cellulose-to-ethanol process

Besides sugar and starch, also cellulose can be converted into ethanol, but the cellulosic biomass-to-ethanol production process is more complicated than the sugar-or starch-to-ethanol process. Cellulosic materials are comprised of lignin, hemicellulose, and cellulose and thus are sometimes called lignocellulosic materials. They have to be converted to five-and six-carbon sugars, before they can be fermented and converted into ethanol. One of the primary functions of lignin is to provide structural support for the plant. Thus, in general, trees have higher lignin contents than grasses. Unfortunately, lignin which contains no sugars encloses the cellulose and hemicellulose molecules, making them difficult to reach.

2.2 Stove development

2.2.1 Ethanol

Compared to traditional fuels, more modern energy sources such as kerosene and liquid petroleum gas (LPG) offer increased efficiencies, reduced emissions and are more user friendly, with the additional benefit of reducing the workload of woman and children. However they release fossil fuel derived GHG's and are often more expensive to both the national economy and the user, with poverty being one of the main barriers to their uptake. Liquid biomass cooking fuels combine some of the advantages of both traditional and new fuels and one such scheme is Project Gaia, an Ethiopian based programme which has developed an alcohol stove which runs on either methanol or ethanol. The stove promoters have found the household liquid fuel market difficult to create as both a critical mass of stoves, and hence fuel, as well as government support is needed to gain the interest of private fuel companies. They also found that aside from cost the stove quality and functionality are key to appealing to the household cook.

Fig. 2.2: Clean Cook stove.

Economic analysis showed the cost of using the ethanol stove was comparable to those of both LPG and kerosene stoves, where as the cheapest option for cooking is the wood-burning (stoves) but, does not consider the environmental problems associated with woodstoves and the time spent gathering fuel.

CHAPTER 3

STOVE DESIGN

3.1 Thermal Efficiency

In this chapter the basic physical principles of combustion and heat transfer will be applied to the design of cook stove burning ethanol-water mixture and for each component of the stove design analysis will be developed. These analyses form the basis for the development of highly fuel efficient stove. To determine accurately the effects on performance and to optimize a design requires through testing as described in Chapter 4.

The heat transfer efficiency are discussed first in terms of conductive, convective, and radiation processes going on in and around the stove. These processes are explained based on information from thermodynamics, heat transfer, and fluid flow.

Table 3.1: Typical Property Values at 20 ^{o}C

Material	Thermal conductivity W/m[^{0}c]	Density Kg/m^{3}	Specific Heat J/kg[^{0}c]
Steel alloy	35 (10-70)	7700-8000	450-480
Fiberglass	0.04	200	670
Water	0.597	1000	4180
Air	0.026	1.177	1000

The heat transfer by conduction of an object can be expressed approximately by the equation:

$$Q = \frac{kA\left(T_1 - T_2\right)}{s} \tag{1}$$

Where Q is the rate of heat transfer,

k is the thermal conductivity of the material,

A is the area,

s is the thickness of the object across which heat is being conducted, and

(T_2-T_1) is the temperature difference between the hot and cold sides.

Thus, we see that if the plate is large and thin (A/s large) the rate of heat transfer will be large. If the plate is small in area and thick, more like a rod (A/s small), the rate of heat transfer will be small. The heat transfer also varies directly with the thermal conductivity and the temperature difference across the object.

Another factor of importance in conductive heat transfer calculations is the ability of a material to store thermal energy, measured as its specific heat. The specific heat of a material is the amount of energy required to raise the temperature of 1 kg of its mass by 1^0C. For a given object, the change in the total heat stored is then given by

$$dE = m * C_p * dT \tag{2}$$

Where: m is the object mass

Cp is its specific heat

dT is its change in temperature.

Thus, the thermal conductivity carries thermal energy through a material; the specific heat and mass of an object store this heat energy. The larger the mass and specific heat of an object the more energy it can store for a given change in temperature. Consequently, a thermally massive object warms up slowly and a thermally lightweight object will warm rapidly. This is called the thermal inertia of an object and this is an important parameter in the stoves. Reducing the heat loss into and through the stove walls (especially the shield) to the outside requires a detailed analysis of the conduction process, which is presented in Section 3.2.4.

Convective heat transfer occurs when a gas or liquid is forced or flows naturally across at a different temperature and then exchanges heat energy by conduction, by a surface of individual particles. Increasing convective heat transfer to the pot is the best way to increase the thermal efficiency of an ethanol-water mixture burning stove. Convective heat transfer follows the equation:

$$Q = h * A * (T_1 - T_2) \tag{3}$$

Where Q is the heat transfer from the fire to the pot

h convective heat transfer coefficient

A area where is the heat exchange

(T_1-T_2): Temperature difference between the flame and the pot.

To increase the heat transfer Q to the pot there are then, three things one can do. First, the temperature T_1 of the flame can be increased. This can be done only by taking optimal space between the shield and flame holder, thus controlling the amount of outside air that enters. Second, as much as the area A of the pot should be exposed to the flame as possible. The pot support should be kept small in area so as not to screen the flame from the pot. The flame should be allowed to rise up around the pot and contact its entire surface. Third, the convective heat transfer coefficient should be increased by increasing the velocity of the flame as it blows past the pot.

Then, the last heat transfer processes is the radiation. All objects (materials) continuously emit electromagnetic radiation due to internal molecular and atomic motion. The higher the object’s temperature, the greater the amount of energy so radiated. The warmth felt on one's skin when standing near a fire (but not in the hot gases) is due to infrared radiation from the fire. The temperature of the object can also be estimated by its color.

Most real materials, however, are not perfect emitters or absorbers. Metals, for example, are very poor absorbers (emitters) because the free electrons within them that give rise to large electrical and thermal conductivities also couple tightly to impinging radiation and screen its penetration into the material -- causing it to reflect instead. Gases such as water vapor and carbon dioxide have strongly frequency-dependent absorption in the infrared corresponding to excitation of vibrational and rotational motion of individual molecules.

3.2 Stove Design Analysis

The stove design is composed of the following parts:

- Fuel tank (pressure vessel)
- Manual-pressure pump
- Burner
- Jacket (wind shield)
- Flame controller
- Utensil support
- Pressure regulator valve (specification)
- Filter in fuel line

3.2.1 Fuel tank (pressure vessel*)*

Pressure vessels are leak proof containers used to hold gases or liquids at a pressure different from the ambient pressure. The end caps fitted to the cylindrical body are known as heads. The term pressure vessel refers to those vessels which are subjected to internal or external pressures greater than 0.7 atmospheric gauge, and vessels with $D/t \geq 20$ may be regarded as thin vessel [9].

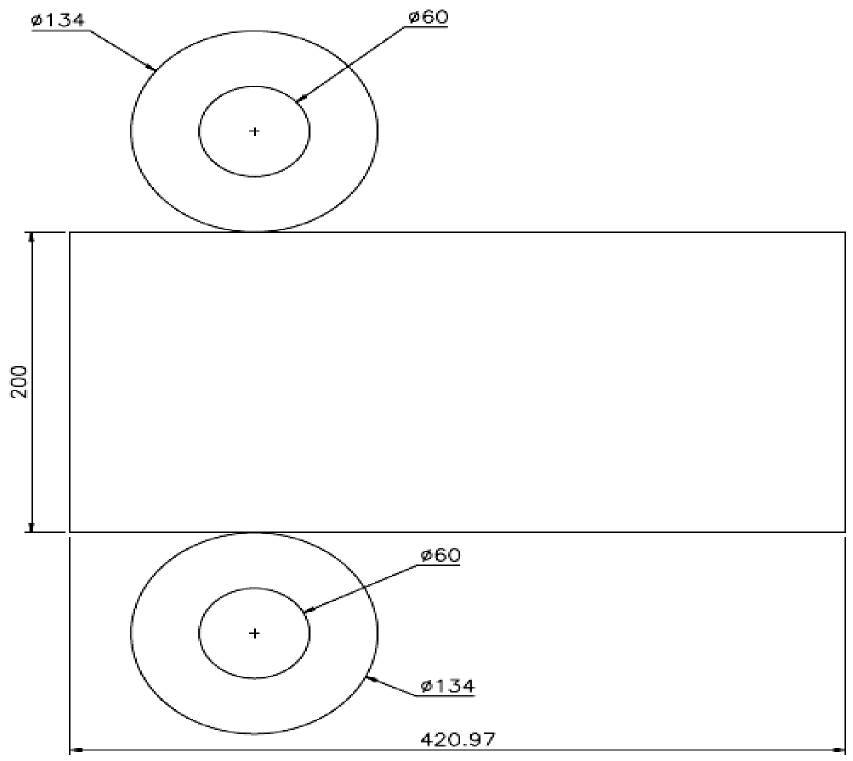


Fig. 3.1: Developed view of fuel tank

In this section, design of pressure vessel, calculate made to determine the thickness of a thin cylinder subjected to:

- *Internal pressure P = 150kpa*
- *Volume=2.6 litre*
- *Inlet pipe diameter = 20mm*
- *Outlet diameter =20mm and,*
- *Material steel, st-37*

Ultimate and yield stress for a number of different metals are given in Appendix C. Based on the design matrix I have to select St-37, because it is locally available, Suitable for welding and has relatively low cost.

From metal tension test report result, which was tested by AAiT mechanical engineering department, the material has

- ✓ *yield stress = 320Mpa*
- ✓ *ultimate stress = 390Mpa.*

For this design analysis apply longitudinal stress and hoop stress theory by considering the following assumptions.

Assumptions

In thin cylinder:

- The hoop stress and longitudinal stress are assumed to be constant throughout the thickness of the wall,
- The radial pressure is negligible as compared to hoop stress and longitudinal stress, but practically these stresses vary from zero at the outer to a value equal to the internal pressure at the inner surface of the cylinder.
- For the purpose of primary analysis of the stress formula, the effect of the ends of the cylinder and presence joints will be neglected [9].
- Since the fuel is a mixture of water and ethanol, assume 0.4 mm corrosion allowance of the material

Fig 3.2 shows the Hoop stress induced on the circumference section when an internal pressure applied on the pressure vessel

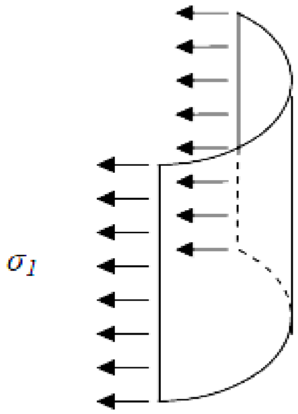


Fig. 3.2: Hoop stress, σt

I. Analysis of shell design

- *Volume analysis*

$$V_T = V_i + 2V_e \tag{4}$$

Where V_T = *total volume*

V_i = *volume of shell*

V_e = *volume of end*

- *Volume of shell*

$$V_i = \frac{\pi}{4} d_i^{\,2} \text{ x h} \qquad (5)$$

Where V_i *=inside volume of shell*

d_i *=inside diameter of shell*

h= height of shell

- *Volume of the end*

$$V_e = \frac{\pi}{3} h_i^{\,2}\left(3R - h_i\right) \qquad (6)$$

Where V_e *=volume of end*

h_i *=inside height of torispherical end*

$R = 0.8*d_e$

d_e *=inside diameter of torispherical end*

1. Thickness of the cylindrical shell

$$t_s = \frac{pd_i}{2fz - p} + \text{corrosion allowance} \qquad (7)$$

Where

t_s *= minimum shell thickness*

p = internal pressure

d_i*= internal diameter*

z= weld joint efficiency, which is given: $0.8 \le z \le 0.9$

f= the allowed value of the nominal design stress for normal operating cases

2. Length of the cylindrical shell

The length of the cylindrical shell is between the ranges of (2-3)d_i

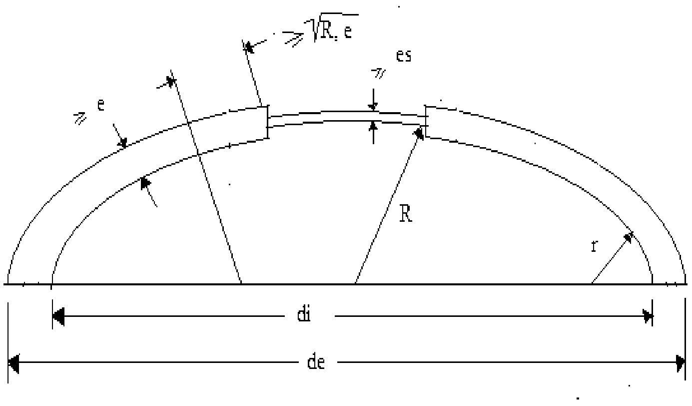


Fig. 3.3: Schematic drawing of kloepper type tori spherical end

For kloepper type tori spherical end

$R=0.8d_e$ and $r=0.154d_e$

The inside length of tori spherical end is given:

$$L_i = R - \sqrt{\left(R - \frac{d_i}{2}\right)\left(R + \frac{d_i}{2} - 2r\right)} \tag{8}$$

Where

d_e = *External diameter*

L_i = *inside length of torispherical end*

II. Analysis of ends design

1. Flat end

For normal operating case minimum thickness of the end is given:

$$t_e = \max\left\{\left(C_1 \, x \, d_i \sqrt{\frac{p}{f}}\right), \left(C_2 \, x \, d_i \sqrt{\frac{p}{f_{min}}}\right)\right\} \tag{9}$$

Where

$$f_{min} = \min\{f; f_s\}$$

$$C_1 = \max\left\{\frac{p}{f}; \frac{t_s}{d_i}\right\}$$

2. Torispherical end

The thickness of the end should be the greatest of t_s, t_y and t_b

i). t_s = required thickness of the end to limit membrane stress in central part

$$t_s = \frac{pR}{2fz - 0.5p} \tag{10}$$

ii). t_y= required thickness of knuckle to avoid axis symmetric yielding

$$t_y = \frac{\beta p(0.75R + 0.2d_i)}{f} \tag{11}$$

iii). t_b= required thickness of knuckle to avoid plastic bucking

$$t_b = \left(0.75R + 0.2d_i\right)\left[\frac{p}{111f_b}\left(\frac{d_i}{r}\right)^{0.825}\right]^{\left(\frac{1}{1.5}\right)} \tag{12}$$

3. Hemispherical Head

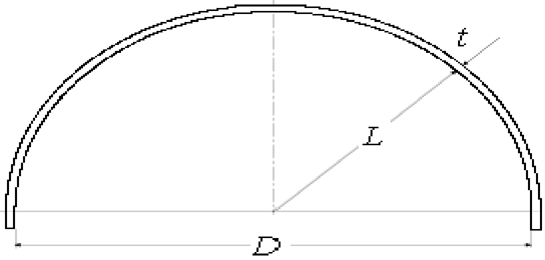


Fig. 3.4: Hemispherical head

By assuming the two portions have internal diameter and different cross sections. The minimum head thickness, t_h of a thin hemispherical shell due to internal pressure is given by:

$$t_h = \frac{pR}{2fz - 0.5p} \tag{13}$$

Detail calculation made to determine the diameter, length, thickness and type of heads of the cylinder are given in Appendix A.

3.2.2 Hand-pressure pump

Working principle

The hand-pump was designed to pump air into the fuel tank by pumping air on the down-stroke. This was achieved by placing one-way valves on the end of the pump. The hand-pump only injects air into the fuel tank while the user pushes down on the pump rod and while lifting the pump rod the non-return valve prevents the air to move back.

During the upstroke, the pump rod draws air through a hole into the seamless pump pipe from the outside. During the down stroke, as more force is added to the pump rod, the volume of seamless pump pipe decreases. As the volume decreases, the space the particles have to move around inside the seamless pump pipe decreases. The particles of air become denser inside the seamless pump pipe and hit the wall.

Thus the hand-pump is filled with a volume V_i of air at atmospheric pressure P_a and ambient temperature T_a. When you push the pump rod, the air is compressed to a new (smaller) volume V_f, raising its pressure. A non-return valve is then opened, allowing air to flow from the pump into the tank until the remaining air in the pump reaches the pressure of the air in the tank, P_t.

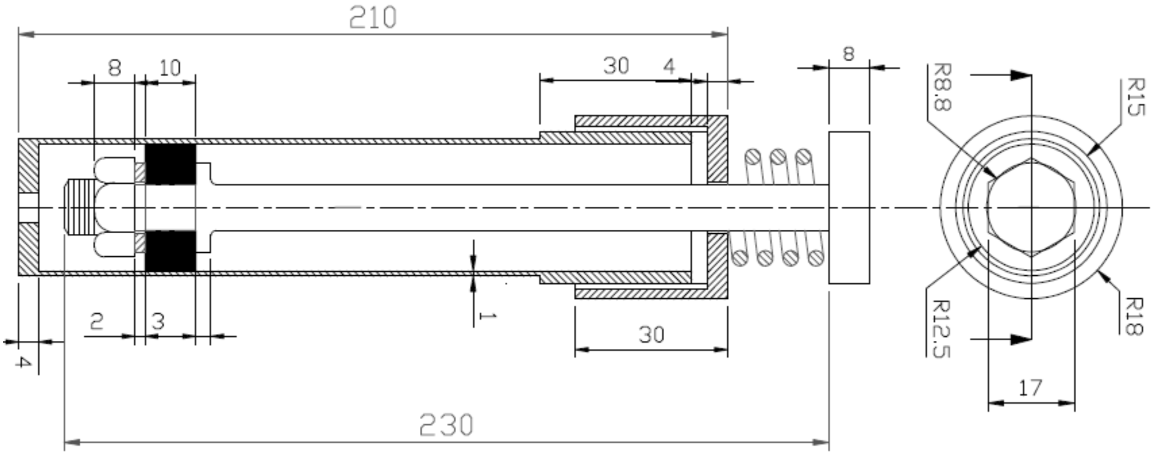


Fig. 3.5: Hand pressure pump

Materials for manufacturing

The materials and parts used to manufacture hand-pump are:

- *seamless pipe*
- *piston,*
- *cylindrical handle,*
- *non-return valve, and*
- *pump rod.*

Assumptions

- The pressure of the air in the tank, P_t, does not change significantly as air flows into the tank from the pump.
- The temperature of the air in the pump does not change significantly while air is flowing into the tank (i.e., this is an isothermal process).
- The air is mainly composed of diatomic molecules with γ =1.4.

Design analysis

From 20-150 kpa pressure is required to flow the fuel from the fuel tank to the burner through the pipe line.

$$P = \frac{F}{A} \tag{14}$$

Where P*= pressure*
F*= force exerted*
A*= cross sectional area*

This was done by pre-determining the number of stroke and the pressure required up to 150 kPa by the hand-pump attached to fuel tank, to operate the stove for a continuous period of 1-2 hours without further pumping. Assuming the user applies 20-40 downward strokes, the user required force is tabulated in the following Table 3.2. The required pressure and the cylinder area are 150 kpa and 0.01049 m^2, respectively, for all stroke numbers.

Table 3.2: User force vs stroke

Stroke No.	Required pressure [kpa]	Pressure per stroke [pa]	Cylinder area [m^2]	Force required (N)
20	150	7500	0.01049	78.6
22	‘’	6818.2	“	71.5
24	‘’	6250	“	65.5
26	‘’	5769.2	“	60.5
28	‘’	5357.1	“	56.2
30	‘’	5000	“	52.4
32	‘’	4687.5	“	49.1
34	‘’	4411.8	“	46.3
36	‘’	4166.7	“	43.7
38	“	3947.4	“	41.4
40	‘’	3750	“	39.3

While within nearly 4-5kg the user pushes down on the pump rod, consider two approaches to get more air into the tank per pump cycle by pushing the pump rod quickly or slowly. Typical calculations are given in Appendix B.

Results show that the fraction of the particles in the pump that are transferred into the tank when the pump pushes quickly is 0.87 and when the pump rod pushes slowly the fraction is 0.75.

So when you pump quickly, not only do you get more pump cycles per unit time, but you also put more air in the fuel tank per cycle (at least according to this simplified model). Of course you have to pump not only faster but also harder, since the average pressure you will pump against will be higher. In fact this higher pressure is the main reason that more particles are transferred to the fuel tank each time.

To calculate the fraction of particles transferred into the pump:

Initial number of particles in a gas

Using the ideal gas law,

$$N_i = \frac{p_a V_i}{k_B T_a} \tag{15}$$

Where

N_i= *initial number of gas particles*

P_a= *atmospheric pressure*

V_i= *initial volume of the pump*

T_a= *ambient temperature*

k_B = *Boltzmann's constant*

Final number of particles in the pump

The gas particles N_f in the pump after the pump and tank have equilibrated is

$$N_f = \frac{p_t V_f}{k_B T_a \left(\frac{V_i}{V_f}\right)^{Y-1}} \tag{16}$$

3.2.3 Burner design

In this design analysis, the standard burner available in the market was used with minor addition/modification in the pipe line and the nozzle diameter.

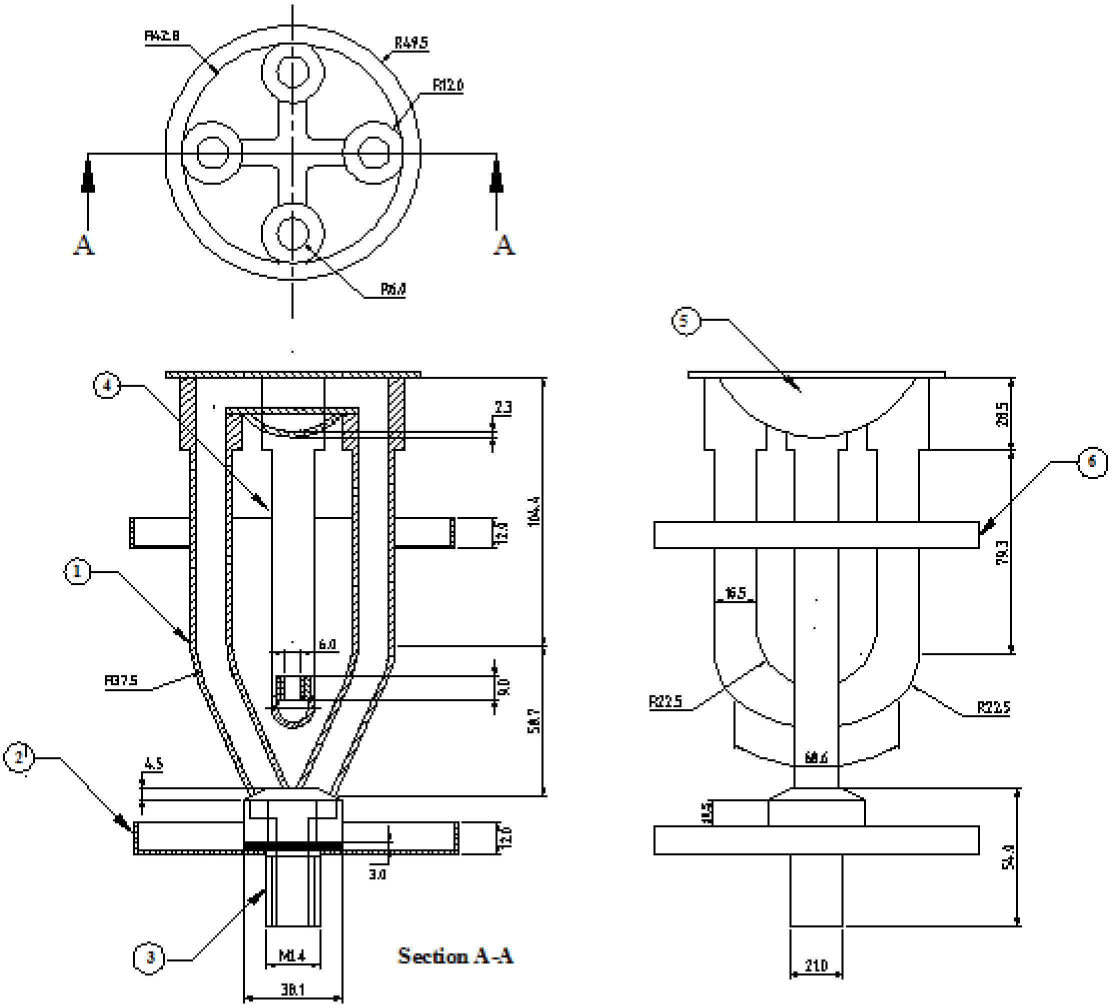


Fig. 3.6: Roarer type burner

The Burner components are:

1. Outer tube	4. Inner tube
2. Spirit cup	5. Vaporizer
3. Burner socket	6. Flame ring seat

The amount of fuel required to produce the required temperature in the stove is looking for. The heat locked up in a fuel is expressed as its calorific value. The calorific value or heating value of a fuel is expressed in kilojoules per kilogram kJ/kg and is a measure of the energy stored in the fuel. The calorific value is only fully realized when one kilogram of the fuel is burned. The percentage of water in fuels is also reflected in the calorific value. High water content will reduce the calorific value of the fuel. The lower heating value, LHV, of a fuel is defined as the amount of heat released by combusting a specified quantity. According to American Petroleum Institute (API), from Table 2.3 the LHV for ethanol fuel is 26.8 MJ/kg.

In order to calculate the amount of fuel required to produce certain energy, the dimension of this fuel is required. The best way to obtain the size of the fuel is to realize how much fuel it is physically possible to flow through the pipe into the burner. In fact, there is no point doing calculation with a huge amount of fuel which is not convenient in the reality. Then, based on the idea of the dimension of the burner which is bought from the local market, the diameter of the nozzle is 0.2 mm. As according to the Roerer burner principle the fuel mixture must flow through the nipple, the calculations are made for four nipple of 0.2mm diameter d. Thus, the volumetric flow rate of the fuel is calculated by assuming to supply about 2.45kw for cooking, it requires a heat output of 2.45kw or 8.82MJ/h and the calorific value Cv of pure ethanol 21.2MJ/l.

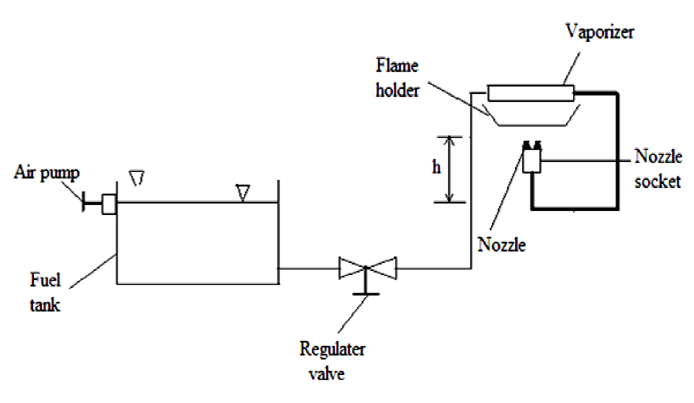


Fig. 3.7: Schematic drawing of pressurized-ethanol oil stove

The force which drives the fuel into the burner is the pressure induced in the fuel tank which passes through the pipeline. The key equation that relates fuel/gas pressure to flow is Bernoulli’s theorem:

$$\frac{p}{\rho} + \frac{v^2}{2g} + z = \text{constant} \qquad (17)$$

where: p is the fuel/gas pressure (N/m^2),

ρ *is the fuel/gas density* (kg/m^3),

v is the fuel/gas velocity (m/s),

g is the acceleration due to gravity (9.81 m/s^2*) and*

z is head (m).

The amount of a fine spray of hot ethanol-water mixture gas used by a burner is controlled by the size of the gas “jet” or “injector orifice”. This is usually a brass thimble with a hole drilled in the end screwed onto the rising ‘’u’’ tube, so that it can be easily replaced.

Mass flow rate through nozzle

The mass of a mixture passing through the pipe:

$$\dot{m} = \rho * \dot{V} \tag{18}$$

Where: $\dot{m}$ = *mass flow rate,*

$\dot{V}$ = *Volumetric flow rate*

ρ = *Density*

Detailed typical calculation to determined flow rate, mass flow rate and velocity of the nozzle are developed in Appendix C.

3.2.4 Jacket (wind shield) and flame holder

The combustion process takes place in a controlled manner in some form of combustion chamber after initiation of combustion by some means, an ignition. This energy is in form of heat, the source of heat is the chemical energy of substances called fuels. The most convenient source of oxygen supply is that of the atmosphere which contains oxygen and nitrogen and traces of other gases. Normally no attempt is made to separate out the oxygen from the atmosphere, and the nitrogen, etc. accompanies the oxygen into the combustion chamber. Nitrogen does not oxidize easily and is inert as far as the combustion process is concerned, but it acts as a moderator in that it absorbs some of the heat of combustion and so limits the maximum temperature reached.

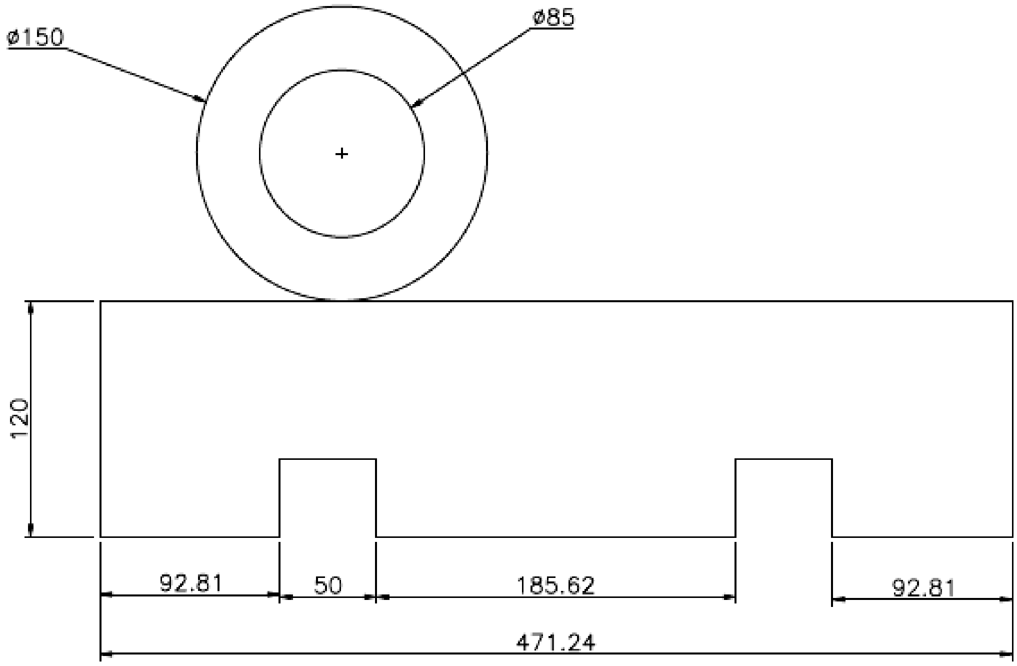


Fig. 3.8: Development view of wind shield (jacket)

Chemical reaction

The combustion products are heat energy, carbon dioxide, water vapor, nitrogen, and other gases (excluding oxygen). Stable and efficient combustion conditions require correct mixtures of fuels and oxygen. In theory there is a specific amount of oxygen needed to completely burn a given amount of fuel, this is the stoichiometric condition. In practice, burning conditions are never ideal. To ensure complete combustion it is usual to supply air in excess of the amount required for chemically complete combustion. Therefore, more air than ideal must be supplied to burn all fuel completely. The amount of air more than the theoretical requirement is referred to as excess air, it is more than what is needed to burn the fuel completely.

$$\text{Fuel} + \text{oxidant} \rightarrow \text{product}$$

Complete combustion of ethanol

It is presumed that the used Ethanol is 96% pure C_2H_5OH. The complete combustion reaction of ethanol is given by

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

In order to study its combustion process, the chemical composition is looking for. Carbon C, hydrogen H and oxygen O are the main components of ethanol fuels. C and H are oxidized during the combustion by exothermic reactions (formation of CO_2 and H_2O). To be able to run the analysis of the combustion reaction the proportion of each element composing the bio-fuel are required. According to The Characterisation of the Physical and Chemical Properties of ethanol, approved by the API, the weight percentage compositions of the ethanol are: C = 52.2%, H = 13.1% and O = 34.7%

As previously said, the stoichiometric ratio is the ideal condition, when the combustion is complete. Thus, from the combustion of the chemical element composing the ethanol, the stoichiometric air/fuel ratio is looking by each constituent is taken separately and the amount of oxygen required for complete combustion is found from the relevant chemical equation.

- For the carbon C:

$$\mathrm{C + O_2 \Rightarrow CO_2}$$

$$\mathrm{12kgC + 32kgO_2 \Rightarrow 44kgCO_2}$$

$$\text{Oxygen required } = 0.522 * \frac{32}{12} = 1.392\,\text{kg/kg fuel}$$

Where the carbon content is 0.522 kg per kg of fuel

$$\text{Carbon dioxide produced } = 0.522 * \frac{44}{12} = 1.914\,\text{kg of CO}_2$$

- For the hydrogen H:

$$\mathrm{H_2 + 1/2O_2 \Rightarrow H_2O}$$

$$\mathrm{1kgH_2 + 8kgO_2 \Rightarrow 9kgH_2O}$$

$$\text{Oxygen required } = 0.131 * 8 = 1.048\,\text{kg/kgof fuel}$$

$$\text{Steam produced } = 0.131 * 9 = 1.179\,\frac{\text{kg}}{\text{kg of fuel}}$$

Table 3.3: Showing the amount of oxygen required for the combustion

Constituent	**Mass fraction %**	**Oxygen required kg/kg fuel**	**Product mass kg/kg fuel**
Carbon	52.2	1.392	1.914
Hydrogen	13.1	1.048	1.179
Oxygen	34.7	-0.347	-
	Total	2.093	

Thus, the oxygen required per kilogram of fuel is 2.093kg.

It is usual in combustion calculations to take air as:

By mass: $O_2 = 23.3\%$ By volume: $O_2 = 21\%$

$N_2 = 76.7\%$ $N_2 = 79\%$

As the air is composed of 21% O_2 and 79% N_2 by volume, and the N_2/O_2 mass ratio is equal to 3.29 the nitrogen required per kilogram of fuel is $2.093 * 3.29 = 6.88kg$

The air is assumed to contain 23.3% O_2 by mass, therefore the air required by kilogram of fuel is $2.093/0.233 = 8.98kg$

As a consequence, Stoichiometric Air/fuel ratio is **8.98**

In fact, the total amount of air for 1kg of fuel is equal to $2.093(O_2) + 6.88(N_2) = 8.98\text{kg}$

As found in the previous chapter the required mass of fuel is 0.32kg. Thus the amount of air needed is:

$$8.98 * 0.32\text{kg of fuel} = 2.87\text{kg of air}$$

As the density of the air is 1.2kg/m^3 the combustion chamber must be able to feed a volume of air:

$$\text{Volume of air in combustion chamber} = \frac{2.87\text{kg of air}}{1.2\text{kg/m}^3} = 2.39\text{m}^3$$

As the amount of fuel is assumed to burn in one hour, this volume is the air which must go through the chamber during this time, 2.39m^3/h.

3.3 Prototype Stove Manufacturing

Manufacturing of this type of stove, including production rates and costs, are given in Tables 3.4 and 3.5. The general procedure used is the following, with specific tasks divided among different workers.

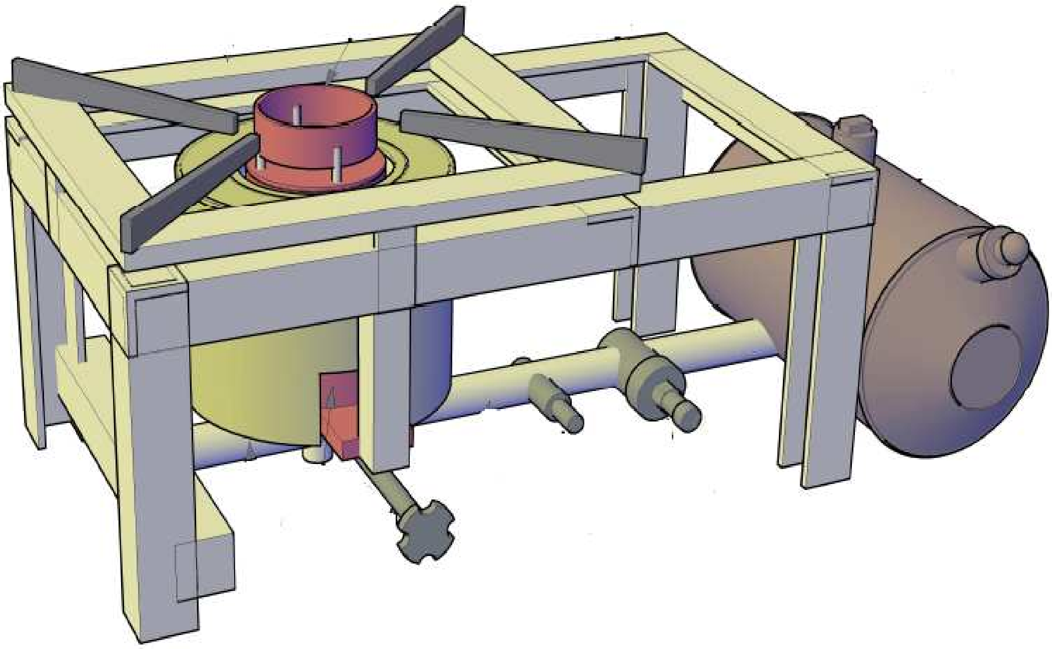
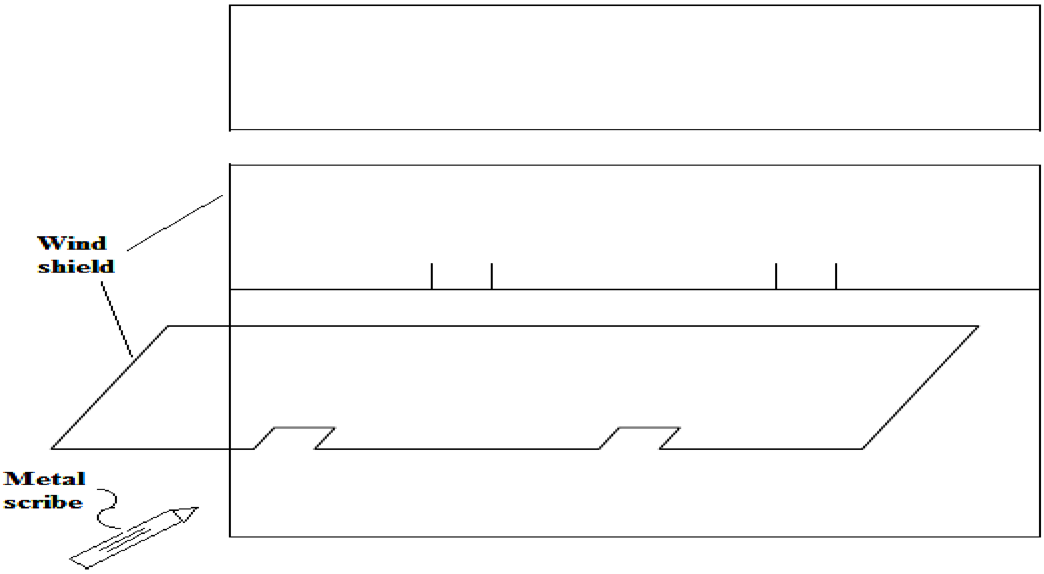


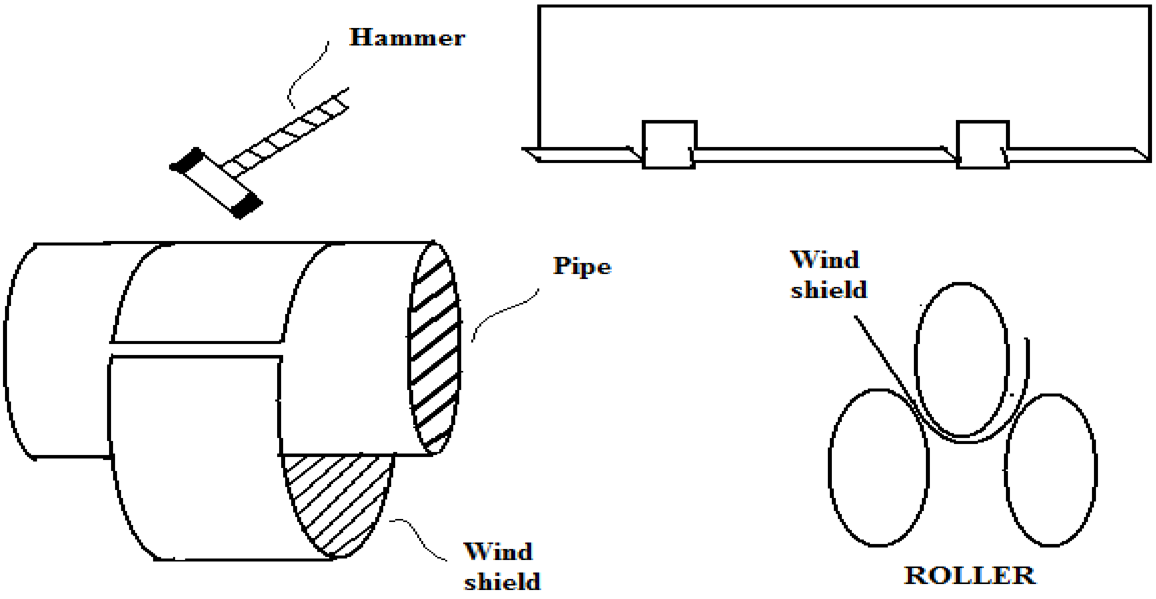
Fig. 3.9: Pressurized-ethanol stove

Wind shield:-

1. The template is traced out on the metal sheet as shown below and cut out in outline. The strips for the air holes are cut out



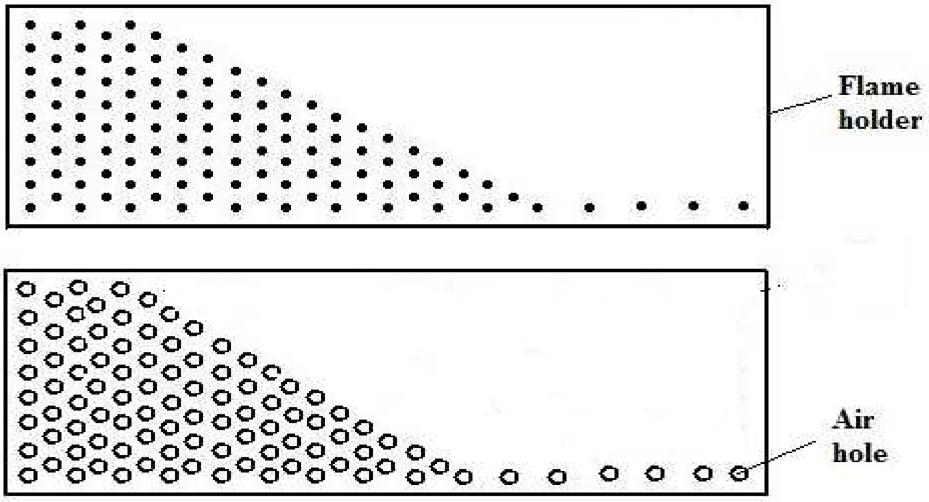
2. The sheet metal is rolled into a cylinder -- it should be as smooth, round, and straight as possible.



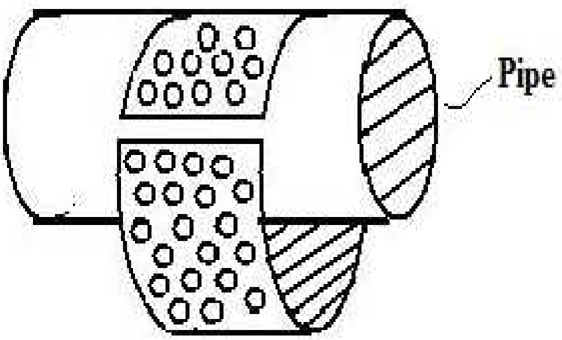
If a sheet metal roller is used, the bottom can be folded over before rolling. If bent by hand, they can be folded after rolling. This provides additional rigidity and prevents the user from being cut on sharp edges.

Flame holder:-

1. Other component such as the flame holder traced out on the metal sheet the required dimension, and then cut out. The air holes punched in and drilled before rolled into a cylinder.



2. The metal is rolled into a cylinder -- it should be as smooth, round, and straight as possible.



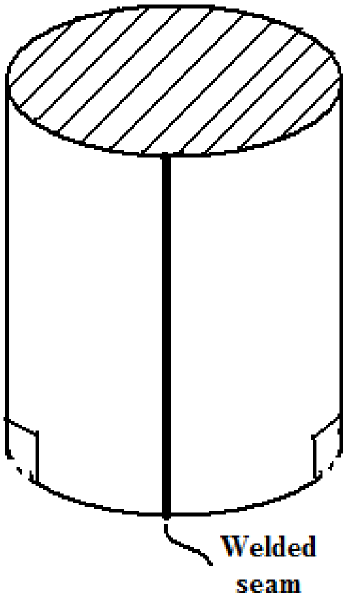
Fuel tank:-

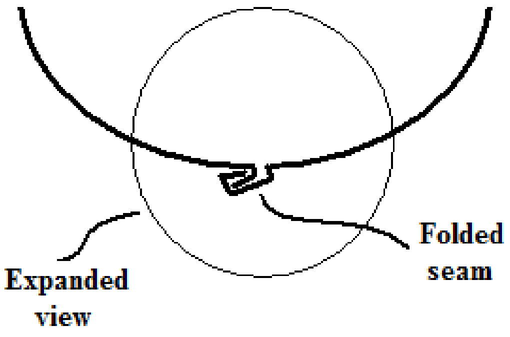
1. Similar metal production was done for fuel tank template, it is traced out on the metal sheet and then cut out in outline, after rolled into a cylinder as I mentioned above by sheet metal roller.

Support:-

Stove support is cut out according the desired dimensions, and then welds horizontal and vertical frames.

The stove is welded together and pan support and burner are welded into place. Alternatively, the walls (wind shield, flame holder and fuel tank) can be locked together by folding.





The stove is given the desired surface finish (painting with heat resistant paint) to improve its rust resistance and market appeal, and to reduce its heat loss by lowering its emissivity.

3.3.1 Production rate

The production rate as a function of each step in the production line is cutting the stove form out of sheet metal and then later welding it and the pot supports into place. This is by far the slowest steps in the production process.

To optimize this rate, it provide addition of better or additional metal cutting and welding equipment may then offer an opportunity to increase shop productivity considerably.

Table 3.4: Production Time for the Stove

No	Production step	Time (minutes)
1	Tracing stove from template	0:20
2	Rolling/hammering into cylinder	0:15
3	Cutting and/or punching flame holder	0:10
4	Cutting stove support and pan support	0:10
5	Tracing nozzle (modification)	0:15
6	Threading and drilling	1:30
7	Welding	0:45
8	Painting	0:15
	Total	3:40

3.3.2 Costs of production

The costs of production as a function of material, labor and electricity is described in Table 3.4. As seen in Table 3.5, the cost of metal accounts for over half the total stove cost. The use of lower cost alternatives such as recuperated scrap or lighter gauge metal may therefore offer a significant opportunity to reduce costs. It should also be noted that labor is a very small component of the total costs; increasing shop productivity by purchasing better metal cutting and welding equipment may then be a less important consideration in this case.

Table 3.5: Production Costs detail

No	**Description**	**Unit**	**Qty**	**Unit Price [birr]**	**Material required**	**Total amount [birr]**
1	**Material cost**					
	a. Metal sheet (1mm)					
	• Fuel tank	pcs	1	220.00	228x605x1	15.17
	• Wind shield	‘’	1	‘’	120x421x1	5.55
	• Flame holder	‘’	1	‘’	120x236x1	3.11
	b. Angle iron (20x20)	berga				
	• stove support	mm	1	140.00	2850x20x2	66.5
	c. RHS (20x20)	berga				
	• Pot support	mm		110.00	960x20x2	17.6
	d. Hand-pump					
	• Seamless pipe	pcs	1	5.00	Ø27	5.00
	• Piston	‘’	1	4.00		4.00
	• Piston rod	mm	1	8.00	Ø10	8.00
	• Spring and nut	‘’	2	3.50		3.50
	e. Burner	pcs	1	60.00		60.00
	• NRV	‘’	1	20.00		20.00
	• PRV	‘’	1	10.00		10.00
	• nozzle	‘’	4	5.00		20.00
	f. Welding					
	• Electrode	pack	10	144.00		6.25
	• Oxy-acetylene					15.00
	g. Paint					
	• Silver spray	tin	1	55.00	1/4	13.75
2	**Labor costs**					
	(three employees)		3	70birr/8hrs	(8.75*3hrs)+((8.75/60)*40min	96.25
3	Operating costs					
	Electricity	kw	50		50*0.27	13.5
	Total Production Costs					**383.18**

CHAPTER 4

OVERVIEW THE PERFORMANCE TESTING OF STOVE

4.1 Introduction

Testing is an essential component of any program that promotes the use of improved ethanol-water mixture burning stove in developing countries. This is true regardless of how programs are administered or by what means the stoves are disseminated. Stove testing is the systematic measuring of the advantages and limitations of a particular stove model. Its primary aim is to help identify the most effective and desirable stoves for a specific social and economic context. With ongoing stove production, a testing program provides essential quality control and may lead to important design modifications.

Increasing the fuel efficiency and safety of a stove may require the concession of some of the advantages of traditional stoves, particularly their lower initial cost, and their flexibility to fit different pots, and the lighting they provide. As fuel costs rise, however, alternative stoves will become increasingly attractive. Detailed water boiling test, permits the determination, the performance and attractiveness of a particular stove at any particular time in any given area. I have added the test finding to this study in Appendixes D, E and F.

The method used to evaluate the efficiency and performance of the stove is based on a group of stove experts by Volunteers in technical Assistance (VITA) introduced a standardized stove-testing concept prepared from proceedings of a meeting convened 1982 in Arlington.

The group formulated the following tests:

The water boiling test (WBT) :-To measure how much fuel is used to boil water under fixed conditions. This is a laboratory test, to be done both at full heat and at a lower "simmering" level to replicate the two most common cooking tasks. While it does not necessarily correlate to actual stove performance when cooking food, it facilitates the comparison of stoves under controlled conditions with relatively few cultural variables.

The Water Boiling Test (WBT) measures the thermal efficiency of the stove, the specific fuel consumption and both maximum and minimum power. The specific fuel consumption (SFC) is the fuel used to boil one litre of water with test conditions corrected to a standard ambient temperature.

The controlled cook test:-To serve as a bridge between the water boiling test and the kitchen performance tests. Trained local cooks prepare pre-determined meals in a specified way, using both traditional and experimental stoves. The Controlled Cook Test (CCT) assesses the stove performance according to local conditions by measuring both the mass of food and fuel used, as well as the time taken, to cook a typical meal. The test gives a more realistic idea of performance than the WBT, but still with control over the variables, and returns the SFC in grams of fuel used per kg of food cooked.

The kitchen performance test:-To measure how much fuel is used per person in actual households when cooking with a traditional stove, and when using an experimental Stove. The tester simply measures how much fuel the family has at the beginning and at the end of each testing period. In reality, a stove will not perform as it does under laboratory conditions due to many factors such as user habits, cooking practice etc. and this leads to a requirement for a field test, called the Kitchen Performance Test (KPT). The KPT measures the specific household fuel consumption (SHFC) and gives the mass of fuel used per standard adult per day.

4.2 Water Boiling Test

The Water Boiling Test (WBT) is a relatively short, simple simulation of common cooking procedures. It measures the fuel consumed for a certain class of tasks. It is used for a quick comparison of the performance of different stoves. Water Boiling Tests use water to simulate food; the standard quantity is two-thirds the full pan capacity.

The adopted WBT procedure called for a standard 5 litre pot to be used with no lid [3]. This did not reflect local cooking practice and the author found it impossible to boil water under these conditions. Therefore the method was adapted to use a 2.3 litre pot with a lid as this was how porridge, rice and vegetables was cooked for a typical family. These modifications will have an effect when comparing results from other studies but for the purposes of this comparative research were justifiable. Each test was repeated three times and the average taken. More details of the WBT can be found in Appendix D and G and full performance equations can be found in Appendix E.

During the test a data and calculation form was completed for the stove. The tests conducted included power, efficiency, and flame temperature, time taken to boil 1 litre of water, fuel capacity, stove outer temperature and fuel vessel outer temperature.

Equipment

a. Appliance (Stove)
b. Ø185 Pots: Stove tests are often conducted with lidded pots to reduce the effect of drafts on evaporation rate from the pot. However, if the testing site is properly protected from drafts, lids should be left off, thus reducing the error caused by condensed water dripping from the lid back into the pot.
c. A balance accurate to +/- 0.5g with a recommended capacity of 15 kg
d. Ethanol-water mixture oil and kerosene
e. Water, within of ambient temperature
f. Timing device
g. Digital thermometer for measuring temperatures up to 105 [degrees] C
h. Forms for recording data and calculations
i. Optional: insulated gloves for handling hot pot.

4.2.1 *Procedure*

i. Note and record the test conditions. Prepare a drawing of the pots and stove to be tested. (Note: in any test series be sure to use the same pots for all tests.) Include all relevant stove dimensions and show how the pots fit into the stove. Note climatic conditions. (air temperature, relative humidity, wind conditions).

ii. Weigh

   a. The empty, dry pots, and record this weight on the data and calculation form.

   b. Fill each pot with 1 litre of water and record the new weight.

iii. Pour a quantity of fuel 75% of the fuel tank capacity, weigh it, and record the weight on the Data and Calculation Form.

iv. Place a thermometer in the pot so that water temperature may be measured in the centre, about 1 cm from the bottom. Record water temperatures and confirm that they vary no more than 2 ^{0}C from ambient.

v. After a final check of preparations, light the burner. Write the exact starting time. Throughout the following "high power" phase of the test, control the flame with the means commonly used locally to bring the first pot to a boil as rapidly as possible.

vi. Regularly record the following on the Data and Calculation Form:

   - the water temperature of the pot;
   - the quantity of fuel in fuel tank;

vii. Record the time at which the water in the pot comes to a full boil.

viii. At this time rapidly do the following:

- Shut the fuel supply by releasing the pressure valve
- Record the water temperature of the pot.
- Weigh the pot, with its water.
- Record all measurements on the Data and Calculation Form.

ix. Weigh the pot with its remaining water, record the weight.

x. For the next 30 minutes maintain the fire at a level just sufficient to keep the water simmering. Use the least amount of fuel possible, and avoid vigorous boiling. Continue to monitor all conditions noted in Step vi. If the temperature of the water in the pot drops more than 5 ^{0}C below boiling, the test must be considered invalid.

xi. Calculate the amount of fuel consumed the amount of water remaining, the test duration and the Specific Fuel Consumption. Minimum and maximum power levels may also be calculated.

4.2.2 Testing parameters and equipment

Climatic conditions

Among the climatic data to be reported during stove testing, the most important are: air temperature, wind conditions, relative humidity and altitude.

- Air temperature affects the rate of heat loss from stove and pot. It also establishes initial water temperature in the Water Boiling Test. Ideally, air temperature measurements should be taken before and after each test so that a mean value can be estimated.
- Wind conditions affect the stove's draft and can have considerable influence on stove performance. Ideally, stove testing should be done only when conditions are calm. Where this is not possible, a windbreak should be erected around the stove to reduce air movement and convective heat losses.

Atmospheric pressure and boiling temperature

The normal boiling temperature of water depends on atmospheric pressure, which is mainly a function of altitude above sea level. At an altitude (H) the normal boiling temperature can be computed from:

$$T_b = 100 - \frac{H}{300}\ {}^0C \qquad (19)$$

When, H is expressed in meters. For example, the normal boiling point is 100°C at sea level, and 95 °C at 1500m altitudes.

In this test the boiling temperature was assumed as 92.3 °C, because the average altitude at the test site 'Ethiopia' at the University of Addis Ababa is about 2300m above sea level. Calculate with the equation (19) gives an exact value of 92.3°C for the boiling temperature.

Note that cooking time increase with reduced boiling temperature at high altitudes. The cooking time is doubled for a temperature decrease of 5° to 10°C, depending on the kind of food (no influence for the WBT).

The temperature of the water in the pot was measured with a digital measurement device from HANNA instrument k-type Thermocouple.

Fig. 4.1: Stove system with temperature measurement set-up and scale

Weight (mass)

Weighting can be done with any good balance. For field-testing, direct reading instruments are preferable, as no adjustments of weights are needed.

Spring balances do a good job if they have a long reading scale and thus good resolution, and if they are used within 20 to 100% of the full capacity. Spring balances should occasionally be checked with calibrated weights (1 litre of water has 1 kg of weight, etc.).

Fig. 4.2: Scale with single measurement box and digital display (aeadam)

The weighting basket used with a balance should be as light as possible, since precision is lost when the difference between two weightings is relatively small. The weight of the whole stove system (stove + pot + water) in the described stove tests was measured with a bench balance from aeadam (Fig.4.2). This scale with a measurement surface 52x40 cm and has a range up to 15 kg and accuracy +/- 0.5 g. The digital display was a CBW-15 Type.

Flame temperature maximum:

The flame temperature test was completed by holding the digital thermometer probe in the hottest part of stove flame (+/-5mm below where the pot base would sit on the stove) for a period of 5 minutes.

Fig. 4.3: Thermocouple measuring device

The temperature of the flame was also measured with a digital measurement device from HANNA instrument k-type Thermocouple.

Calorific Values

Calorific values are normally expressed as either gross calorific value, also known as the higher heating value, or as the net calorific value, also known as the lower heating value. The gross calorific value is defined as the heat liberated when the material is completely burned to carbon dioxide and liquid water at 25 ^{0}C. The net calorific value is the same except that the water is assumed to remain in the gaseous phase (i.e., steam) at 100 ^{0}C. For cook stove designers and testers, the net calorific value is the more useful.

Calorific value of supplied fuel is a prime data for calculation of efficiency of a stove. Calorific value of fuel is taken as the input energy while determining the efficiency of stoves. In practical aspects, due to contamination of different substances and ways of fuel extraction, calorific values of any fuel vary from specimen to specimen. As the calorific values of fuel vary that directly affect the value of efficiency regardless of same experimental and calculation procedure. For each specimen of fuel the calorific value has to be determined by using *a bomb calorimeter***.** This would give accurate result in determining the efficiency of stoves under experiment.

Adding percentage of water to pure ethanol reduces the effective calorific value of pure ethanol by just 2260 kJ/kg water the amount of energy needed to raise the temperature of water to boiling and evaporate it. This should be compared to the calorific value for pure ethanol 26.8 MJ/kg. For example, if 4% of water is adding with 96% of pure ethanol the mixture will have just (0.96) (26800) =25.632 kJ of energy in it, of which about 90.4 will be used to evaporate the water. Instead of a presumed 26800 kJ of energy in the kilogram of pure ethanol, there are only 25.542 kJ.

Volume

Volumes can be measured with graduated bottles. Commercial bottles with known volumes with a measurement scale were used. For example, 80% ethanol concentration by weight, the required volume of water and ethanol is as follows

$$\text{Volume} = \frac{\text{mass}}{\text{density}} \tag{20}$$

Thus,

$$\text{Volume of water} = \frac{0.2\text{kg}}{1000\text{kg/m}^3} = 200\text{ml}$$

$$\text{Volume of ethanol} = \frac{0.8\text{kg}}{789\text{kg/m}^3} = 1014\text{ml}$$

Therefore, for 1kg of the mixture 1214ml volume of mixture is required.

Pot and stove description

Largely dimensional relations between the stove and the pot determine the test results. To make this kind of test as much as possible comparable to the reality in the households of the user, original pot from the local market was chosen. A complete description of the used pot, like size, shape, weight, capacity, material, etc. are shown in the Table 4.1 below.

Table 4.1: Pot properties

Pot	**Diameter [mm]**	**Height [mm]**	**Weight [g]**	**Capacity [litre]**	**material**
1	185	85	187.5	2.3	steel

Fig. 4.4: Steel pot with 2.3 litre capacity

Stove outer body temperature

One of the key features of the testing was to determine how the user would interface with the hot product. If the stove showed signs of becoming unstable, it would be required that the user move the stove. This test was created to determine how hot the stove became +/-

1hour to 1.5 hours burning. The measure was taken where the user was most likely to hold the stove in order to move the stove.

4.3 Concepts of Efficiency and Power

There are many different ways of looking at stove performance and of measuring stove efficiency. A widely used method compares energy that goes into the stove with the energy that comes out, to determine Percentage of Heat Utilized (PHU). A broader concept of efficiency accounts for energy losses in evaporation. Once water reaches the boiling point, the amount of additional heat it absorbs is relatively small.

In water-based cooking the pot requires only enough heat to maintain boiling temperatures all else is excess. This excess heat is used to generate steam, which escapes from the pot without adding anything to the cooked food. Thus a stove that is regulated to maintain simmering temperature with at least production of steam is, in that respect, most efficient.

4.3.1 Power rating

The power rating test was used to determine the minimum and maximum power out put of the stove. It is important to know these power levels as the cooking requirement in low income households include the range from simmer heat to boiling heat. The fundamental process for testing power output is to measure the amount of fuel used over a period of time, this is determined in a calculation with calorific value attached to the specific fuel.

$$P = m_{fuel} \frac{C_v}{t} \tag{21}$$

Where

P = *power in kW*

m_{fuel} = *fuel consumed in kg during test*

t = *the time interval in s*

C_v = *lower calorific value in kJ/kg*

For the maximum power rating the flame was set to the highest blue flame level with little or no yellow flame and this was kept as constant as possible through out the test process. Design power is the power level at which the flame holder is completely filled with flames, while the highest of the flames above flame holder are minimal. For most stoves the maximum blue flame luckily is equal to design power.

For the minimum power rating the stove turned down to the least possible flame was showing, this was still a blue flame and kept constant for the duration of minimum power rating test.

4.3.2 Efficiency

Efficiency of a stove could be categorized as burning efficiency and overall efficiency. Burning efficiency of a stove accounts for the capacity of the stove in terms of combustion of fuel. In other words ability of the stove to change the energy from fuel to heat energy is related with burning efficiency. The ability of the stove to change the energy from fuel into the energy gained by the specimen such as water, rice, milk etc is termed as overall efficiency of the stove. Generally efficiency of stove is indicated by overall efficiency.

Overall efficiency of stove depends upon different conditions such as temperature, pressure, wind speed, specific heat capacity of the vessel, bottom and overall shape of vessel, weight of vessel, size of vessel and amount of specimen. Thus different tests for efficiency could yield different results of the same stove. Calorific value (MJ/kg or kJ/ Lit) of the fuel is the input energy for stove and should be accounted in course of efficiency measurement. Calorific values of fuels may vary from sample to sample procured at different locations.

Efficiency of cook stoves could be calculated by several methods. In this study efficiency of cook stoves was determined by calculating the heat gained by the water subjected for heating and amount of fuel consumed during this process. Heating process is classified as Low Power Phase and High Power Phase**.** Heating of water from initial water (subjected to boiling) temperature T_1°C to boiling point is termed as High Power Phase (HPP). During this phase water in pot gains energy from fuel with the help of burning stove and that value of energy is equivalent to energy required to raise the temperature of that mass of water from T_1°C to boiling point. In Low Power Phase predetermined weight of water at boiling point was subjected to boil for 30 minutes and energy gained by this water is calculated by multiplying latent heat of vaporization (L_{wboil}) of water and mass of vaporized water. Fuel consumed during each process is the input energy for these phases.

From the procedure described above two types of efficiency can be calculated. First thermal efficiency, which is the product of combustion, heat transfer and control efficiency. The equation to calculate the thermal efficiency is:

$$\eta = \frac{m_w (T_b - T_1) * C_w + m_{eva} L_{boil}}{m_f * C_v} \tag{22}$$

Second overall efficiency, which is calculated by dividing output energy by input energy. In this process we have to include the heat gained by vessel in which water was boiled.

$$\eta_{overall} = \frac{m_w * C_w * (T_b - T_1) + (m_{eva} * L_{boil}) + m_p * C_p * (T_b - T_1)}{(m_f * C_v)} \tag{23}$$

Where

$\eta_{overall}$=*Overall efficiency*

m_p = *Mass of pot*

C_p = *Specific heat capacity of pot*

$(T_b – T_1)$ = *Change in temperature (from* T_l *to boiling Point)*

m_w = *Mass of water*

C_w = *Specific heat capacity of water = 4190 J/kg*^{o}*c*

m_{eva} = *Mass of evaporated water during LPP*

L_{boil} = *Latent heat of boiling of water*

m_f = *Mass of consumed fuel*

C_v = *Calorific Values of Fuel*

4.3.3 Specific Fuel Consumption

Specific fuel consumption can be defined for any number of cooking tasks and should be considered “the fuel required to produce a unit output” whether the output is boiled water or a meal. In the case of the WBT, it is a measure of the amount of fuel required to produce one litre of boiling water (Note it is the water left in the pot at the end of the test (m_w) that is used in the calculation). To enable a fairer comparison of stoves tested in different environmental conditions the specific fuel consumption is corrected to account for differences in initial water temperatures. The correction is a simple factor that “normalizes” the temperature change observed in test conditions to a “standard” temperature change of 75 ºC (from 25^0 C to 100^0 C).

$$SC^T C = \frac{m_f}{m_w} x \frac{75}{T_b - T_1} \qquad [\text{g fuel/g of water}] \tag{24}$$

Where

m_f= *the mass of fuel burned*

m_w= *the mass of water remaining at the end of the period.*

There is no temp-corrected specific consumption in the simmer phase because the test starts at T_b and the change in temperature should be limited to a few degrees.

4.3.4 Firepower

This is a ratio of the fuel energy consumed by the stove per unit time. It does not return the power output to the pot, rather the maximum available power output from the fuel (in Watts).

$$FP_c = \frac{m_f \, x C_v}{60x\left(t_2 - t_1\right)} \qquad [w] \qquad (25)$$

Where m_f= *mass of fuel burned*

C_v= *calorific value (lower heating value)*

$(t_2$-$t_1)$= *time difference during test*

4.3.5 Ignition the stove

The ignition process starts by the user filling the stove to 75% capacity, closing the fuel cap and pressure release valve, pressuring the stove slightly with the stove pump, allowing the ethanol-water mixture to flow out the nozzle to fill the pre-ignition cup, then releasing pressure through using the pressure release valve once the cup is near full. Thereafter the user soaks the pre-light or light assist (asbestos swab) in the fuel. The pre-light or light assist is then lit and placed in the pre-ignition cup area once more. Once the area has been engulfed in flame in period for a period of 1 minute or more, the user is required to seal the pressure release valve and pressure the stove until required flame is obtained. Once the stove starts settling down the pre-light or light assist is removed. The pre-light or light assist (asbestos swab) is a very effective tool and makes lighting the stove reasonably easy and safe.

4.3.6 Control of the flame

The stove is controlled by means of pressure and release. The pump is used to generate pressure to create a larger flame for higher heat, and the pressure release valve on the fuel cap is used to release this pressure for lower heat settings. This system works very well. The unfortunate aspect of this system is the pump which is assembled within the stove.

The stove works well at pressure between 20kpa and 150kpa, with higher heat generated at the higher pressure setting. However the user is required to pump the stove any where from 50 to 100 times to generate the higher pressures required. The pump has a strange action of pressure on some strokes and release on others, making for a difficult to control action by the user. The pump ergonomics of the placement also make it very difficult to add pressure to the stove safely while the stove is functioning. Additional hazards occur when the stove have a pot on top. All of the pump mechanism grab and release pressure through out the pumping action this happens at awkward times and this back pressure or no back pressure has the user slipping the pump and bumping the stove alarmingly. All of the pumps seals need to be taken out and flared throughout the stoves use in order to try to generate the pressures required. Using the pump internal pump to generate pressure beyond 150kpa is near impossible.

CHAPTER 5

TEST RESULTS AND ANALYSIS

The WBT tests were done with one pot type. Each test was three times repeated and the average was determined. The results are grouped into the efficiency and emissions of different pre-determined ethanol concentration, and then compare pressurized-ethanol stove, which is used 60% (w/w) ethanol concentration fuel, and wheel band stove, which is a typical example of adapted kerosene fuel, of their efficiencies.

5.1 Efficiency

5.1.1 Time to boil

Time to boil was measured beginning when the ethanol-water mixture considered lit and ending when water started boiling (at local atmospheric pressure). Fig. 5.1 and 5.2 compare the typical temperature profile for different ethanol-water mixture with 2.3 liter pot. Our stove uses 90 % (w/w) ethanol concentration fuel brought water to boil more quickly than any other ethanol concentrations. Table 5.1 to 5.5 shows the time taken for the three tests performed.

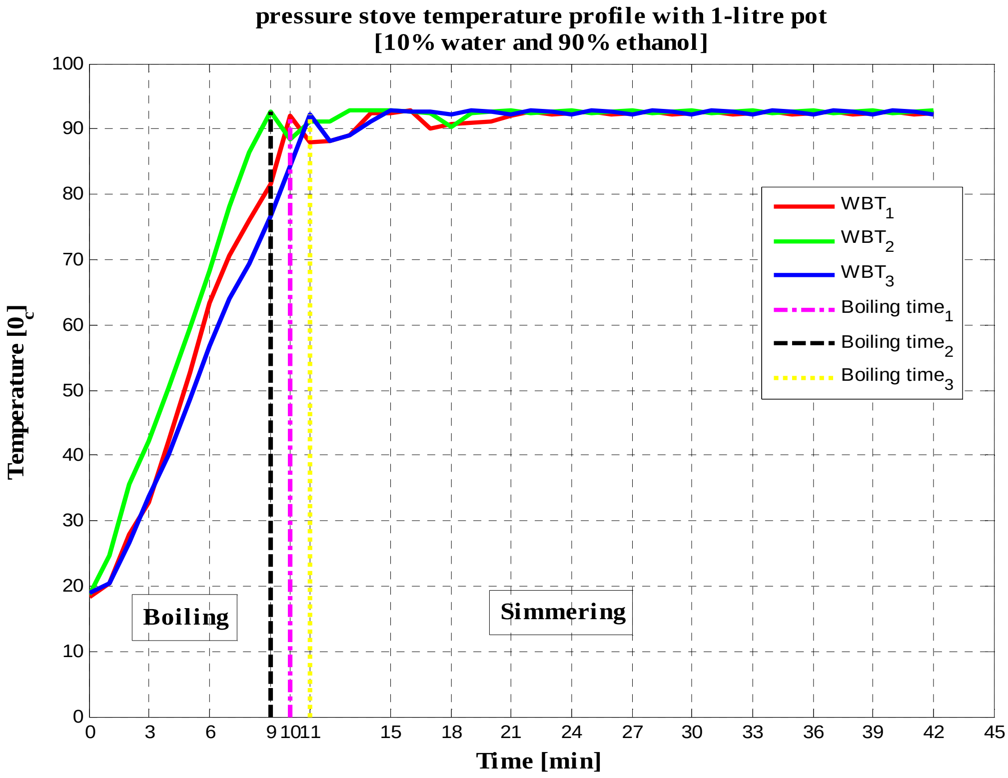


Fig. 5.1: Temperature profile of the whole cooking test for the 90% ethanol in the mixture

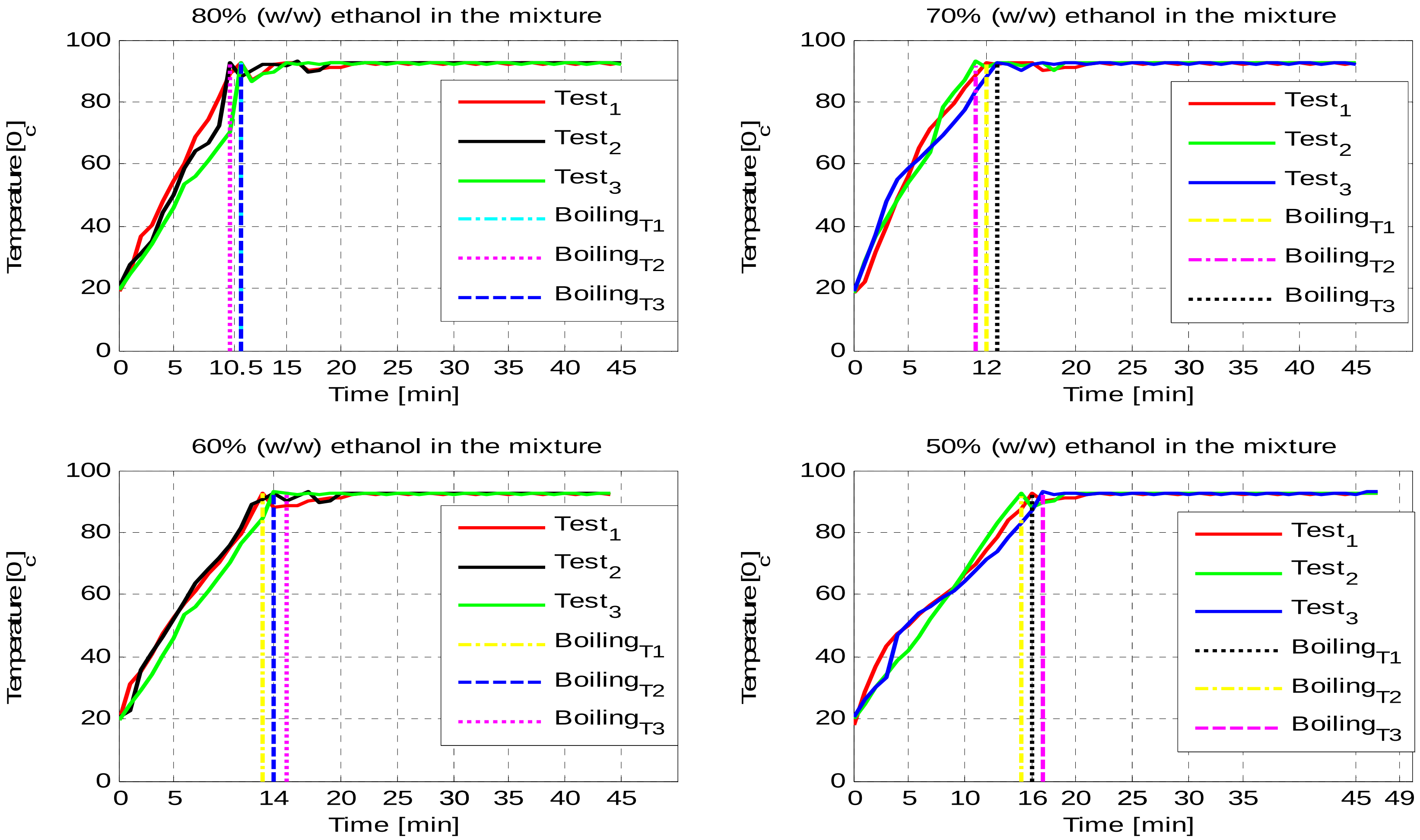


Fig. 5.2: Temperature profile of the whole cooking test for the 80% ethanol in the mixture

As is mentioned in section 4.3, three similar pots filled with 1 litre of water were used. The time it takes for the water in the pot to start boiling and the amount of water evaporation were measured. These data are presented in Tables 5.1 to 5.5. These tables contain all the relevant data to calculate the heat transfer efficiency during high power phase and low power phase, as well as the overall efficiency itself. For each type of test the tests procedure were similar. The tests were done in two phases, the boiling phase and the simmering phase. The simmering, low power phase was always 30 minutes directly after the water boiled at the high power phase.

Table 5.1: Efficiency test results of 90% (w/w) ethanol concentration

Test No .	Water (lit)	Boil time (s)	m_{eva} (kg)	m_{fuel} (kg)	E_{in} (kJ)	E_{vess} (kJ)	E_{1out} (kJ)	E_{2out} (KJ)	η_{Boil} (%)	η_{Simmer} (%)	$\eta_{Overall}$ (%)
1	1	540	0.226	0.098	2341.6	6.3	328.3	509.7	30.1	41.4	35.5
2	1	600	0.232	0.11	2532.8	5.9	309.8	521.0	25.9	39.7	32.5
3	1	600	0.233	0.113	2700.0	6.2	317.3	527.8	27.9	34.3	31.1
Average									**28.0**	**38.5**	**33.0**

Table 5.2: Efficiency test results of 80% (w/w) ethanol concentration

Test No .	Water (lit)	Boil time (s)	m_{eva} (kg)	m_{fuel} (kg)	E_{in} (kJ)	E_{vess} (kJ)	E_{1out} (kJ)	E_{2out} (KJ)	η_{Boil} (%)	η_{Simmer} (%)	$\eta_{Overall}$ (%)
1	1	660	0.244	0.16	3263.6	6.1	325.1	543.5	22.2	3	26.4
2	1	600	0.239	0.13	2738.9	6.1	316.8	532.3	27.7	33.8	30.9
3	1	660	0.243	0.12	2476.6	6.4	338.9	536.7	29.6	40.9	35.1
Average									**26.5**	**35.1**	**30.8**

The heat capacity of pot no.1 is negligible effect by preheating phase of the stove. Therefore all the average heat transfer efficiency values are calculated including the result of test no.1. When one looks as the results boiling the efficiency at high power phase for 60% (w/w) ethanol concentration is higher than 90% (w/w) ethanol in the mixture. We note the variation could come from a numbers of factors, only some of which are related to high radiation loss, the flames will probably miss most of the pot's bottom surface and some of the heat will be lost up the sides and carbon monoxide emissions.

In making thermal efficiency comparisons between different ethanol concentrations there were no significant differences. We found that at low concentration there is additional power provided due to the pressure exerted by the steam. There are definite limits, however, to the amount of water that can be mixed. Too much will cause excessive cooling and misfiring. However at lower power phase, as the ethanol concentrations decrease, the efficiency of the stove decreases. This is due to the reduced water content in the fuel mixture.

Table 5.3: Efficiency test results of 70% (w/w) ethanol concentration

Test No.	Water (lit)	Boil time (s)	m_{eva} (kg)	m_{fuel} (kg)	E_{in} (kJ)	E_{vessel} (kJ)	E_{1out} (kJ)	E_{2out} (KJ)	η_{boil} (%)	η_{simmer} (%)	$\eta_{Overall}$ (%)
1	1	720	0.236	0.17	3019.7	6.0	324.2	520.9	25.7	30.0	27.8
2	1	780	0.224	0.16	2838.9	6.0	352.8	464.3	25.9	31.9	28.6
3	1	780	0.231	0.14	2567.6	5.9	319.1	512.1	30.2	34.3	32.0
Average									**27.3**	**32.1**	**29.5**

Table 5.4: Heat transfer efficiency test results of 60% (w/w) ethanol concentration

Test No.	Water (lit)	Boil time (s)	m_{eva} (kg)	M_{fuel} (kg)	E_{in} (kJ)	E_{vess} (kJ)	E_{1out} (kJ)	E_{2out} (KJ)	η_{boil} (%)	η_{simmer} (%)	$\eta_{Overall}$ (%)
1	1	780	0.215	0.22	3369.1	6.1	414.0	384.8	18.0	37.3	23.5
2	1	840	0.217	0.15	2238.5	5.9	439.1	355.3	43.1	29.5	35.2
3	1	840	0.207	0.17	2572.3	5.9	448.7	320.2	41.9	21.5	29.7
Average									**34.3**	**31.2**	**29.5**

Table 5.5: Heat transfer efficiency test results of 50% (w/w) ethanol concentration

Test No.	Water (lit)	Boil time (s)	m_{eva} (kg)	M_{fuel} (kg)	E_{in} (kJ)	E_{vess} (kJ)	E_{1out} (kJ)	E_{2out} (KJ)	η_{boil} (%)	η_{simmer} (%)	$\eta_{Overall}$ (%)
1	1	960	0.232	0.272	3337.4	5.9	462.4	373.3	19.7	39.0	24.9
2	1	900	0.228	0.190	2331.3	5.9	426.9	391.5	39.2	31.9	34.9
3	1	1020	0.240	0.241	2957.1	5.9	462.3	382.2	41.9	20.8	28.4
									33.6	**30.6**	**29.4**

Where

Water (kg):- Mass of water at T_1 ^{o}C *subjected to test.*

m_{eva}*: - Mass of water evaporated during test.*

m_{fuel}*: - mass of ethanol-water mixture consumed during test.*

E_{vess}*:- Energy gained by vessel,*

E_{1out}*: - Energy gained by water during High Power Phase,*

E_{2out}*: - Energy gained by water during Low Power Phase,*

Ein: - Energy content of fuel consumed during high Power Phase and low Power Phase

5.1.2 Thermal efficiency and overall efficiency of the stove

Table 5.6 shows the thermal efficiency and overall efficiency over all phases of the WBT. Overall thermal efficiency results for 90%, 80%, 70%, and 60% (w/w) ethanol in the mixtures were better than that of 50% (w/w) ethanol in the mixture. All ethanol concentration, including 50% (w/w) ethanol-water mixture, showed higher efficiency during the simmer phase than the boiling phase.

Table 5.6: Thermal efficiency and overall efficiency of the entire WBT comparisons for different ethanol-water mixture

Fuel composition (Ethanol-water mixture)	**Thermal efficiency over entire WBT [%]**	**Overall efficiency over the entire WBT [%]**
90% (w/w) ethanol in the mixture	32.83	33.04
80% (w/w) ethanol in the mixture	30.64	30.82
70% (w/w) ethanol in the mixture	29.65	29.83
60% (w/w) ethanol in the mixture	29.65	29.54
50% (w/w) ethanol in the mixture	23.72	24.23

When one looks the comparison result, in overall test phase, the overall efficiency of 60% (w/w) ethanol in the mixture is only 29.54%, yet for the same amount of water to boil, the overall efficiency of 90% (w/w) ethanol in the mixture is 33.04%, a difference of 4%.

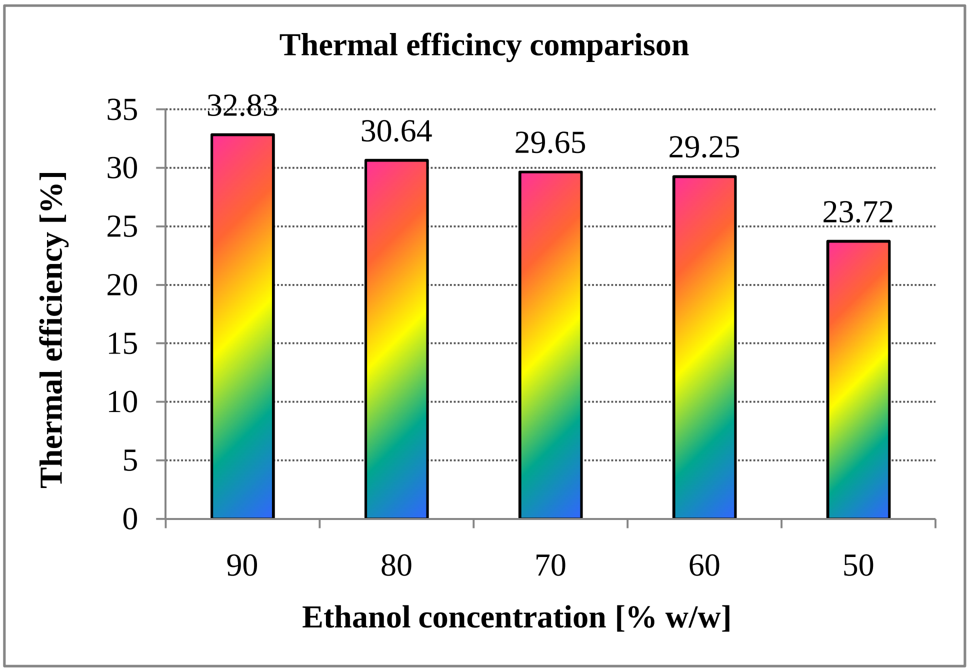


Fig. 5.3: Thermal efficiency comparison chart for the ethanol-water mixture

Which seems to be to low, could be influenced by the reduced ethanol content in the fuel mixture. Therefore a minimum of 60% (w/w) ethanol-water mixture in the solution can be utilized in the stove.

The determined efficiencies are nearly optimal efficiencies due to the fact that only the smallest required amount of ethanol-water mixture was used to boil and simmer the water. As expected the efficiency of the ‘stove-pot system’ increases with increasing the water volume in the pot.

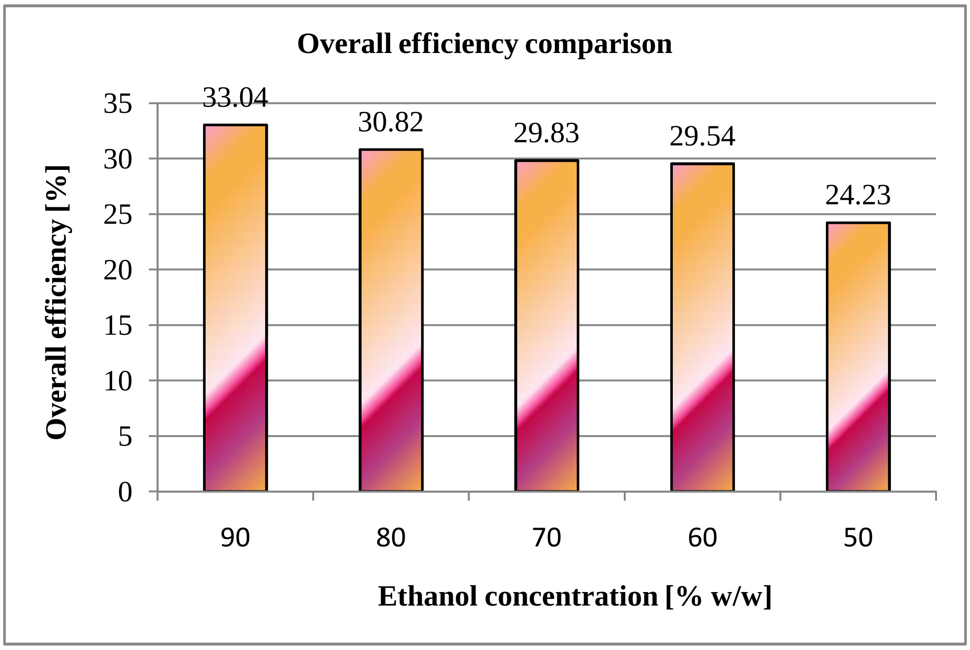


Fig. 5.4: Efficiency comparison chart for the ethanol-water mixture

The results for the ethanol-water mixture stove prototype are not totally satisfying, but with the low price and other parameters compare to other stoves, like the kerosene and LPG this stove is an acceptable product for the target market in development countries. Improvements in the design of the ethanol-water mixture stove have to be done to make it more successful.

5.1.3 Specific Fuel Consumption

The specific fuel consumption is a good approach to compare stoves in the WBT. It is defined in the WBT as ‘’the ethanol-water mixture required to produce a unit output’’ whether the output is boiled water.

Our results show the temperature-corrected specific fuel consumption, which adjusts for difference initial water temperature.

As seen in the table of temperature-corrected specific fuel consumption (Table 5.7), the simmer phase accounted for a large portion of the fuel consumed for each ethanol concentration. The temperature-corrected specific fuel consumption of 60% (w/w) ethanol in the mixture needs in the WBT for heating up the 1 litre amount of water nearly double to heat the same amount of water by using the fuel mixture of the 90% (w/w) ethanol concentration. This comes probably from the chemical reaction which the water added to the mixture is changed to vapour phase more.

Table 5.7: Ethanol-water mixture consumption comparisons

Fuel composition (Ethanol-water mixture)	**Simmer phase [g of fuel/g of water]**	**Over entire WBT [g of fuel/g of water]**
90% (w/w) ethanol in the mixture	70	140
80% (w/w) ethanol in the mixture	100	180
70% (w/w) ethanol in the mixture	110	210
60% (w/w) ethanol in the mixture	100	240
50% (w/w) ethanol in the mixture	140	330

The consumption increases progressively with increasing water content in the fuel mixture, although this consumption rate increase gradually becomes smaller. Thus the low concentration have more chance part of the energy of ethanol is used to evaporate water, which does not take part in the combustion process.

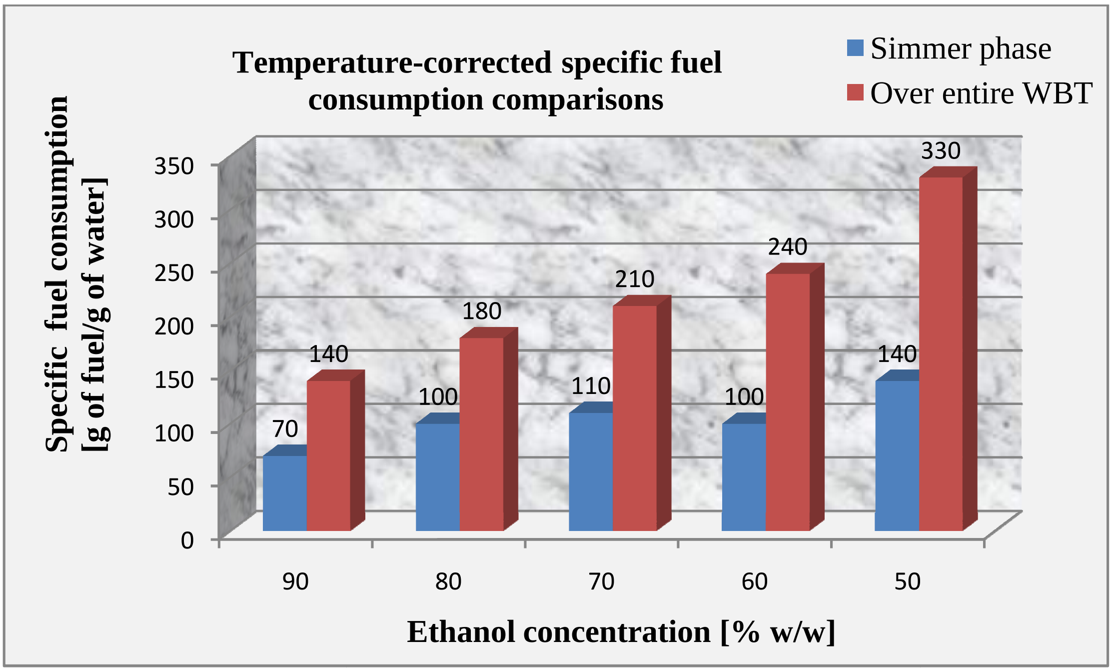


Fig. 5.5: Temperature-Corrected Specific Fuel Consumption for Simmer and entire WBT

Related to the efficiency the 90% (w/w) ethanol in the mixture in the fuel mixture has better specific fuel consumption, which is remarkable in the test with the one litre amount of water. However, the stove gives best results in terms of ease of use, low cost and performance with 60% (w/w) ethanol in the mixture. In addition, even if high specific fuel consumption, using the pressurized-ethanol stove with 60% (w/w) ethanol in the mixture, is comparable to those of the conventional liquid fuel alternatives.

5.1.4 Average Stove Power

The following parameter describes the average power output of the stove fire and how much power the stove can utilize due to the design to the pot. In Section 4.3 under power and energy the relation and determination of this parameter are described in more detail. The 60% ethanol concentration has about 8% higher stove power, because of more consumed ethanol-water mixture.

Table 5.8: Stove power comparison

Fuel composition (Ethanol-water mixture	**Simmer Phase [kW]**	**Over entire WBT [kW]**
90% (w/w) ethanol in the mixture	0.76	1.06
80% (w/w) ethanol in the mixture	0.82	1.16
70% (w/w) ethanol in the mixture	0.87	1.10
60% (w/w) ethanol in the mixture	0.69	1.04
50% (w/w) ethanol in the mixture	0.62	0.98

In Figure 5.6, the blue flame maximum power output as a function of time is given. This power is dependent on the pre-arrenged fuel regulator setting of the operator and there is arbitrary.

The low power output of the 50% (w/) ethanol concentration is due to the large fuel consumption, and consequently of the lowering of the fuel level in the fuel tank. As the amount of water content in the mixture increases the excess water content will cause the mixture to cooling and misfiring.

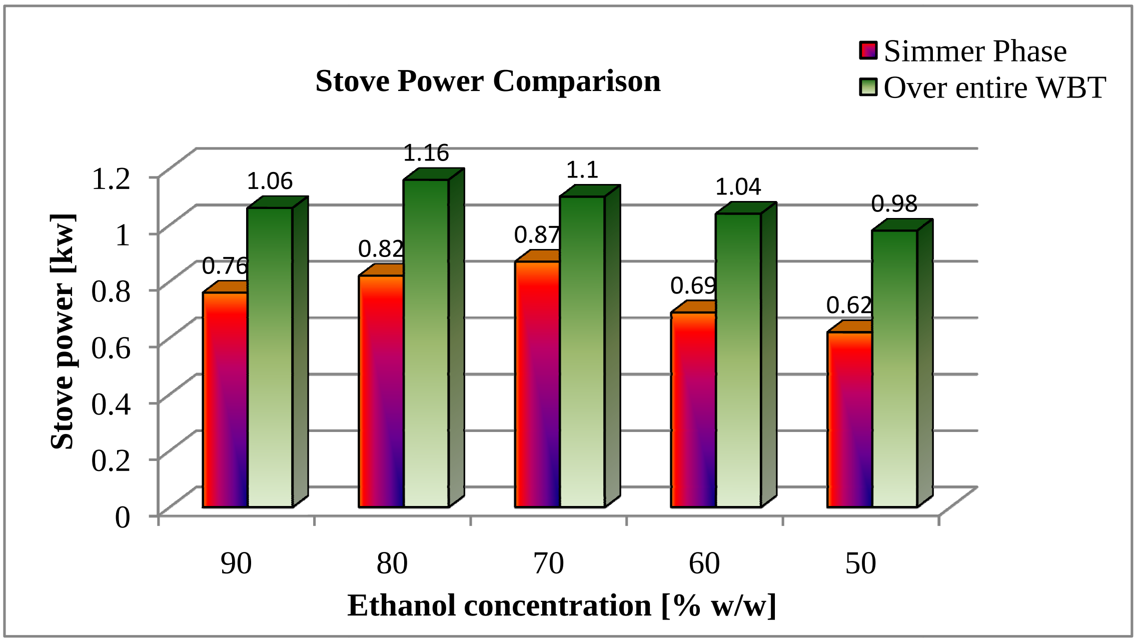


Fig. 5.6: Stove power comparison charts

The stove was tested for varying ethanol percentages. Fig. 5.7 shows the effect of increasing ethanol concentrations on the performance of the stove over entire WBT. The stove capacity increases with increasing ethanol concentrations since the fuel-flow rate is maintained constant. As the ethanol concentrations increase, the efficiency of the stove increases over the entire WBT (from 29.5 to 33 %).

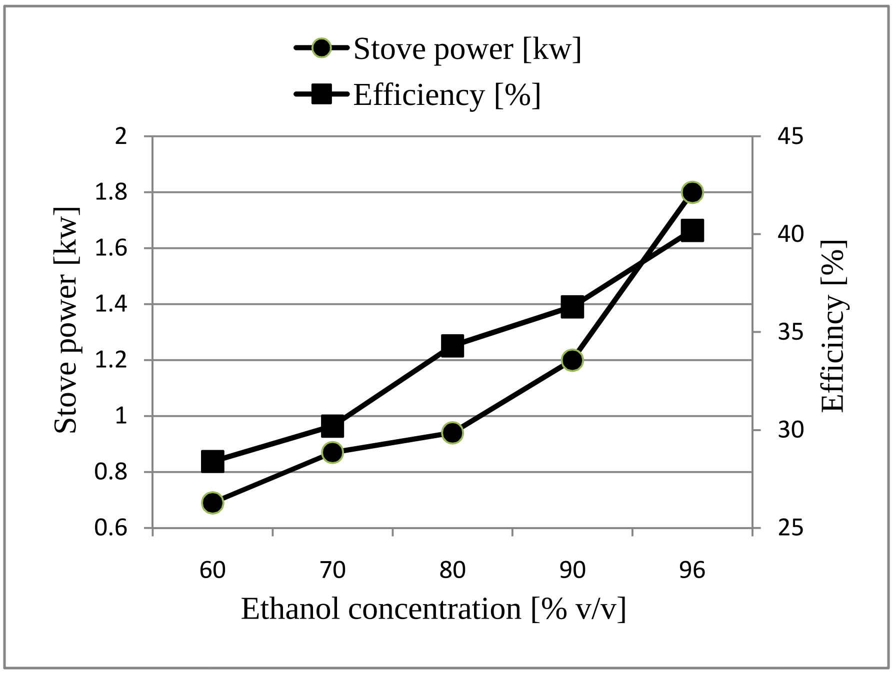


Fig. 5.7: Stove performance with increasing ethanol concentrations

5.2 Comparative Test of Fuel used Ethanol-Water Mixture and Kerosene

For inclusion in testing, we attempted to obtain a stove that was already widely available in low income households in urban countries of Ethiopia. Based upon these criteria as well as availability of the cook stove for testing, wheel brand which is a typical example of an adapted kerosene stove is chosen for inclusion in the comparison.

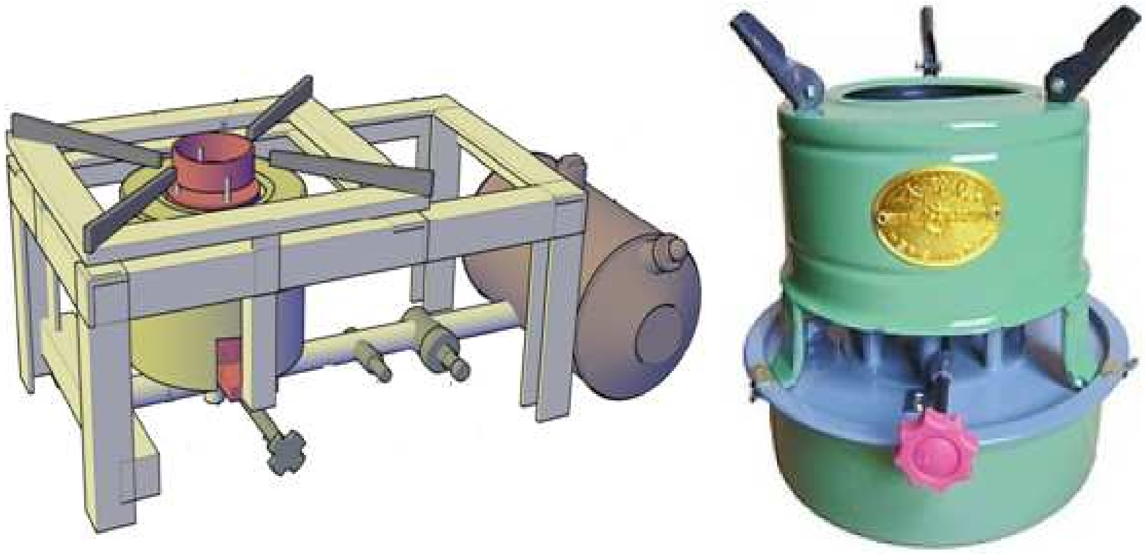


Fig. 5.8: cooking stoves

From left to right:

1) The Pressurized-ethanol stove
2) The Wheel brand stove

5.2.1 Time taken to boil

Time to boil was measured beginning when the ethanol-water mixture considered lit and ending when water started boiling (at local atmospheric pressure). The pressurized – ethanol stove using 60% (w/w) ethanol in the mixture fuel brought to boil one litre of water more quickly than kerosene stove. In the hot start phase, water heated on the pressurized-ethanol stove boiled in only 14 minutes, yet the same amount of water took 16 minutes to boil in wheel brand stove, a difference of almost 2 minutes.

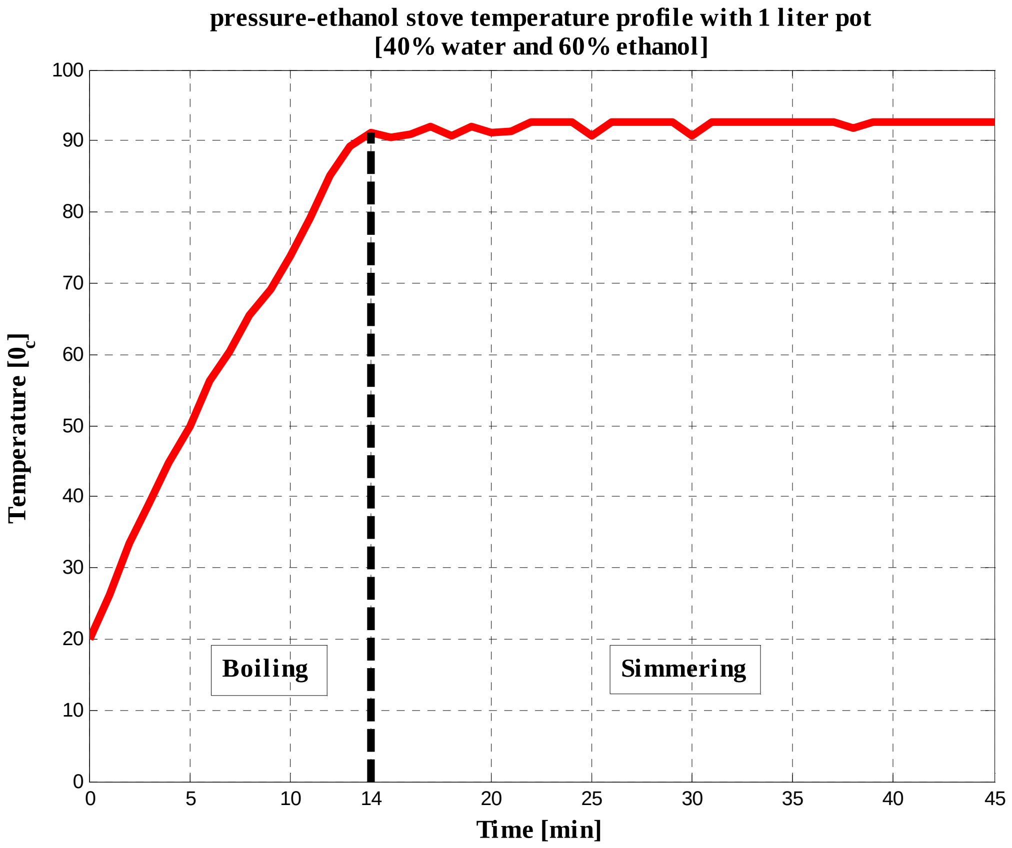


Fig. 5.9: Temperature profile of the whole cooking test for the pressurized-ethanol stove

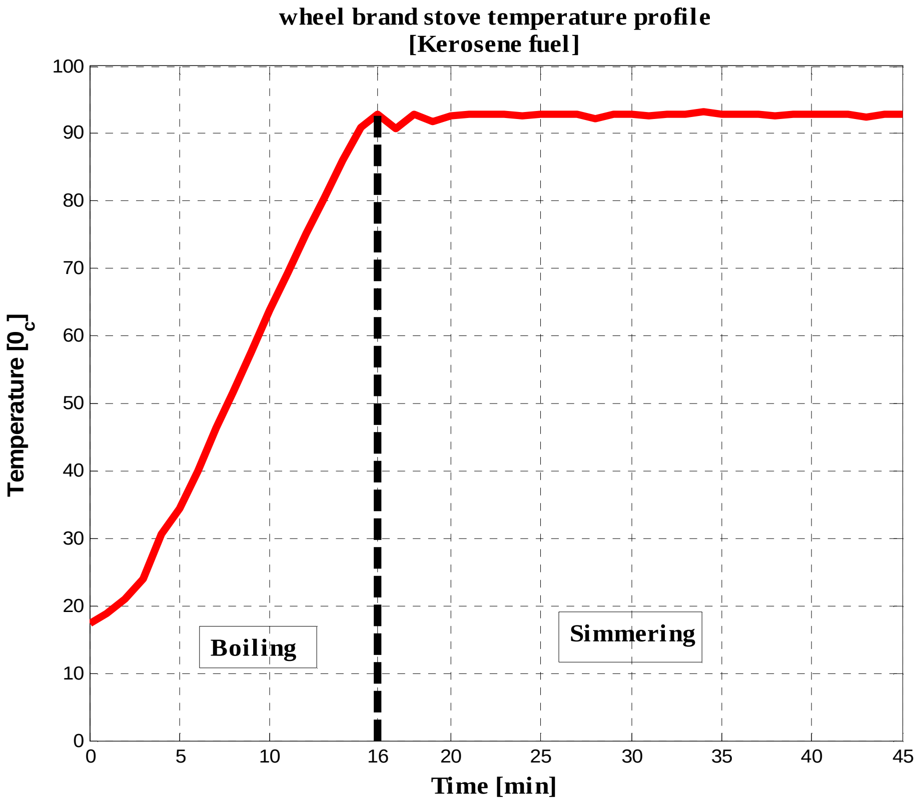


Fig. 5.10: Temperature profile of the whole cooking test for the wheel brand stove

5.2.2 Thermal efficiency

Thermal efficiency is the ratio of the heat content of increasing the water temperature and evaporating the mass of water released as steam, to the energy consumed by burning ethanol-water mixture.

Table 5.9: Thermal efficiency over the simmer phase and the entire WBT

	Thermal efficiency [%]	**Overall efficiency [%]**
Pressurized-ethanol stove	29.25	29.54
Wheel brand stove	31.39	31.67

Table 5.9 above shows the thermal efficiency and the overall efficiency over all phases of the WBT for stove. The overall efficiency of wheel brand stove calculated as per adopted methodology mentioned above is found to be 31.67%, which is better than that of pressurized-ethanol stove 29.54.

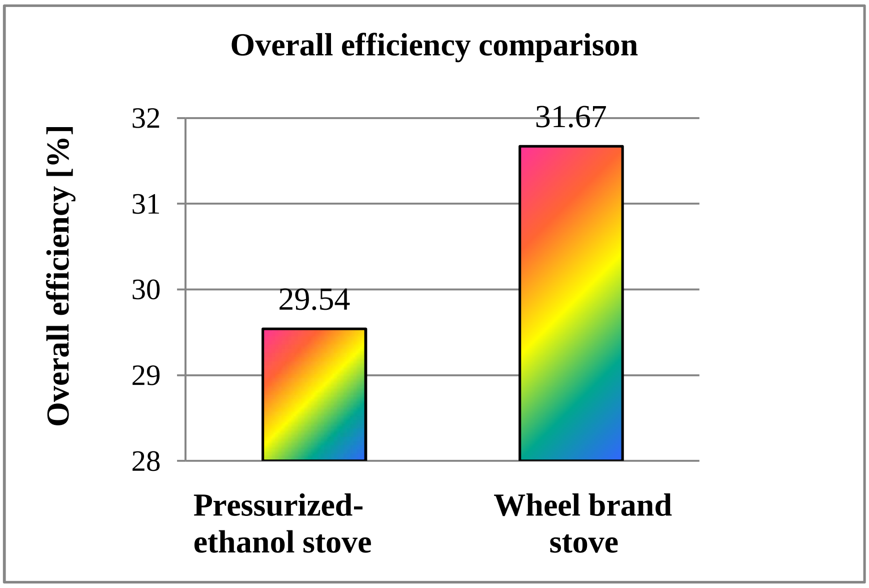


Fig. 5.11: Overall efficiency over the entire WBT

Fig.5.11 shows the overall efficiency over all phases. The wheel brand stove was the more efficient than pressurized-ethanol stove using fuel 60% (w/w) ethanol in the mixture.

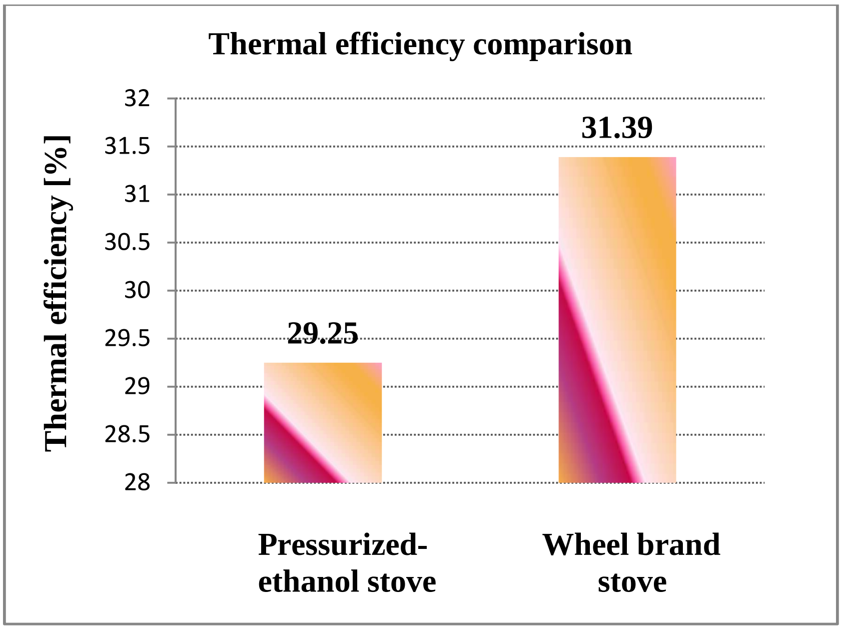


Fig. 5.12: Thermal efficiency of the stove

The graph illustrating overall thermal efficiency of the stoves over the three tests performed for each stove (Fig.5.13) is provided to illustrate the variability in results between tests. For example, considering the un-average individual data points, the pressurized-ethanol stove had greater efficiency than wheel brand stove. We note the variation could come from a number of factors, only some of which are related to stove design, which is the flame regulator had some difficulty to regulate the same level of the stoves, and that a larger sample size would be useful for future analysis.

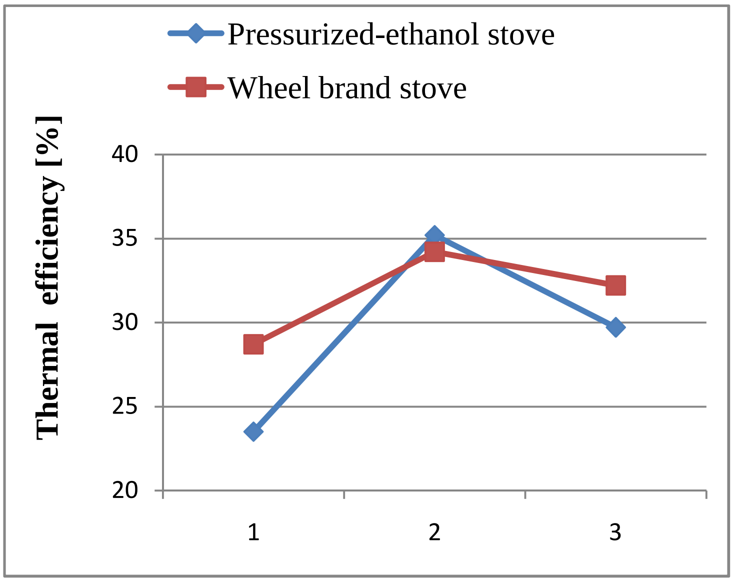


Fig. 5.13: Thermal efficiency, simmer test by test

5.2.3 Specific fuel consumption

Table 5.10 shows the rate of fuel consumption (during simmer phase and over entire WBT to boil and simmer 1 liter of water) with each stove. The simmer phase accounted for large portion of the fuel consumed for each stove.

Table 5.10: Temperature-corrected specific fuel Consumption for Simmer and entire WBT

	Simmer phase [g]	**Total WBT [g]**
Pressurized-ethanol stove	102	240
Wheel band stove	43	86

The figures presented suggest that for one liter of water pressurized-ethanol stove would be used significantly higher than wheel band stove. The depicted high fuel consumption of the pressurized-ethanol stove in this case can be explained in two ways. One explanation is the, since fuel is a mixture of ethanol and water, the water content will therefore not do any useful work until it converts to steam, so due to the water content in the mixture the fuel consumption is high compare to kerosene stove.

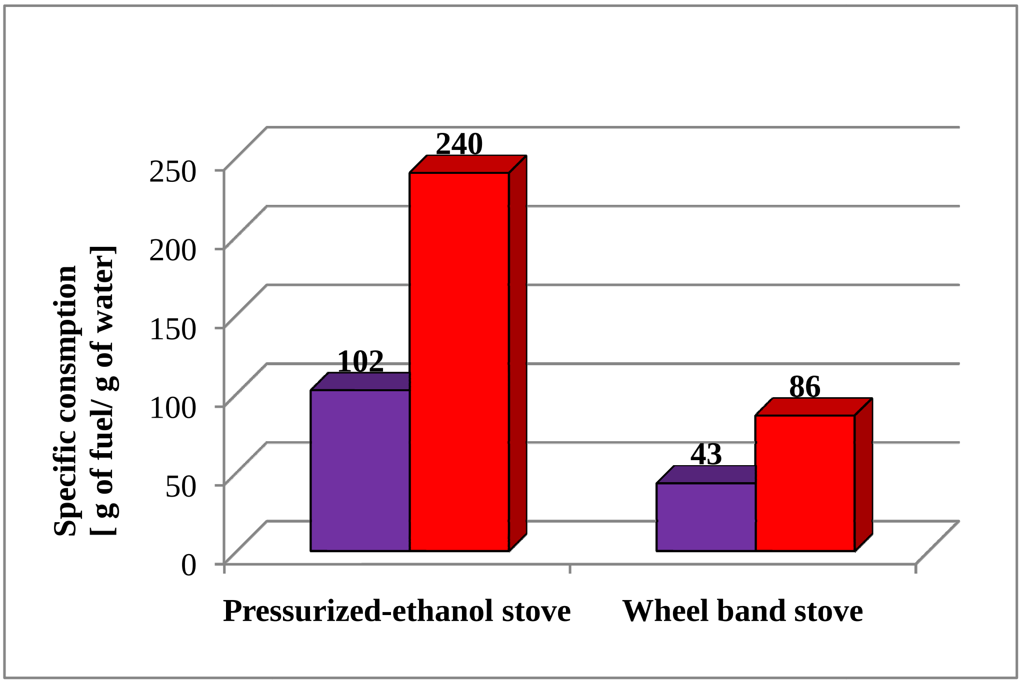


Fig. 5.14: Temperature-corrected specific fuel Consumption over entire WBT

Another explanation for the higher fuel consumption by the pressure-ethanol stove is due to with the fuel regulator malfunctioning. If the stove is continuously operated at the high power phase throughout the cooking cycle that is without making appropriate adjustments to the low power phase for simmering fuel consumption goes up and in fact there is heat loss to the surrounding.

The actual boiling of water with the pressure-ethanol stove was a little violent than that with the kerosene stove. It took some time before the pot with boiling water was taken of the burner. During this small period of time it is reasonable to assume that more water vapour escaped. This is due to the starting process being governed by the heat transfer rate from the nozzle to the burner head, with fuel consumption gradually increasing due to a rising stove temperature, which in turn increases the vaporisation rate and hence the power output.

5.2.4 Performance

During the entire water boiling test the wheel brand stove gave firepower of 0.91kW and a thermal efficiency of 31.7%, boiling 1 litres of water in 16 minutes with the lid on (Table 5.11). The lower firepower is due to low fuel consumption and took longer time during the test and the energy gained by kerosene fuel.

Table 5.11: Average stove power comparison

	Pressurized-ethanol stove [kW]	**Wheel brand stove [kW]**
Over entire WBT	1.04	0.91
Simmer phase	0.69	0.73

During entire water boiling test the pressurized-ethanol stove gave a thermal efficiency of 29.5%, which also burns ethanol-water mixture vapour. The stove firepower was 1.04kW and the test duration was statistically inseparable from that of the kerosene stove. So in this test both stoves were of a different ‘output’ power to the pot. The higher thermal efficiency of the wheel brand stove is partly due to the more efficient combustion of the fuel, when compared to pressurized-ethanol fuel.

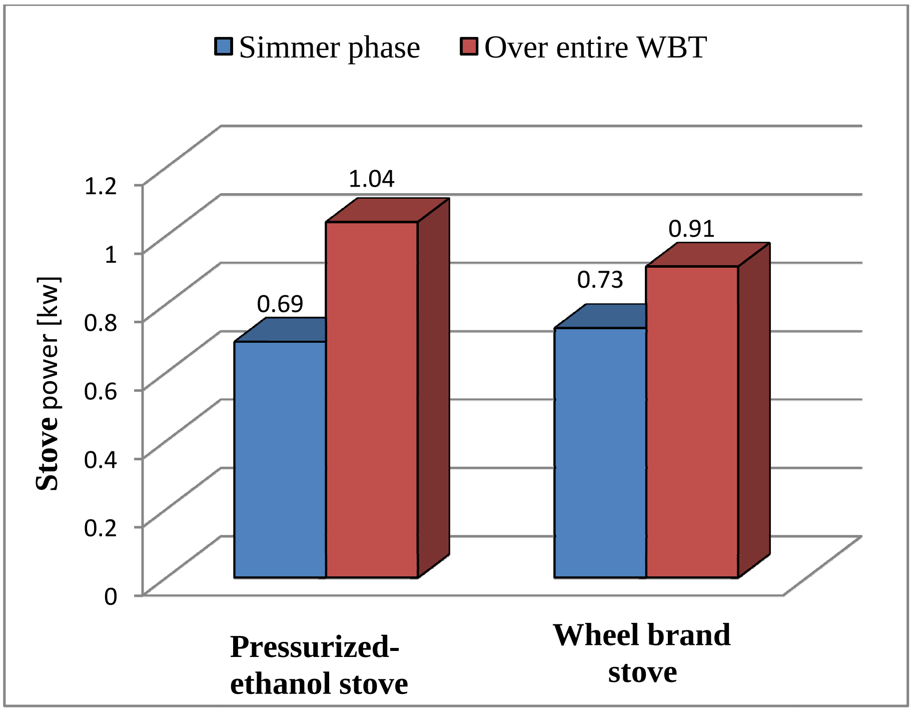


Fig. 5.15: Stove power comparison for pressurized-ethanol stove and wheel brand stove

5.3 EMISSION MEASUREMENT

5.3.1 Emission and health

In theory, the complete combustion of bio fuel in a combustion device like a cook stove should result in the release of just carbon dioxide and water, which do not fall under the category of pollutants. However, it is very difficult to ensure complete combustion in cook stoves due to the heterogeneous nature of the combustion process, lack of proper control, and design constraints. Thus, the emission of pollutants during small-scale biomass combustion is unavoidable, in or outside the kitchen. The level of pollution will vary depending on the types of stoves and fuels used.

Alcohol burning stove always produce at small level carbon monoxide and its release with other combustion products in a kitchen or other enclosed space will increase the concentration of carbon monoxide. Depending on stove, kitchen volume and air exchange rate, and carbon monoxide concentrations can reach such level that it will affect the health of the user. Carbon monoxide is a dangerous gas that should be aware and not profitable. Several reactions may produce it as main product or by-product. Table 5.12 shows the health implications of major pollutants that are normally emitted from biomass burning.

Table 5.12: Mechanism of principle health effects from major pollutants

pollutant	Mechanisms of health effects
Carbon monoxide	- Inhalation into respiratory system - Absorption into blood from lungs - Elevated carboxyhemoglobin (HbCo) levels - Reduced oxygen to body tissues - Possible cilia-state impact on lung clearance
Particulates	- Inhalation into respiratory system - Deposition in respiratory tract - Irrigation and toxicity
Formaldehyde	- Irritation of mucosa - Toxicity to cilia - Reduction in lung clearance ability - Possible carcinogen

Source: [11]

The most dangerous pollutant Carbon monoxide (CO) is a colorless, odorless and highly poisonous gas, which gets created by incomplete combustion (lack of oxygen) of fossil fuels. CO has a strong affinity to hemoglobin (Hb) in the blood which carries oxygen (O_2) to body tissues. CO deprives the tissues of the necessary supply oxygen. However, binding force of CO to Hb is about 300 times that of O_2 to Hb. The poisoning signs are head age, dizziness, weakness and finally the death. In the air concentration up to 10 ppm CO are unserious. As a measure of the toxication of the CO concentration in the blood are assumed. For 20 % CO-Hb toxicities signs are occur and 65% CO-Hb are deadly for human being. The effect of the carbon monoxide concentration in the atmosphere as a function of the exposure time for various conditions of labor is shown in Fig. 5.16.

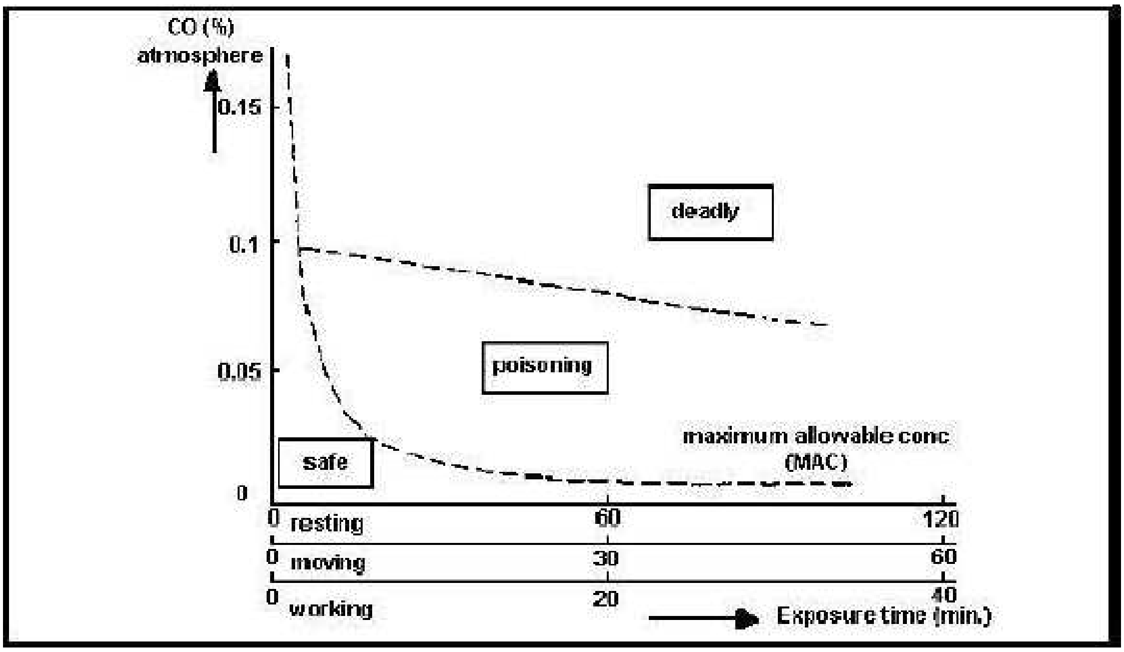


Fig. 5.16: Effect of carbon monoxide concentration in the atmosphere as a function of exposure time for various condition of labour

Another colourless, odourless and poisonous gas, carbon dioxide (CO2), gets created in all breathing and combustion processes of fossil fuels. For human being it is deadly in a concentration of 20 vol. % and in the range from 8-10 vol. % it causes head age, dizziness, weakness and finally unconsciousness. In working rooms the concentration shouldn’t be higher than the maximal allowable concentration (MAC) of 5000 ppm.

5.3.2 Emission measurement and results

The flue gas composition analyses was done with a combustion gas analysing measurement, called KM9104, which was borrowed from the thermal engineering lab. This measurement device is used to control the flue gases in central heating system based on different fuels like oil, gas or coal.

Fig. 5.17: Combustion gas analyser KM9104

It can measure different values like, CO, CO_2, O_2, Tgas, T_{net} and Tamb, and calculate combustion efficiency and flue excess air and losses at the same time. In the measurement device the maximum CO_2 value for the stoichiometric (ideal) Combustion, related to 21 % O_2 in the air and depending on the burned fuel was adjusted.

Table 5.13: Emission test results for 60% ethanol concentration

Time (Min)	**T_{gas} (^oC)**	**T_{amb} (^oC)**	**O_2 (%)**	**CO_2 (%)**	**CO (ppm)**
5	115	19	20.5	0.3	115
10	73	20	20.7	0.2	159
15	104	20	20.8	0.1	99
27	121	20	20.8	0.3	86
48	148	21	20.7	0.1	22

In the above Table 5.13 are the results from the emission tests for different times shown. The first values were taken when the fire in the stove was well burning. Other values were taken after boiling of the water and at the end of the test.

The results can be converted in volume percent or parts per million with the conversion factor 0.01 vol.%=100 ppm.

These results, which were taken from a stove operated in optimal conditions, show the serious problematic described in the section 5.3.1.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

Considering the current shortage of fuel in the country, the rate at which traditional forests are being depleted and the escalating costs of electricity, ethanol-water mixture oil is well placed to penetrate as a low-income household fuel for cooking.

Thanks to a wide background study of the cooking technology, an efficient stove running on 40 % w/w ethanol-water mixture has been successfully developed.

The main reason for the choice of low concentration of ethanol is its inherent safety. Due to the extremely low value (3.3 %) of the lower limit of inflammability, the use of pure ethanol for household purposes is dangerous. Because higher percentage of ethanol concentration can release vapours that form explosive mixture at temperature above the flash point. This problem can be overcome by the use of ethanol mixtures in a suitably designed stove. The 40 % ethanol-water mixture is less flammable than pure ethanol, making it safe to handle and hence ideal for household cooking purposes.

The drop in efficiency observed (33 to 24) as the alcohol content decreases in the mixture of the pressurized-ethanol stove is because a part of the energy of ethanol is used to evaporate water, which does not take part in the combustion process. This reduces the flame temperature and consequently the efficiency.

This design has shown some efficiency with a good transmission of the heat produced by the combustion to the cooking areas. With a good material selection, the stove is cost-effective, durable and easy to build with most of the material already available in the local market. Then, by using the ethanol-water mixture as a fuel, the pressurized-ethanol stove showed smokeless and smell-free cooking environment and makes it some environmentally friendly features compared to kerosene and firewood.

Within the limited time given for this thesis, we designed and manufactured a pressurized-ethanol stove with the above mentioned features. However, for a more efficient product the following additional features can be added:

- By increasing the flame height to optimum value, the interaction area between the flame and the pot ring can be improved.
- By purchasing an appropriate flow regulator valve, definite and multiple intermediate control levels can be achieved between simmer and full power.

- Although different diameters of the nozzle were examined in thesis, it can be modified to an optimum value to enhance the efficiency of the pressurized-ethanol stove.
- The high fuel consumption at a low power setting could be overcome by controlling the fuel flow regulator during operation.
- The arrangement of the wind shield might be improved in order to have a better air flow, for example, using narrow sections so as to maintain the ideal combustion ratio.

The efficiency results of the ethanol-water mixture by using water boiling test have given indications of the performance of the fuel under the workshop environment. For a more detailed understanding of the performance of the ethanol-water mixture, there is a need to conduct elaborate CCT and KPT tests where field variables such as degree to which food is cooked, food quality and quantity are controlled.

To make the stove reachable and accessible for dissemination other important parameters, like price, reliability, durability and ease of maintenance have to be considered.

In general, considering its low price and relatively similar efficiency with kerosene, this pressurized-ethanol stove prototype is satisfactory and acceptable product for the target market of developing countries. Consequently, so as the ethanol fuel is available and accessible to low-income households, there is a need for the government and the private sector to work out means of reducing the cost of the fuel and its distribution.

This thesis has been an interesting opportunity to improve the engineering skills that have been learned during this course. The combustion and heat transfer have been some of the key topic of this thesis.

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APPENDIX A

Typical calculations for fuel tank

1. Cylindrical shell thickness

$$f = \min\left[\frac{R_{po.2/t}}{1.5}, \frac{R_{m/20}}{2.4}\right]$$

Where

$R_{p0.2/t}$ = *minimum proof (yield) strength*

$R_{m/20}$ = *minimum tensile strength*

Therefore

$$f = \min\left[\frac{320\text{Mpa}}{1.5}, \frac{390\text{Mpa}}{2.4}\right]$$

$$f = \min[213.33\text{Mpa}, 162.5\text{Mpa}]$$

Thus, the thickness of the cylinder is < see equation 7>

$$t_s = \frac{150\text{kpa} * d_i}{2 \,x\, 162.5\text{Mpa} * 0.85 - 150\text{kpa}}$$

$$t_s = 0.0054 d_i$$

From the geometry

$$d_e = d_i + 2t_s$$

$$d_e = d_i + 2(0.00054 d_i)$$

$$d_e = 1.00108 d_i$$

2. *Length of the cylindrical shell*

The inside length of tori spherical end is given <see equation 8>

$$L_i = 0.8d_e - \sqrt{\left(0.8d_e - \frac{d_i}{2}\right)\left(0.8d_e + \frac{d_i}{2} - 2(0.154d_e)\right)}$$

$$L_i = 0.800864d_i - \sqrt{(0.800864d_i - 0.5d_i)(0.800864d_i + 0.5d_i - 0.30833264d_i)}$$

$$L_i = 0.2544d_i$$

- Volume of end <see equation 6>

$$V_e = \frac{\pi}{3} * (0.2544d_i)^2 (3 \,x\, 0.800864d_i - 0.2544d_i)$$

$$V_e = 0.14559 d_i^3$$

From volume analysis <see equation 4>

$$0.0028\text{m}^3 = \frac{\pi}{4} d_i^2 \text{ x } 2d_i + 0.29118 d_i^3$$

$$d_i = \sqrt[3]{\frac{0.0028\text{m}^3}{1.862}} = 0.114\text{m}$$

$$d_i = \underline{\underline{114\text{mm}}}$$

Therefore,

- The length of the cylindrical shell is:

$$L = 2 \text{ x } 114\text{mm}$$

$$L = \underline{\underline{228\text{mm}}}$$

- The thickness of cylindrical shell

$$t_s = 0.0054\text{mm x } 114\text{mm} + 0.4\text{mm}$$

$$t_s = \underline{\underline{1\text{mm}}}$$

By thin wall theory, of a cylindrical shell under hydrostatic loading would produce a uniform circumferential stress. Therefore the cylinder thickness is safe for the shell.

- External diameter of the shell

$$d_e = d_i + 2t_s$$

$$d_e = \underline{\underline{116\text{mm}}}$$

1. ***Flat end***

For normal operating case minimum thickness of the end is given:

$$\frac{p}{f} = \frac{150\text{kpa}}{162.5\text{Mpa}} = 0.00092$$

$$\frac{t_s}{d_i} = \frac{1\text{mm}}{114\text{mm}} = 0.0087$$

- The minimum thickness of the flat end <see equation 9>

$$t_e = 0.0087 \text{ x } 114\text{mm x } \sqrt{0.00092}$$

$$t_e = \underline{\underline{0.03\text{mm}}}$$

Which is <<< the analysis thickness

2. Torispherical end

For kloepper type

$$R = 0.8d_e \quad \Rightarrow \quad R = 92.8\text{mm}$$

$$r = 0.154d_e \quad \Rightarrow \quad r = 17.86\text{mm}$$

This dimension satisfies the following condition of applicability

$$r \le 0.2d_i\ , r \ge 0.06d_i\ , r \ge 2t_s\ , t_s \le 0.08d_e \text{ and } R \le d_e$$

i). required thickness of the end to limit membrane stress in central part <see equation 10>

$$t_s = \frac{150\text{kpa x } 92.8\text{mm}}{(2\text{ x }162.5\text{Mpa x } 0.85) - (0.5\text{ x }150\text{kpa})}$$

$$t_s = 0.05\text{mm}$$

ii). required thickness of knuckle to avoid axis symmetric yielding <see equation 11>

$$t_y = \frac{0.76\text{ x }150\text{kpa}\left(0.75\text{ x } 92.8\text{mm} + 0.2\text{ x }114\text{mm}\right)}{162.5\text{Mpa}}$$

$$t_y = 0.065\text{mm}$$

iii). required thickness of knuckle to avoid plastic bucking <see equation 12>

$$t_b = \left(0.75\text{ x } 92.8\text{mm} + 0.2\text{ x }114\text{mm}\right)\left[\frac{150\text{kpa}}{111\text{ x }162.5\text{Mpa}}\left(\frac{114\text{mm}}{17.86\text{mm}}\right)^{0.825}\right]^{\left(\frac{1}{1.5}\right)}$$

$$t_b = 0.1\text{mm}$$

The greatest value of the thickness of torispherical end is t_b=0.1mm.

3. Hemispherical Head

The thickness of hemispherical end <see equation 13>

$$t_h = \frac{150\text{kpa x } 57\text{mm}}{\left(2\text{ x }162.5\text{Mpa x } 0.85\right) - \left(0.5\text{ x }150\text{kpa}\right)}$$

$$t_h = 0.03\text{mm}$$

Since these value is much less than the thickness of shell it is difficult to weld and not easy available in local market. Therefore I take the thickness of the shell for the ends.

APPENDIX B

Typical calculation-hand pump

Area of the cylinder:

$$A = 2\pi\pi r(+ r)$$

$$A = 2 * 3.14 * (0.0125m)^2 * (0.120m + 0.0125m)$$

$$A = 0.01049m^2$$

Let the number of stroke required is 40. Therefore for pressure require per stroke:

$$P = \frac{150kpa}{40} = 3.75kpa$$

$$F = \frac{3.75kpa}{0.01049m^2} = 39.3N \approx 4kg$$

To get more air into the tank per pump cycle by pushing the pump rod quickly or slowly consider two approaches.

Approach-1: ***<u>when the pump rod pushes quickly</u>***

If the pump rod pushes quickly, the compression of air in the pump occurs adiabatically. Therefore to find the absolute temperature T_f of the air inside the pump after a rapid compression from volume V_i to volume V_f , assuming an ambient temperature of T_a.

Initial volume of the hand-pump <see equation 15>

$$V_i = \pi r^2 l$$

$$V_i = \pi * (0.0125m)^2 * 0.16m = 7.8 * 10^{-5} m^3$$

$$N_i = \frac{101{,}325 p_a * 7.8x10^{-5} m^3}{0.287 \frac{kpa\, m^3}{kg\, k} x298k} = 0.09kg$$

Final number of particles in the pump < see equation 16>

The gas particles N_f in the pump after the pump and tank have equilibrated is

let V_i=6V_f

$$N_f = \frac{p_t V_f}{k_B T_a \left(\frac{V_i}{V_f}\right)^{Y-1}}$$

$$N_f = \frac{150\text{kpa x} 1.3\text{x}10^{-5}\text{m}^3}{0.287\frac{\text{kpa m}^3}{\text{kg K}}\text{x } 298\text{K}\left(\frac{7.8\text{x}10^{-5}\text{m}^3}{1.3\text{x}10^{-5}\text{m}^3}\right)^{1.4-1}} = 0.1\text{x}10^{-4}\text{k}g$$

Determine the fraction of the particles in the pump that are transferred into the tank:

$$f = 1 - \frac{p_t}{p_a}\left(\frac{V_f}{V_i}\right)^{Y}$$

$$= 1 - \frac{150\text{kpa}}{101.325\text{kpa}}\left(\frac{1.3\text{x}10^{-5}\text{m}^3}{7.8\text{x}10^{-5}\text{m}^3}\right)^{1.4} = 0.99$$

Approach-2: ***when the pump rod pushes slowly***

If the pump rod pushes slowly, the compression of air in the pump occurs isothermally. Isothermal means "at constant temperature." T_f=T_a

Initial number of particles in a gas

Using the ideal gas law,

$$N_i = \frac{p_a V_i}{k_B T_a}$$

$$N_i = \frac{101{,}325p_a * 7.8\text{x}10^{-5}\text{m}^3}{0.287\frac{\text{kpa m}^3}{\text{kg k}}\text{x}298\text{k}} = 0.09\text{k}g$$

Final number of particles in the pump

The gas particles N_f in the pump after the pump and tank have equilibrated is

$$N_f = \frac{p_t V_f}{k_B T_a}$$

$$N_f = \frac{150\text{kpa x} 1.3\text{x}10^{-5}\text{m}^3}{0.287\frac{\text{kpa m}^3}{\text{kg K}}\text{x } 298\text{K}} = 0.2\text{x}10^{-4}\text{kg}$$

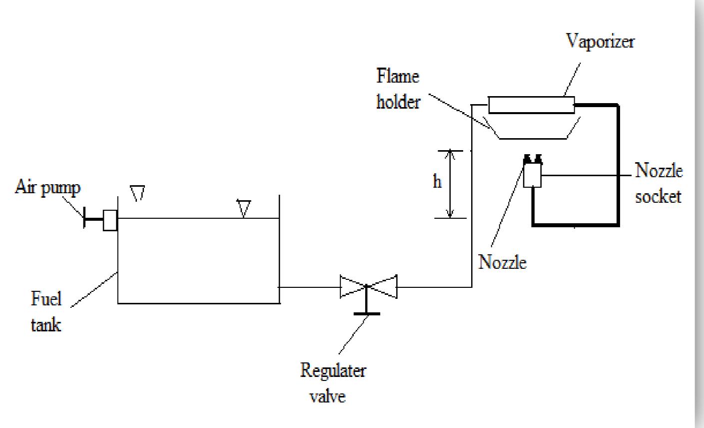
Determine the fraction of the particles in the pump that are transferred into the tank:

$$f = 1 - \frac{p_t}{p_a}\frac{V_f}{V_i} \quad = 1 - \frac{150\text{kpa}}{101.325\text{kpa}}\frac{1.3\text{x}10^{-5}\text{m}^3}{7.8\text{x}10^{-5}\text{m}^3} = 0.75$$

APPENDIX C

Typical calculation for burner

The stove was designed to supply about 2.45kw for cooking, it requires a heat output of 2.45kw or 8.82MJ/h and the calorific value Cv of pure ethanol 21.2MJ/l.



Schematic drawing of pressurized-ethanol oil stove

Thus the flow rate required is given:

$$\dot{Q} = \frac{8.82\,\mathrm{MJ/h}}{21.2\,\mathrm{MJ/l}} = 0.4\frac{\mathrm{l}}{\mathrm{h}} = 0.4*10^{-3}\frac{\mathrm{m}^3}{\mathrm{h}}$$

Flow rate required for each nipple is given:

$$\dot{V}_{each} = \frac{\dot{V}}{4} = \frac{0.4*10^{-3}\mathrm{m}^3/\mathrm{h}}{4} = 0.1*10^{-3}\mathrm{m}^3/h$$

Velocity of each nipple

$$V = \frac{\dot{V}_{each}}{A_n} = \frac{0.1*10^{-3}\mathrm{m}^3/\mathrm{h}}{\pi*0.0001^2} = 0.86\mathrm{m/s}$$

As the density of the ethanol is to be 789kg/m^3, the mass flow rate of the amount of fuel is: <see equation 18>

$$\dot{m} = 789\mathrm{kg/m}^3 * (0.4*10^{-3}\mathrm{m}^3/\mathrm{h})$$

$$\dot{m} = 0.32\mathrm{kg/h} \approx 0.08*10^{-3}\mathrm{kg/s}$$

Thanks to the calorific value Cv, from the mass the heat emitted from the fuel combustion is found:

$$\text{Heat} = \dot{m} * C_V$$

$$q = (0.08 * 10^{-3}\,\text{kg/s}) * 26.8\,\text{MJ/kg}$$

$$q = 2.45\,\text{kw}$$

Thus, the heat produced by the amount of fuel suitable in the stove is 2.45kw.

To maintain the air space pressure required for fuel tank closed and ¾ capacity of the tank is filled with ethanol-water mixture. Apply Bernoulli’s theorem at 45mm above the level of the mixture in the fuel tank. < see equation 17 >

$$P_t = w\left[\frac{V_2^{\,2}}{2g} + z_2\right] = 7.737\,\text{kN/m}^3\left[\frac{(4 * 0.86\,\text{m/s})^2}{2 * 9.81\,\text{m/s}^2} + 0.045\,\text{m}\right] = 5\,\text{kpa}$$

While 0.2kg force is applied on the pump knob, the pressure in the fuel tank:

$$P = \frac{F}{A} = \frac{20\text{N}}{\frac{\pi}{4} * (0.025\,\text{m})^2} = 40.7\,\text{kpa}$$

APPENDIX D

	Unit	**Over entire WBT**	**High power phase**	**Low power phase**
			Boil.	**Simmer**
Specific heat capacity of water	kJ/(kg*^{0}c)	4.186	4.186	4.186
Specific heat capacity of pot	kJ/(kg*^{0}c)	0.45	0.45	0.45
Evaporation enthalpy of water	kJ/kg	2260	2260	2260
Dry weight of pot	kg	0.1875	0.1875	0.188
Initial water temperature	°C	17.3	17.3	92.5
Initial water amount	kg	1	1	0.994
Water amount after boiling	kg	0.774	0.994	0.774
Water vaporized	kg	0.226	0.006	0.220
Boiling temperature of water	°C	92.5	92.5	92.5
Lower heating value	kJ/kg	23894	23894	23894
Total fuel consumed	kg	0.098	0.0465	0.051
Heat utilized to the water	kJ	825.5	328.3	509.7
Heat utilized to the pot	kJ	6.3	6.3	0.3
Utilized ethanol energy	kJ	2341.6	1111.1	1230.5
Thermal efficiency		0.353	0.296	0.414
	%	35.3	29.6	41.4
Overall efficiency		0.4	0.3	0.4
	%	35.5	30.1	41.4
Stove testing time	min	39	9	30
	s	2340	540	1800
Stove power(fire)	Kw	1.00	2.06	0.68
Average cooking power	kw	0.35	0.61	0.28
Specific standard demand	kg/kg	0.43	7.75	0.23
Specific fuel consumption	kg/kg	0.13	0.05	0.07

Test protocol calculated parameter for the Pressurized-ethanol stove prototype, example by using as fuel of 90% (w/w) ethanol concentration during first test.

APPENDIX E

In case of overall efficiency containing one litre of water:

- ✓ Energy Gained by water in High Power Phase

  = Mass of water * Specific Heat Capacity of Water * Rise in Temperature

  $= 1 * 4.19 * (92.5 - 17.3)$

  $= \underline{\underline{315}}\,\text{kJ}$

- ✓ Energy Gained by Vessel

  = Mass of Vessel * Heat Capacity of Vessel * Rise in temperature

  $= 0.1875 * 0.45 * (92.5 - 17.3)$

  $= \underline{\underline{6.3}}\,\text{kJ}$

- ✓ Energy Gained by water in Low Power Phase

  = Mass of Water vaporized * Latent Heat of Boiling of Water

  $= 0.163 * 2260$

  $= \underline{\underline{368.38}}\,\text{kJ}$

- ✓ Energy content of consumed fuel

  = Quantity of Fuel * energy content of unit amount of fuel

  $= 0.098 * 26800$

  $= \underline{\underline{2626.4}}\,\text{kJ}$

Hence,

- ✓ Overall Efficiency

  = [(Energy gained by water in HPP + Energy gained by water in LPP + Energy Gained By vessel) /Energy content of consumed fuel] * 100%

  $$= \frac{(315 + 6.3 + 368.38)}{2626.4} * 100\%$$

  $= \underline{\underline{26.26\%}}$

APPENDIX F

WATER BOILING TEST
DATA AND CALCULATION FORM

*Test Number*______________________

*Location*_________________________

*Date*_____________________________

*Test conditions*___________________

*Stove*____________________________

*Remarks*_________________________

*Tester*___________________________

	Initial Measurement	**End of high power phase**	**End of low power phase**
Dry weight of Pot #1	*a)* ______		
Dry weight of Pot #2	*b)* ______		
Quantity of fuel	*c)* ______*kg*	*i)* _____*kg*	*q)* _____*kg*
Weight of Pot #1 with water	*d)* _____*kg*	*j)* _____*kg*	*r)* _____*kg*
Weight of Pot #2 with water	*e)* _____*kg*	*k)* _____*kg*	*s)* ____ *kg*
Water temperature, Pot #1	*f)* _____[^{o}c]	*m)* ____[^{o}c]	*t)*___ [^{o}c]
Water temperature, Pot #2	*g)*____[^{o}c]	*n)* _____[^{o}c]	*y)*___ [^{o}c]
Time	*h)* _____	*p)* ____	*z)*_____

(Use the graph outline on reverse side to record changes in water temperature)

CALCULATIONS	***HIGH POWER PHASE***	***LOW POWER PHASE***
Fuel consumed	*A) c-i =* _____*kg*	*H) i-q =*____*kg*
Water vaporized, Pot, #1	*B) d-j =* ____*kg*	*I) k-q =*____*kg*
Water vaporized, Pot #2	*C) e-k =* ____*kg*	*J) j-r =*_____ *kg*
Consumption ratio	*D) B/(B+C) =* ___	*K) H/(H+I) =*___
Specific fuel consumption	*E) C/D =* _____	*M) L/M =*____
Duration of test	*F) h-p =* ____	*N) z-p =*____
Burning rate	*G) C/H =* _____*kg/min*	*S) L/R =*___*kg/min*

Overall Specific Fuel Consumption (SFC): (C+L)/(D+M) = ____

APPENDIX G

90% (w/w) ethanol concentration	Unit	Test											
		1			2			3			Average		
		Stove	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**
Fuel consumed	kg	0.10	0.05	0.05	0.11	0.051	0.055	0.113	0.051	0.0645	0.11	0.05	0.06
Initial water amount	kg	1.00	1.00	1.00	1	1	1	1	1	1	1.00	1.00	1.00
Water vaporized	kg	0.23	0.01	0.22	0.232	0.0065	0.225	0.233	0.005	0.228	0.23	0.01	0.22
Stove testing time	min	39.00	9.00	30.00	2400	600	1800	2400	600	1800	1613.00	403.00	1210.00
Stove power	kw	1.00	2.06	41.02	1.1	2.0	0.7	1.1	1.9	0.9	1.06	2.01	14.20
Average cooking power	kw	0.35	0.61	0.28	0.3	0.5	0.3	0.3	0.5	0.3	0.35	0.55	0.29
Specific fuel consumption	kg/kg	0.13	0.05	0.07	0.15	0.05	0.07	0.15	0.05	0.08	0.14	0.05	0.07
Thermal stove efficiency	%	35.26	29.55	41.42	32.3	25.4	39.6	30.8	27.4	34.2	32.80	27.45	38.44

80% (w/w) ethanol concentration	Unit	Test											
		1			2			3			Average		
		Stove	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**
Fuel consumed	kg	0.16	0.07	0.08	0.13	0.0555	0.075	0.118	0.0555	0.0625	0.13	0.06	0.07
Initial water amount	kg	1.00	1.00	1.00	1	1	1	1	1	1	1.00	1.00	1.00
Water vaporized	kg	0.24	0.01	0.24	0.239	0.0085	0.230	0.243	0.0105	0.232	0.24	0.01	0.23
Stove testing time	min	41.00	11.00	30.00	40	10	30	41	11	30	40.67	10.67	30.00
Stove power	kw	1.33	2.26	0.99	1.1	1.9	0.9	1.0	1.8	0.7	1.16	1.99	0.86
Average cooking power	kw	0.35	0.49	0.30	0.4	0.5	0.3	0.4	0.5	0.3	0.35	0.51	0.30
Specific fuel consumption	kg/kg	0.21	0.07	0.11	0.18	0.06	0.10	0.16	0.06	0.08	0.18	0.06	0.10
Thermal stove efficiency	%	26.23	21.82	30.65	30.7	27.2	33.8	34.9	29.1	40.9	30.60	26.04	35.13

70% (w/w) ethanol concentration	**Unit**	**Test**											
		1			**2**			**3**			**Average**		
		Stove	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**
Fuel consumed	kg	0.17	0.07	0.10	0.16	0.0765	0.0805	0.142	0.0595	0.0825	0.16	0.07	0.09
Initial water amount	kg	1.00	1.00	1.00	1	1	1	1	1	1	1.00	1.00	1.00
Water vaporized	kg	0.24	0.01	0.23	0.224	0.0235	0.200	0.231	0.011	0.220	0.23	0.02	0.22
Stove testing time	min	42.00	12.00	30.00	43	13	30	43	13	30	42.67	12.67	30.00
Stove power	kw	1.20	1.78	0.96	1.1	1.8	0.8	1.0	1.4	0.8	1.10	1.65	0.87
Average cooking power	kw	0.33	0.45	0.29	0.3	0.5	0.3	0.3	0.4	0.3	0.32	0.44	0.28
specific fuel consumption	kg/kg	0.23	0.08	0.13	0.21	0.08	0.10	0.20	0.06	0.11	0.21	0.07	0.11
Thermal stove efficiency	%	27.57	25.25	30.01	28.4	25.5	31.9	31.8	29.7	34.3	29.24	26.81	32.08

60% (w/w) ethanol concentration	**Unit**	**Test**											
		1			**2**			**3**			**Average**		
		Stove	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**
fuel consumed	kg	0.22	0.15	0.07	0.15	0.068	0.0795	0.1695	0.0715	0.098	0.18	0.10	0.08
Initial water amount	kg	1.00	1.00	1.00	1	1	1	1	1	1	1.00	1.00	1.00
Water vaporized	kg	0.00	0.05	0.17	0.217	0.065	0.152	0.207	0.07	0.137	0.14	0.06	0.15
Stove testing time	min	43.00	13.00	30.00	44	14	30	44	14	30	43.67	13.67	30.00
Stove power	kw	1.31	3.00	0.57	0.85	1.23	0.67	1.0	1.3	0.8	1.04	1.84	0.69
Average cooking power	kw	0.30	0.53	0.21	0.3	0.5	0.2	0.3	0.5	0.2	0.30	0.53	0.20
specific consumption	kg/kg	1.03	3.08	0.41	0.7	1.0	0.5	0.8	1.0	0.7	0.84	1.72	0.55
Thermal stove efficiency	%	23.36	17.71	37.29	35.0	42.5	29.4	29.4	41.4	21.5	29.25	33.87	29.42

50% (w/w) ethanol concentration	**Unit**	**Test**											
		1			**2**			**3**			**Average**		
		Stove	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**
Fuel consumed	kg	0.27	0.19	0.08	0.19	0.09	0.1	0.241	0.091	0.15	0.23	0.13	0.11
Initial water amount	kg	1.00	1.00	1.00	1	1	1	1	1	1	1.00	1.00	1.00
Water vaporized	kg	0.00	0.07	0.16	0.228	0.06	0.168	0.240	0.076	0.164	0.16	0.07	0.16
Stove testing time	min	46.00	16.00	30.00	45	15	30	47	17	30	46.00	16.00	30.00
Stove power	kw	1.21	2.48	0.53	0.86	1.23	0.68	1.0	1.1	1.0	1.04	1.60	0.75
Average cooking power	kw	0.30	0.48	0.21	0.3	0.5	0.2	0.3	0.5	0.2	0.30	0.47	0.21
Specific fuel consumption	kg/kg	0.37	0.22	0.10	0.27	0.10	0.13	0.34	0.11	0.20	0.33	0.14	0.14
Thermal stove efficiency	%	24.69	19.43	39.00	34.6	38.7	31.9	28.2	41.4	20.8	29.15	33.16	30.56

Wheel brand stove (kerosene fuel)	**Unit**	**Test**											
		1			**2**			**3**			**Average**		
		Stove	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**	**Stove**	**Boil**	**Simmer**
Fuel consumed	kg	0.05	0.03	0.03	0.05	0.026	0.027	0.0645	0.026	0.0385	0.06	0.03	0.03
Initial water amount	kg	1.00	1.00	1.00	1	1	1	1	1	1	1.00	1.00	1.00
Water vaporized	kg	0.00	0.01	0.15	0.207	0.032	0.175	0.261	0.04	0.221	0.16	0.03	0.18
Stove testing time	min	46.00	16.00	30.00	45	22	30	45	18	30	45.33	18.67	30.00
Stove power	kw	0.84	1.28	0.61	0.85	0.85	0.65	1.0	1.0	0.9	0.91	1.06	0.73
Average cooking power	kw	0.24	0.34	0.19	0.3	0.3	0.2	0.3	0.4	0.3	0.28	0.33	0.23
specific fuel consumption	kg/kg	0.07	0.03	0.03	0.07	0.03	0.03	0.09	0.03	0.05	0.08	0.03	0.04
Thermal stove efficiency	%	28.37	26.43	31.66	33.9	33.8	35.0	31.9	35.7	30.8	31.39	31.98	32.51

Comparison of the results from the pressure stove prototype with different ethanol concentration tested

APPENDIX H

06.30.2011

Bottles of ethanol water mixture


06.30.2011

Top view (the stove and weight balance set up)

06.30.2011

Place alcohol on spirit cup for preheating the burner

06.30.2011

Strike a match to ignite the stove


06.16.2011

The pressurized-ethanol stove flame

06.30.2011

Water boiling test set up