COMPARISION OF BIOMASS COOKSTOVES IN SRI LANKA

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Dissertation submitted in partial fulfillment of the requirements for the Degree Master of Engineering in Energy Technology

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February 2017

ABSTRACT

Biomass plays an important role in Sri Lanka Energy Sector. The consumption of biomass in the commercial and household sector is declining due the popularity of fossil fuels. Consumption of biomass is getting less popular due to various reasons. Handling difficulties due to various sizes, combustion difficulties due to various calorific values, low combustion efficiency due to high moisture content and high storage and transportation cost due to bulk size and moisture.

To evaluate the performance of selected biomass cookstoves thermal efficiency together with other performance parameters were tested by Shell Foundation Version 4.3.2 Water Boiling Test. The tested stoves are Semi-enclosed firewood cookstove, popular Anagi-2 firewood stove, Turbo charcoal stove, Desha Shakthi saw dust pellet stove and Spectra saw dust pellet stove. Desha Shakthi stove shows the highest efficiency of 0.59 at high power operation while Spectra shows 0.43 and fallen in to the tier 4 of IWA matrix. Turbo charcoal stove categorized in to tire 2 as it is having thermal efficiency of 0.26. Anagi-2 and semi-enclosed stoves can be categorized in to tire 1 since they are having efficiencies of 0.17 and 0.15 respectively.

Anagi- 2 stove shows the lowest time to boil while DeshShakthi stove takes highest time to boil water. Desha Shakthi stove shows lowest burning rate which is 5 g/min while Anagi -2 shows the highest burning rate of 28.65g/min. Specific fuel consumption of Desha Shakthi is the lowest as 0.05 kg of fuel per kg of water while semi-enclosed stoves shows the highest as 0.16.

Overall average specific energy consumption of Desha Shakthi stove is the lowest as 1.10 kJ/kg of water and highest of Anagi-2 as it is 5.27 kJ/kg of water. The highest fire power of 8712.71 W is shown by Anagi-2 while Desha Shakthi has the lowest fire power as 1279.58 W.

To categories stove emissions and safety under IWA performance matrix, the emission tests also should be done during the WBT. When comparing the designs of stoves there is a possibility of improving the performance of Spectra stove by introducing design modifications.

ACKNOWLEDGEMENT

I take this opportunity to acknowledge all individuals and organizations that supported me in carrying out this research and writing the thesis from the beginning to the end.

First of all should thank Dr. Chathura Ranasinghe, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa for his guidance and comments given as the supervisor of this research.

My heartiest gratitude is delivered to Dr. Himan Punchihewa, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa for his incomparable contribution and encouragement given me and for his hard work as the Course Coordinator.

I would like to thank Mr. Sandanayake for his support and encouragement given to me from the start to the end of the course.

A special thank goes to Mr. H M Ranasiri, Head of the Department, Mechanical Engineering Technology and Maritime Studies, Institute of Technology for giving me support and encouragement to make this study a success.

At this moment, I highly appreciate the invaluable support given to me during the testing the staff of Thermodynamic Laboratory of University of Moratuwa by providing information and lab equipment. Special thanks goes to the staff of the Work Shop of University of Moratuwa for giving me their support to make the hood for the test.

Finally I herewith acknowledge all staff members of University of Moratuwa and outside personnel for the miscellaneous support given to me in completion of this research.

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LIST OF ABBREVIATIONS

PJ	-	Pica Joules
CEB	-	Ceylon Electricity Board
ICS	-	Improved Cook Stoves
NGO	-	Nongovernmental Organization
toe	-	tons of oil equivalent
SLSEA	-	Sri Lanka Sustainable Energy Authority
CO_2	-	Carbon dioxide
CO	-	Carbon monoxide
DC	-	Direct current
WBT	-	Water boiling test
IDEA	-	Integrated Development Association
IDB	-	Industrial Development Board
NERD	-	National Engineering Research and Development
CCT	-	Control Cooking Test
KPT	-	Kitchen Performance Test
SUMs	-	Stove Use Monitors
ITI	-	Industrial Technology Institute
DC	-	Direct Current
IWA	-	International Workshop Agreement
ISO	-	International Organization for Standardization

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Appendix A - Spread Sheets of Collected Data

Appendix B - Calculation Results

Appendix C - Fuel Test Results

1 INTRODUCTION

This chapter provides information mainly on background of the research and significance of the selected area of research. Specific problem identified and the solutions expected by the research are also stated at the end of the chapter.

Research methodology, collected data, results of data analysis and relevant discussions are coming under the subsequent chapters

1.1 Contribution of Biomass on National Energy Economy of Sri Lanka

As a developing country biomass plays an important role in the national energy economy in Sri Lanka. According to the Sri Lanka energy balance in 2014, biomass has taken the share of 42.22% from total annual primary energy. That is the value of 206.27 PJ out of total of 488.52 PJ in 2014. The primary energy consumption in Sri Lanka is given in the Table 1.1 and the percentage share of primary energy is shown in Figure 1.1.

Table 1.1: Annual Primary Energy Consumption in Sri Lanka in 2014[1]

Source	Thousand (toe)	PJ	%
Biomass	4,911.25	206.27	42.2
Petroleum	4,626.84	194.33	39.8
Hydro	875.93	36.79	7.5
Coal	920.65	38.67	7.9
New Renewable Energy	296.70	12.46	2.6
Total	**11,631.37**	**488.52**	**100**

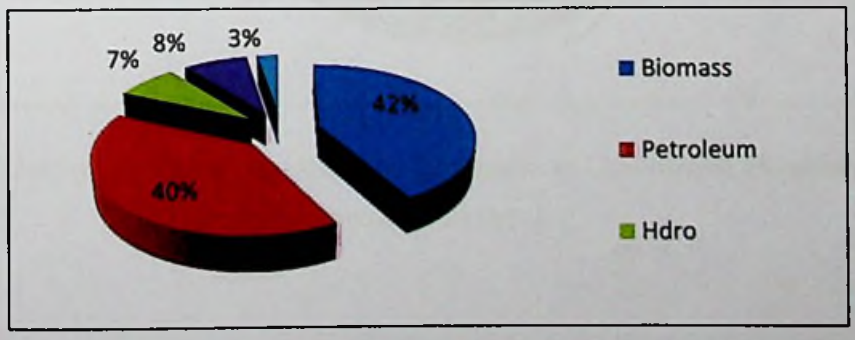

Figure 1.1: Percentage Share of Primary Energy Consumption in Sri Lanka 2014[1]

Households, Commercial and other sectors of the country consumed 44.7% of the annual energy supply while 25.9 % consumed by the industrial sector. Other 29.4% of the annual energy supply was consumed by the transport sector. The main source of energy in the sector of transport is petroleum. 73.8% of the energy needs of the industries was supplied by biomass (1,745 thousand toe) while commercial, household and other sectors used 76.8% of their annual energy needs (3,139 thousand toe). The percentage share of energy sources other than transport sector are shown in Figure 1.2 and Figure 1.3.

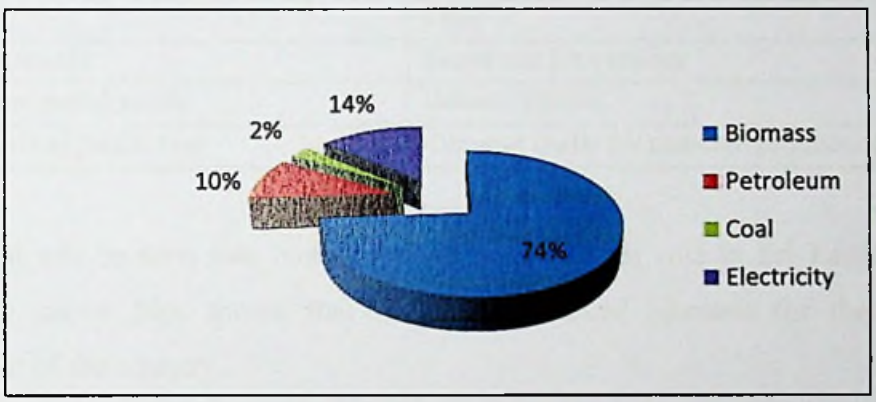

Figure 1.2: Percentage Energy Consumption by Sources in Industrial Sector in 2014 [1]

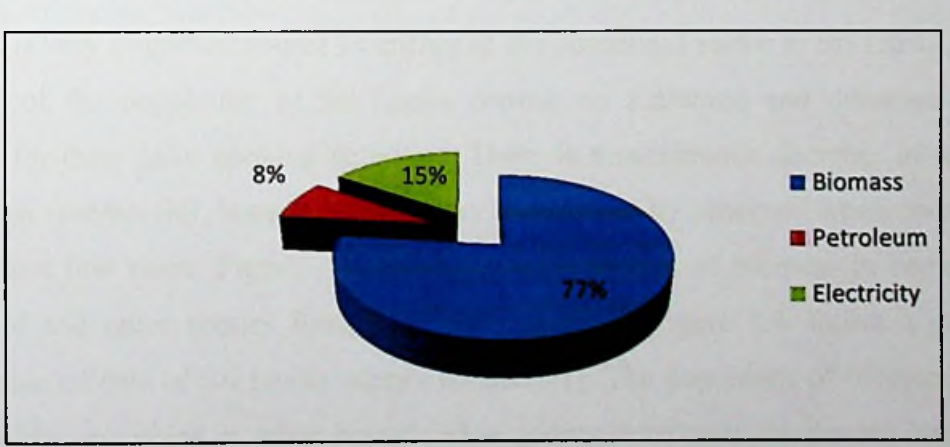

Figure 1.3: Percentage Energy Consumption by Sources in Commercial, Household and Other Sectors in 2014 [1]

There are few sectors using biomass as their main source of energy. Table 1.2 shows the list of sectors which use fuelwood as main source of energy [3].

Table 1.2: The Industries use biomass as their main energy source [3]

Sectors	
Agro Industry	Coconut Processing
	Rubber Processing
	Tea Processing
Manufacturing Industry	Brick
	Tiles
	Lime
Household	Fuelwood for cooking
Commercial sector	Bakers, Hotels
Charcoal production	Coconut shells for charcoal production

Therefore, it can be seen that biomass plays an important role in Sri Lanka's energy sector. The above data shows that the importance of biomass for the economic development of the country.

1.2 Use of Biomass in Household Sector in Sri Lanka

Biomass is very important source of energy in the household sector in Sri Lanka. Nearly 90% [3] of the population of Sri Lanka depend on fuelwood and other sources of biomass for their daily cooking activities. There is a continuous decrease in usage of biomass in commercial, household and other sectors can be observed when considering data of past few years. Figure 1.4 shows the consumption of biomass in commercial, household and other sectors form year 2009 to 2014. Figure 1.4 shows a graphical presentation of data of Sri Lanka energy balance [1]. The popularity of biomass for the daily cooking activities in urban household is getting drastically decreasing because of the unavailability and handling problems in biomass. Barriers in utilizing biomass will be discussed under chapter Literature Review.

The biomass fuels are crucial importance, especially for rural household sector. They conduct their cooking activities in biomass cookstoves in traditional way. The cookstove

is the major biomass energy consuming device used in the household sector. The use of biomass as a traditional source of energy in cookstoves is characterized by low efficiencies.

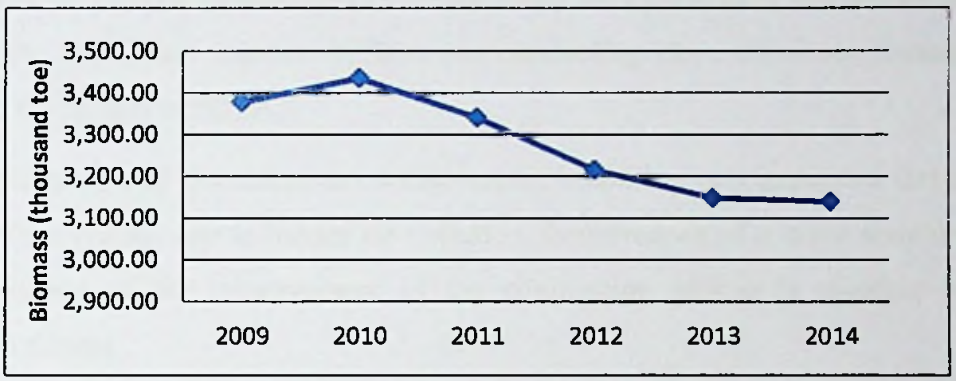

Figure 1.4: Consumption of biomass in Commercial, Household and other Sectors form year 2009 to 2014 [1]

1.3 Background of the Problem

The biomass plays an important role in the national energy economy and economic development of the country. According to the statistical data, annual primary energy consumption, annual energy consumption in the industrial sector and annual energy consumption in household, commercial and other sectors are dominated by biomass as a source of energy. Sources of biomass are from rubber plantations, coconut plantations, cinnamon plantations, home gardens, crop plantations, natural forests and etc. Although the consumption of biomass in commercial and domestic sector getting decline due to various reasons, still is the dominant source of energy in all these sectors.

The cooking activity is the main biomass consuming activity in the household and commercial sector of the country. Although the dissemination programs are carried out by various NGOs to introduce ICS in place of traditional cookstoves, the fuel wood is still being used in traditional way with high moisture content.

There are various types of improved cooksoves which are using non conventional biomass fuels like coconut shell charcoal and pellets can be found in the market. Most of these ICS have done WBT to find the efficiency but not have done emission test. University of Motatuwa has done a study on some initially developed cookstoves like Anagi and Sarvodaya cookstoves [3]. In that study the efficiencies and emission factors were taken from other sources. SLSEA was conducting stove efficiency testing by the WBT in the facility of IDEA.

The improvement of low emission cookstoves are becoming very important factor due to the health problems due to indoor air pollution. Performance of a stove should provide the indication of the improvement of the combustion efficiency together with the emission factors.

There are various types of ICS can be found island wide. Some companies have developed cookstoves which are using non conventional fuelwood like sawdust pellets and charcoal as the fuel. Though these types of fuel and cookstoves are not so popular among users, in order to popularize, there is a vital requirement for a study of standard performance testing including emission testing for newly developed ICSs. There are two pellet cookstoves (products of Desha Shakthi and Spectra Industries) one charcoal cookstove have identified for the inclusion in testing.

1.4 Problem statement

The performance testing methods for biomass ICS have been improved and developed over the past few years in the world. Some companies have developed various ICS to use with nonconventional biomass fuels in Sri Lanka. A proper performance testing and analysis have not been done for the last two decades. Therefore, identification and encouragement of better cook stove design is been lagging behind. There is a need of selecting a method of performance and doing performance testing of selected ICS and performance analysis for Sri Lanka.

1.5 Aim

Performance categorization of selected Improved Cook Stoves in Sri Lanka.

1.6 Objectives

- Investigate the methods used to assess the performance of biomass cookstoves.
- Study the performance of selected cookstoves use in urban households in Sri Lanka.

1.7 Methodology

- ***Selection of biomass cookstoves used in urban household for the study.***

Five cookstoves were selected based on several categories. Two cookstoves were selected (Anagi 2 and semi-enclosed stove) due to the widely availability and massive consumption. These two stoves are used with traditional firewood. Three cookstoves were selected on the basis of consumption of non-conventional biomass as the fuel. The Turbo charcoal stove consumes coconut charcoal while Spectra and Desha Shakthi use saw dust pellet as their fuel. All these cookstoves are widely available in urban areas of the country.

- ***Collection of information on performance testing methods parameters and standards available.***

Shell Foundation Household Energy Project Water Boiling Test version 4.2.3 was selected to evaluate the stoves in this study. This method has been standardized and improved over last few years than other methods and also it is widely used for this type of studies. The emission testing was not done due to unavailability of instruments. Time to boil, thermal efficiency, burning rate, specific fuel consumption, specific energy consumption and fire power are the performance testing parameters considered in this study

- ***Conduct performance testing for the selected cookstoves.***

Water Boiling Test of the stove has to be done in the laboratory under a controlled environment. The environmental conditions like relative humidity, temperature and pressure of the test area should not change during the time of the tests as these conditions affect the final results of the test. This testing was performed under controlled conditions at Thermodynamics Laboratory of University of Moratuwa on a clear sunny climatic day.

- ***Analysis and comparison of stoves.***

The cookstoves were analyzed according to the ISO International Workshop Agreement performance matrix which gives guidance for rating cookstoves. The cookstoves were compared on the performance indicators selected above.

2 LITERATURE REVIEW

2.1 Barriers of Utilization of Biomass

2.1.1 Availability of Biomass

There is a continuous decline of percentage contribution of biomass in primary energy sector over past years [1]. This is due to the popularity of fossil fuels due to the availability and convenient way of handling. The main sources of this biomass are from fuel wood from forests, plantations, home gardens, coconut and rubber plantations and other agricultural lands [3]. However most of these sources are not sustainable.

2.1.2 Low Combustion Efficiencies due to High Moisture Content of Biomass

Moisture content of biomass varies in a large range 9% to 40% wet basis. It depends mainly on its source. According to Sir Lanka energy balance the consumption of biomass in 2013 was 12,425 thousand tones. Assuming average of wet basis moisture content 30% the biomass contains 3,757 thousand tones of water. This amount of water is evaporated during the combustion.

2.1.3 Problems in Transportation and Storage of Biomass

Transportation and storage of biomass is also a drawback since its bulkiness and the degradation. As discussed in the previous topic the waste of transportation cost due to moisture content. Biomass is also available in various sizes depending on the source. Fire wood is in large logs whereas saw dust in fine particles. This affects the method of usage of biomass. Finally affect the process efficiency.

2.2 Benefits of Biomass Utilization

Generally the energy from biomass is not convenient with fossil fuels under present technology and market conditions in the most of the countries including Sri Lanka. The production of biomass for energy will produce a verity of benefits. These benefits vary

from case to case. However, some of them are, offsetting greenhouse gas emissions from the combustion of fossil fuels, creating jobs and income through the development of a new industry and utilization of locally produced raw materials, and enhancing energy security by reducing dependence on imports.

2.2.1 Depletion of Fossil Fuel

The global daily consumption of liquid fuel is about 96 million barrels. The figure 2.1shows history and projected values of global liquid fuel production and consumption in million barrels. The price of fossil fuels will increase with economic development unless we have to move to alternatives of fossil fuels. Increased use of biomass will extend the lifetime of diminishing crude oil supplies. And also it can be seen the important environmental advantages of biomass utilization in terms of reduction of natural resource depletion.

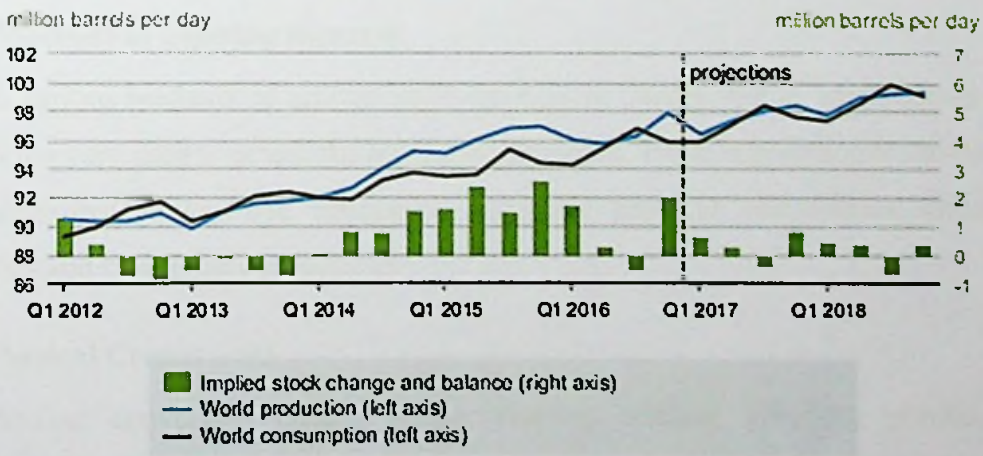

Figure 2.1: World Liquid Fuels Production and Consumption [4]

2.2.2 Solution to Global Warming

Increase in emission of greenhouse gases is a threat to the world climate. It was estimated that about 20 million metric tons of CO_2 were expected to be released

in the atmosphere every year. If this trend continues, some extreme natural disasters can be expected like excessive rainfalls and floods, droughts and local imbalances due to climate changes. Biomass is a carbon neutral resource in its life cycle and primary contributor of greenhouse effect.

2.2.3 Energy security

The economies of developing countries like Sri Lanka are depending on the price of a barrel of crude oil in the world oil market. Fluctuation of oil price affect the economy of the country. Energy security means consistent availability of sufficient energy in terms of affordable prices. Biomass is a domestic resource which is not subjected to world price fluctuations of supply uncertainties as of imported fossil fuels.

2.2.4 Foreign Currency

There are opportunities for developing countries to get foreign currency by exporting bio-energy

2.3 Methods of Utilizing Biomass

There are various methods of utilization of biomass in energy sector. Main conversion methodologies are used to match the utilization purposes. These conversion technologies can be classified in to three categories. They are physical conversions, chemical conversions and biological conversions.

2.3.1 Physical Conversions

Physical conversion include sizing, shaping, milling, grinding, grinding to decompose the biomass structure to increase its surface area to accelerate chemical, thermal or biochemical reactions. It also covers separation, extraction, distillation, etc. for obtaining useful ingredients of biomass as well as densification (bailing, pelletization and briquetting), torrefaction, drying or moisture control for making biomass more suitable for transportation and storage. The detail of densification will be discussed in detail later. Physical

conversion technologies are also used as a pretreatment for chemical and biological processes.

2.3.2 Chemical Conversions

Chemical conversion includes processes like hydrolysis, partial oxidation, combustion, carbonization, pyrolysis, hydrothermal reactions for decomposing biomass and also synthesis, polymerization and hydrogenation for constructing new molecules of reforming biomass. Generation of electrons in oxidation process of biomass can be used for fuel cells to generate electricity.

2.3.3 Biological Conversion

Biological conversion is mainly composed of fermentation process to generate ethanol, methane or acetone-butanol.

2.3.4 Biomass Densification

The transportation and storage of biomass is also a drawback since its bulkiness and the degradation. Biomass is also available in various sizes depending on the source. Fire wood is in large logs whereas saw dust in fine particles. This difficulty in handling and storing of biomass like agricultural waste can be overcome by densification process. This is simply a compaction process of residues into high density and thereby improve the quality of fuel. Densified biomass can be found in bails, briquettes and pellets. Figure 2.2 shows densified biomass products – bails, briquettes and pellets.

Figure 2.2: Bails, briquettes and pellets

The densification process improves net calorific valve of materials. The products are easy to handle, transport and store. The fuel is in uniform size and easy to use in combustion process. The densification provide a solution for problems of disposing the agricultural waste and able to utilize non-conventional biomass for the national energy economy.

2.4 Availability of Biomass in Sri Lanka

According to Sri Lanka's energy demand in 2014 in Industrial sector, 70% was supplied by the fuelwood whereas 3% is from baggas. 4,436.04 thousand toe in the household, commercial and other sectors, 64.3% is supplied by biomass [1]. Altogether is about 12,696.47 thousand tones of fuelwood. This biomass are supply from various sources like home gardens, coconut plantations, crop lands, forest plantations, rubber plantations and processing residues. The table 2.1 shows the estimated percentage supply of biomass by source.

Table 2.1: Estimated supply of Biomass by source [2]

Source	Amount percentage (%)
Home gardens	26
Coconut plantations	19
Crop lands	19
Natural forest	7
Rubber plantations	7
Forest plantations	4
Processing residues	3
others	14

2.4.1 Availability of non conventional biomass sources in Sri Lanka

There are agricultural wastes like paddy husk, paddy straw, sugarcane tops, maize stalks, maize cobs and cassava stalks, still not properly utilize for any production.

Table 2.2: Annual availability of non-conventional biomass sources [9].

Biomass resource	Annual availability Mt	Energy available Toe
Paddy straw	5,940,030	2,272,732
Paddy husk	676,156	233,998
Sugarcane tops	297,465	112,250
Maize cob	37,619	14,627
Maize stalk	275,594	82,737
Saw dust	214,200	99,196
Total	7,441,055	2,815,540
% of national need of biomass	60%	60%

About 60% of the paddy husk is been used as fuel for parboiling in rice mills at low efficiency combustion. But 40% of that still leave as a waste and end up with environmental problems. Saw dust is the other valuable biomass resource generate as a waste from timber industry. At the moment very small amount of saw dust is used in other industries and for cooking in household sector.

Table 2.2 shows annual availability of some biomass resources. The above amount of biomass and energy is wasted each year without proper utilization. Main common barriers of utilization of above resources are discussed in previous sections. Most of these resources are field based byproducts. Therefore it is not possible to fully utilize this biomass unless we need to find some mechanisms to collect at least some percentage of it.

2.5 History of ICS in Sri Lanka and Present Situation

During the period of 1950 to 1970 governments in the region of Asia together with NGOs initiated programs to dissemination programs to improve the efficiency of the biomass cookstoves [3]. With the drastically increased of oil prices due to oil crisis in 1970, various improved biomass cookstove models were developed by several research organizations in Sri Lanka. Extensive research and development activities were carried

out by various institutions in the country. Specially thermodynamics, heat transfer and other aspects were studied and tried to come up with a better improved cookstoves. During the initial stage number of NGOs together with governmental institutes were try to introduce several ICS design models but was not successful. In 1987 Ceylon Electricity Board (CEB) and ITDG introduced single pot stove named Anagi 1 and tow pot stove named Anagi 2. The Anagi 2 cookstove became most popular ICS in island wide household sector although it was made mainly for users in urban area. CISIR, IDB and NERD Centre also developed different cookstoves but not as popular as Anagi-2 model.

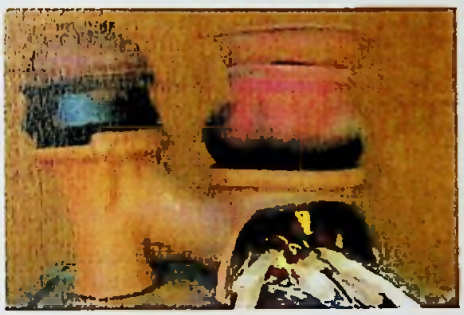

Figure 2.3: Popular Anagi -2 cookstove

There are various ICS can be found in the market which are produced by various manufacturers. During the period of 1985 to 1990s stove dissemination programs were carried out by Srvodaya–ITDG project. Large number of Potters were trained and used to promote ICS Island wide. Although potters were trained by various organizations, it was found that the ICS including Anagi found in the market are not up to the standers [5].

Figure 2.4: Various types of cookstoves available in the market

Although there are various other ICS available in the market, most of the stoves consumed fuelwood in traditional way. The main sources of this fuelwood are from home gardens, forest plantations, coconut and rubber plantations and other agricultural lands. Because of the variations in availability, handling and storage difficulties cause of indoor air pollution and smoke and soot in pots, the popularity of fuelwood is getting decreased.

Figure 2.5: New ICS found in the market.(Coconut shells use as fuel ,more like NERD Gasifier stove)

In order to find a solution for the above mentioned problem some of private sector companies developed ICS to use with the non-conventional biomass like pellets and charcoal. Desha Shakthi, Spectra pellet stoves and Turbo coconut shell charcoal cookstove among them. The biomass pellets are produced mainly by saw dust and small composition of paddy husk. The detail of the pellet cookstove will be discussed under the following heading.

2.5.1 Pellet cookstoves

The cookstoves which are using biomass pellets as fuel rarely found in the market. The companies developed these stoves should supply the fuel pellets for the customer. The company named Desha Shakthi Pvt. Ltd developed pellet cookstoves in two sizes for domestic usage and commercial (small scale hotels) applications. The company used to deliver the fuel pellets for their customers.

Figure 2.6: Desha Shakthi pellet cookstove and fuel pellet

Figure 2.7: Spectra pellet cookstove

2.6 Methods of Performance Testing of ICS

When improving the fuelwood cookstoves there was a necessity of a standard system of evaluating the performance of the cookstoves. Over the past years many test procedures have been developed to express the performance of a stove by its efficiency. Then it was understood that it is not fare to compare the stoves only by its efficiency as real users of stove are interested on other parameters like burning rate, less smoke, less emissions and less soot in pots. Actually the efficiency of a stove may vary due to lot of other parameters like the operator, fuel sample being used, pot and stove combination, food to be cooked and etc. There are four different test procedures can be found and were developed to minimize the variations between actual situations to the tested results.

2.6.1 Water Boiling Test (WBT):

The WBT is a laboratory test which is used to evaluate the performance of a stove. The test should be done inside a laboratory under a controlled environment. A pot of water is to be boiled by using the fuel that is to be used with the stove to be tested. This test procedure focuses on a simulation of coking practices by water boiling and hence it does not represent the actual cooking conditions in a kitchen which are being used. But WBT is very useful at the time of the design of cookstoves [6].

This testing process involves three main stages [7]. They are cold start high power phase, hot start high power phase and low power simmer phase.

- **Cold start high power phase:** At this phase the stove should be at ambient temperature and the water of ambient temperature should be raised up to the boiling point. This simulates rapid cooking tasks involved in the kitchen.
- **Hot star high power phase:** At this stage the water at ambient temperature should be raised up to the boiling temperature when the stove is already at hot condition. Therefore the hot start high power phase should start just after the cold start high power phase. This practice is also important for stoves as most of the time stoves are with high mass and may keep worm during actual practice.
- **Simmering phase:** This phase involves maintaining the boiling water simmering temperature i.e. water temperature should maintain few degrees (2 -3 degrees) below the boiling point about 45 minutes. This test simulates the simmer cooking practices which is much needed in actual cooking practice.

  The full WBT should be a combination of above three phases. If the stove to be tested does not have ceramic covers and less weight then only the cold start and simmer phases can be used to evaluate.

Advantages of WBT:

1) WBT is a quick and simple procedure to carryout

2) Required minimum resources and also less expensive. Does not require complex logistics.

3) Easy calculations and hence can give exact values of parameters to measure.

4) Easy to replicate the test from one area to another area

5) Useful at the time of designing of stoves

Disadvantages of WBT:

1) WBT does not represent the actual performance of the stove during real cooking environment. It provides only a rough approximation. Therefore may give inaccurate results during application. Does not evaluate the cookstove utilization patterns in the real situations.

2) The test must be carried out under the same conditions in order to compare results

3) Trained technicians are required to perform the WBT.

2.6.2 Controlled Cooking Test (CCT)

CCT is a laboratory or field test to measure the performance of a cookstove. The testing is carried out while cooking an actual meal using traditional cooking methods. This should be carried out by a person who also familiar with cooking in traditional way and also familiar with the stove which is being tested. CCT evaluate the performance of cookstoves using standardized local cooking task under the ideal cooking conditions in a local / project area. The fuel consumption and the speed of cooking are the key indicators that can be measured from this method [8].

Advantages of CCT:

1) This method provides reliable results than the WBT since it is done more closer to the actual cooking conditions.
2) CCT is simple and consume less time when compare to KPT.

3) This method is cheaper and also required minimum when compare to KPT but expensive than WBT.

Disadvantages of CCT:

1) The outcomes of this method cannot be translated to different project areas.
2) CCT still does not reflect the uncontrolled usage that is sensitive to operator behavior (fuel composition, moisture, food procurement and etc.). This method may not be able to predict the outcomes of uncontrolled usage of the cookstove in actual practice.
3) The persons who are used to carry out the cooking tasks need to have a prior training.

2.6.3 Kitchen Performance Test (KPT)

KPT is a field test that evaluates the cookstove performance in real kitchen settings in the field. Therefore it is a complex test. This KPT process involves qualitative and quantitative measurements. KPT is capable of determining the fuel consumption, user satisfaction and impacts and effectiveness of the cookstoves [8].

Advantages of KPT: stoves

1) Can get better understanding of stoves performance in a real operating condition in the field.
2) KPT able to determine the behavioral changers of the users.

Disadvantages of KPT:

1) Very expensive method and time consuming and labor incentive.
2) Very complex process and needs field research skills.
3) Because this method is uncontrolled situation there is a high possibility of variability of results.

4) KPT is not suitable for stove design and these results cannot be used to compare the performance of different cook stoves.

2.6.4 Stove Use Monitors (SUMs):

In this method the temperature of the cookstoves are measured with the help of electronic temperature data loggers. This method can be used to determine reliable estimates of stove utilization patterns by the beneficiaries. This measure the temperature changes over a period of time and stored in a memory of a data logger [8].

Advantages of SUMs :

1) SUMs method is a cheap and reliable method.
2) SUMs method provides stove utilization patterns by the beneficiaries
3) Easy to install in cookstoves that are been used in the field.

Disadvantages of SUMs:

1) SUMs is limited to measurement of stove utilization patters

2.6.5 Comparison of four techniques:

Table 2.3 shows a simple comparison of above mentioned stove performance test methods with regards to the key indicators required by the stakeholders.

Table 2.3: Simple comparison between cookstove performance testing methods.[8]

Yes – possible to measure, No – Difficult to measure

Parameter	Controlled environment		Non controlled environment	
	WBT	CCT	KPT	SUMs
Determining stove overall efficiency	Yes	Yes	No	No
Determining fuel consumption (specific meal)	Yes	Yes	Yes	No
Time of speed of cooking	Yes	Yes	No	No
Assessing stove utilization patterns	No	No	Yes	Yes
Evaluating the adaptation of cookstove	No	No	Yes	Yes
Evaluating the sustainability of the cookstove project	No	No	Yes	No
Gauging user satisfaction	No	No	Yes	No

In addition to above methods Bhatt (1983) has defined eight testing methods to determine efficiency of stoves.

They are;

1) Water boiling tests
2) Constant heat output method
3) Constant temperature raise method
4) Constant time method
5) Cooking simulation tests
6) Process simulation tests for large stoves used in small scale industries
7) Indirect method
8) Approximate method

Bhatt has used these methods to evaluate various types of wood fired appliances. He has suggested that to determine cookstove efficiency strictly from design considerations, irrespective of the users capacity for utilizing the output heat energy, the water – evaporation method may be used.

2.7 Shell Foundation and WBT

Shell Foundation started in around 2001 and identified a requirement of a bench mark for biomass ICS worldwide because many ICS did not work. They engaged in revising and improving the WBT. They did a literature review and examined national tests, including those China and India. They came out with better WBT incorporated procedures that were perceived to be the best available. With this start, over the years the Shell Foundation WBT procedures were being improved and the latest version of the Version 4.2.3 which includes the emission testing.

2.8 International Organization for Standardization (ISO) International Workshop Agreement (IWA)

In 2012 stake holders and 23 countries were met together to establish an ISO IWA that provides interim guidance for rating cookstoves on four performance indicators; efficiency, total emissions, indoor emission and safety. An IWA is an ISO document

produced through workshop meetings to address a rapid emerging market need, and can be used as a precursor to international standards. This cookstoves IWA serves as a guideline for governments, policy makers, investors, manufacturers and other stakeholders. IWA framework has introduced multiple tires of performance (0 to 4) for each of the four indicators mentioned above. Table 2.4 shows the IWA performance Matrix.

Table 2.4: IWA Performance Metrics [7]

IWA WBT Tiers	Units	Tier 0	Tire 1	Tier 2	Tier 3	Tier 4
High power thermal efficiency	%	< 0.15	≥ 0.15	≥ 0.25	≥ 0.35	≥ 0.45
Low power specific consumption	MJ/min/L	> 0.05	≤ 0.05	≤ 0.039	≤ 0.028	≤ 0.017
High power CO	g/MJd	>16	≤ 16	≤ 11	≤ 9	≤ 8
Low power CO	g/min/L	>0.2	≤ 0.2	≤ 0.13	≤ 0.1	≤ 0.09
High power PM	mg/MJd	> 979	≤ 979	≤ 386	≤ 168	≤ 41
Low power PM	mg/min/L	>8	≤ 8	≤ 4	≤ 2	≤ 1
Indoor emissions CO	g/min	>0.97	≤ 0.97	≤ 0.62	≤ 0.49	≤ 0.42
Indoor emissions PM	mg/min	>40	≤40	≤17	≤8	≤2
Safety	Johnsons	<45	≥45	≥75	≥88	≥95

3 METHOD

3.1 Selection of Stoves to be Tested

There are five cookstoves have been selected for this study. Two of these are firewood stoves used widely in country for the comparison with other ICS. The Semi-enclosed cookstove and Anagi 2 stoves are readily available in the market and also widely being used in urban households in Sri Lanka [5]. There are charcoal cookstoves also used in some of urban households in Sri Lanka. Turbo charcoal cookstove was randomly selected for this study for comparison with other stoves. Two pellet cookstoves, Desha Shakthi and Spectra stoves were selected as these are the only pellet cookstoves developed in the country. These cookstoves are selected because these are using with non-conventional biomass fuels like charcoal and pellets. Details of the Turbo charcoal stove, Desha Shakthi and Spectra stoves will be discussed in the next heading.

Figure 3.1: Selected firewood cookstoves: Anagi 2 and Semi-enclosed cookstove

3.1.1 Turbo charcoal cookstove

This charcoal stove was developed and marketed by a local company. This stove consists of three parts. Steel combustion tray is used to hold the fuel charcoal and act as the combustion chamber, clay outer chamber is used to hold the combustion tray. It has an electric fan fixed from which the primary combustion air is supplied. Clay ash plate (tray) to collect ash that falls through the holes in the combustion chamber. The electricity is supplied for the fan by a DC 12V, 500 mA output power adapter. Supply air can be controlled by a switch to provide

high and low air supply. These pots are marketed in urban households where electricity is available. The gap between the pot and the stove is about 5 mm.

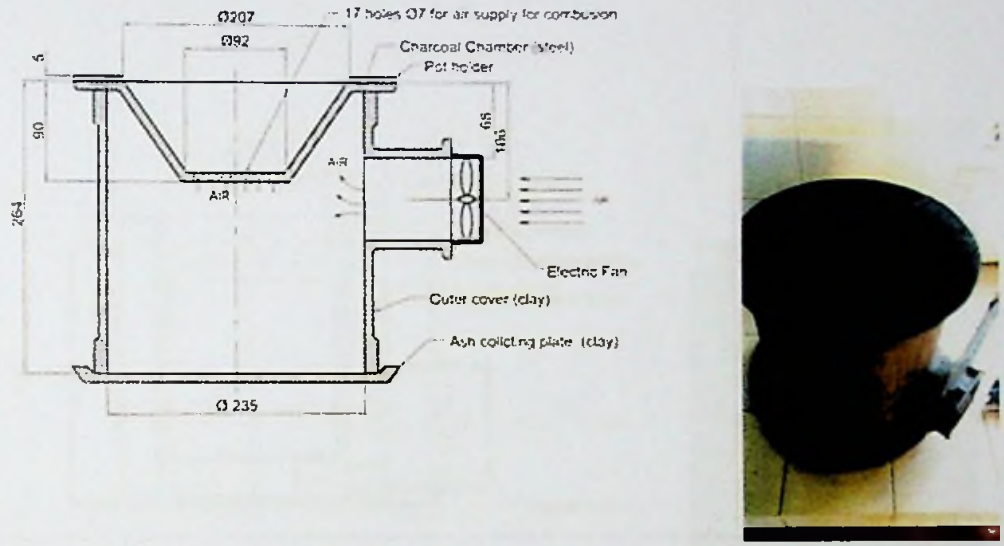

Figure 3.2: Selected Turbo charcoal cookstoves

3.1.2 Desha Shakthi Pellet Cookstove

This pellet cookstove developed by the Desha SakthiPvt Ltd. It is made in metal sheets and the air is supplied by a small fan. They have developed two sizes of stoves to use in commercial activities and household activities. It consists of tree chambers as shown in the Figure 3.3. Fuel should fill in to the inner chamber which can be removed from the stove so that the ash and char can be easily removed from it. It has a mesh bottom so that the primary air for combustion is supplied through the mesh. The combustion is taken place in the inner chamber. The outer chamber has two walls through which the secondary air passed and supply through holes made around from the top of the chamber. This air is act as a secondary air supply to the flame. This secondary air is preheated due to the heat of the chamber. Outer cover is act as a safety cover of the stove. The air is supplied through a damper by an electric fan (5 VDC, 1A).The fan has a option of speed controller in three stages. The combustion process is a batch wise

process and also the combustion starts from the top layer of the fuel. There is need of kerosene or some other fuel to initiate the ignition of the fuel pellets at the beginning. The gap between the pot and the stove is about 11 mm.

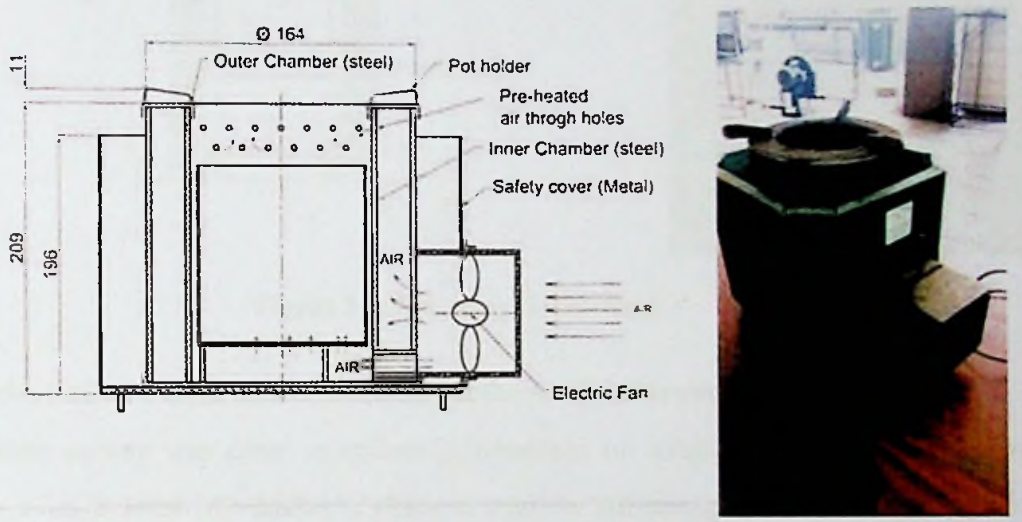

Figure 3.3: Desha Shakthi Pellet Cookstove

3.1.3 Spectra Pellet Cookstove

Spectra pellet cookstove is a newly developed ICS by the Spectral Industries Pvt. Ltd. It has two main components. The inner combustion chamber made out of stainless steel and can be taken out from the top. The fuel pellet is filled in to the inner chamber and combustion taken place in this chamber. The outer chamber is made out of steel and it is insulated. The combustion air is supplied by a fan which is in the bottom of the stove as shown in the figure. The electricity is supplied for the fan by a DC 12V, 500 mA output power adapter. Supply air can be controlled by a switch. This ICS is a new design and has not in the stage of commercially available. This pot is selected to have a comparison with the Desha Shakthi stove.

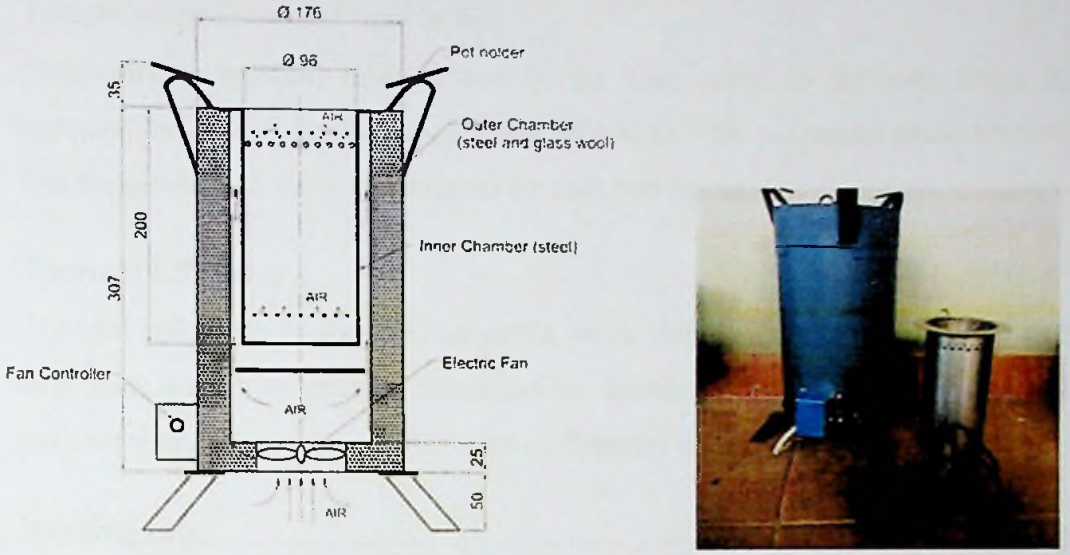

Figure 3.4: Spectra pellet cookstove

3.2 Selection of Performance Testing Methods and Parameters for the Study

A literature survey was done to collect information on available performance testing methods of ICS used in various cookstove studies. Advantages and disadvantages of performance testing methods have been discussed under the literature review heading. After considering the simplicity and available resource the WBT was selected. Since the WBT has been standardized and improved over last few years Shell Foundation Household Energy Project Water Boiling Test version 4.2.3 was selected to evaluate stoves in this study. The emission testing was not done due to unavailability of instruments. Therefore, following performance testing parameters were selected for comparison.

i. Time to boil

ii. Thermal efficiency

iii. Burning rate

iv. Specific fuel consumption

v. Specific energy consumption

vi. Fire power

3.2.1 Temperature corrected time to boil

Temperature corrected time to boil is the time taken to increase water at temperature 25^0C to boiling temperature of 100^0C. This parameter provides how fast the given cook stove can achieve the required operation.

3.2.2 Thermal Efficiency

Thermal efficiency is the ratio of useful work done by the stove (to heat and evaporate water) to energy consumed by burning of fuel. This is a useful parameter to compare the performance of different cookstoves.

3.2.3 Burning rate

The burning rate gives a measure of the rate of fuel burning while bringing water to boiling temperature. This is calculated by dividing the equivalent dry fuel consumed by the time taken to boil the water in the pot.

3.2.4 Temperature corrected specific fuel consumption

Specific fuel consumption is the amount of dry fuel need (kg) to produce one kg or liter of water to boil from room temperature. This is calculated by dividing the equivalent dry fuel consumed by amount of water used for the test. This also can be calculated to find the temperature corrected specific fuel consumption. The temperature corrected Specific furl consumption Specific fuel consumption to bring water from 25 ^{0}C to 100^0C. This parameter can be used compare stoves on different ambient temperatures.

3.2.5 Temperature corrected specific energy consumption

Specific energy consumption is the amount of fuel energy (kJ) to produce one kg or liter of water to boil from room temperature. This is calculated by multiplying temperature corrected dry fuel consumed by LHV of the fuel.

3.2.6 Fire Power

Fire power is the fuel energy consumed to boil the water divided b the time to taken to boil which gives the average power output of the stove in Watts.

3.3 Preparation for the Test

International WBT method is used to conduct performance testing for this study. The latest version Shell Foundation Household Energy Project Water Boiling Test version 4.2.3 was used to evaluate the stoves. The test has to be conducted in three stages.

1) Cold start high power phase:
2) Hot start high power phase
3) Low power simmer phase

The test of the stove has to be done in the laboratory under a controlled environment. Therefore it has to be done in a place where there is no effect of the wind. But the place should have clean air environment so that the combustion process should take place without problem. The environmental conditions like relative humidity, temperature and pressure of the test area should not change during the time of the tests as these conditions affect the final results of the test. This testing was performed under controlled conditions at Thermodynamics Laboratory of University of Moratuwa on a clear sunny climatic day.

Capacity of 3 liter two aluminum flat bottom pots were purchased from the market and used throughout the tests. These aluminum pots are readily available in the local market. Each stove were tested by commencing few water boiling trials with using the pots to familiarize the stove and find approximate amount of fuel need in each phase.

During the test trials it was found that sand should be used to stop the fire in Desha Shakthi and Spectra stoves. And also found that it is difficult to separate un-burn fuels from the char left in the stove. And also even after stopping the air

supply, the fuel keeps on burning without flame. Therefore clean sand is used to stop the combustion process completely. A measured quantity of cleaned is used to put in to the stove to stop the combustion process and after that it was easy to separate un-burn fuel from char and it was successful. (This procedure can be adopted with this type of fuels)

With other cookstoves using firewood and charcoal, it was easy to stop the fire and separate the char from the unburned fuels.

3.3.1 Selection of Fuels for the study

Rubber wood was selected as the firewood for the Anagi2 and semi-enclosed cookstove. Since in the urban households, rubber wood is readily available in the market. The Desha Shakthipelltes were used as these were the only available pellets in market. Coconut shell charcoal were made in traditional way as the users used make then at their homes.

4 DATA COLLECTION AND ANALYSIS

The equipment used for the WBT process are Stop watch, electronic balance to measure the weights of fuel and water, thermocouple with a data logger to be kept inside the water in the pot. This thermocouple was inserted in the middle of the pot and held 50 mm above the bottom of the pan. The temperature of the water was measured and taken down in 60 seconds time intervals. All these instruments were calibrated prior to the test.

Figure 4.1: While conducting WBT in the thermodynamics laboratory

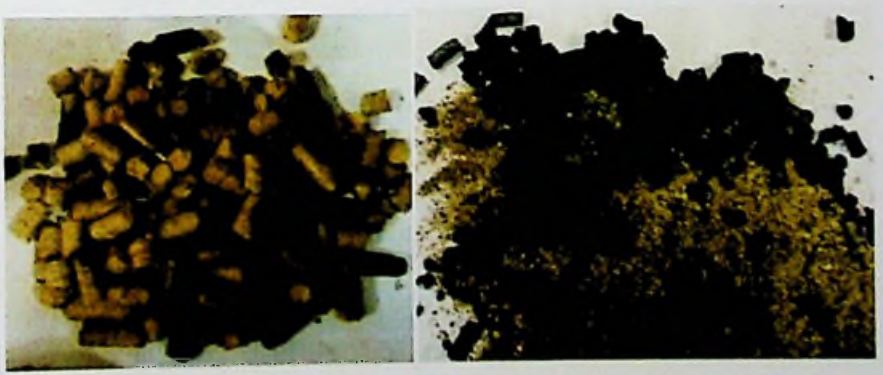

Figure 4.2 : After the boiling process the separated un-burn fuel and char with sand

To start the initial ignition of the stove small weight of kerosene or coconut leaves has to be used as advised by the stove supplier. This weight of the kerosene also noted down and make sure to use same amount of during test.

In order to achieve repeatability of the test trials all the environmental parameters were kept constant as advised by the WBT protocol. Three test trials were conducted to get an average in each test and recorded in a data spread sheet.

The moisture content of rubber wood, coconut charcoal and pellets which were used for the testing were tested by ITI and also the calorific value of pellets also tested by ITI. The calorific value of fire wood (rubber) and Coconut shell charcoal was taken from the previous test results. Data collected spread sheets are attached in the Annexure A. specimen calculation of the study is been done for Desha Shakthi pellet stove and given below. The calculations are based on the Shell Water Boiling Test Protocol version 4.2.3

4.1 Abbreviations used in calculations

LHV_{fuel} - Low heating value of fuel used

MC_{wet} -Moisture content of fuel (wet basis)

LHV_{char} -Low heating value of char

T_b -Water boiling temperature

T_a - Ambient temperature

P1 -Weight of empty pot #1

P2 -Weight of empty pot #2

K - Weight of sand

Kc - Weight of sand + char

F_i - Weight of fuel before test

F_f - Weight of unburned fuel after test

$P1_i$ - Weight of pot #1+water before test

$P2_i$ - Weight of pot #2 + water before test

$P1_f$ - Weight of pot #1+water after test

$P2_f$ - Weight of pot #2 + water after test

$T1_i$ - Water temperature at pot #1 before test

$T2_i$ - Water temperature at pot #2 before test

$T1_f$ - Water temperature at pot #1 after test

$T2_f$ - Water temperature at pot #2 after test

Δt - Time taken to boil water at pot #1

C - Weight of char after the test

W_v - Mass of water vaporized during the test

f_m - Weight of fuel consumed (moist)

ΔC - Net changed in char during the test

W_r - Effective mass of water boiled

f_d - Equivalent dry fuel consumed

Δt^T - Temperature corrected time to boil

h - Thermal efficiency

r_b -Burning rate

SC - Specific fuel consumption

SC^T - Temperature corrected specific fuel consumption

SE^T - Temperature corrected specific energy consumption

SE - Specific energy consumption

FP - Fire power

4.2 Calculations of LHVs

4.2.1 Low Heating value (LHV) of Coconut Shell Charcoal

Gross calorific value of charcoal (High heating Value) is taken as 7764 kcal/kg [10] .

(Considering 1 kcal/kg = 4.184 kJ/kg)

Therefore HHV = 7764 x 4.184 kJ/kg

= 32484.6 kJ/kg

Considering the difference between HHV and LHV of charcoal as 1320 kJ/kg [7]

LHV = 32484.6 - 1320

= 31164.6 kJ/kg

4.2.2 Low Heating Value of Rubber Wood

Gross calorific value (HHV) of rubber wood is taken as 4676cal/g [11]

(Considering 1 kcal/kg = 4.184 kJ/kg)

Therefore HHV = 4676 kcal/kg

= 4676 x 4.184 kJ/kg

= 19564.4 kJ/kg

Considering the difference between HHV and LHV of charcoal as 1320 kJ/kg [7]

LHV = 19564.4 - 1320

= 18244.4 kJ/kg

4.2.3 Gross Calorific Value of Pellet

Gross calorific value (HHV) of Pellet is taken as 3982 kcal/kg (Test results from ITI given in Appendix D)

(Considering 1 kcal/kg = 4.184 kJ/kg)

Therefore HHV = 3982 kcal/kg

= 3982 x 4.184 kJ/kg

= 16660 kJ/kg

Considering the difference between HHV and LHV of charcoal as 1320 kJ/kg [7]

LHV = 16660 - 1320

= 15340.7 kJ/kg

4.2.4 Calorific value of Charcoal

Net calorific value (LHV) of charcoalis taken as 12800 Btu/lb[www. Engineeringtoolbox.com]

(Considering 1 Btu /lb = 2.326 kJ/kg)

Therefore LHV = 12800 x 2.326 kJ/kg

= 29772.8 kJ /kg

4.3 Specimen Calculation for Desha Shakthi pellet stove – trial 1 – cold start

4.3.1 The variables that are constant for the trial 1

LHV_{fuel}	Low heating value of fuel pellet	=	15340.7	kJ/kg
MC_{wet}	Wet basis moisture content of pellet	=	0.111	
LHV_{char}	Low heating value of char of pellet	=	29,773	kJ/kg
T_b	Water boiling temperature	=	99.2	^0C
T_a	Ambient temperature	=	30.5	^0C

4.3.2 The variables that are measured during the trial 1 –cold start

P1	Weight of empty pot #1	=	169.91	g
$P1_i$	Weight of pot #1+ water	=	2723.63	g
F_i	Weight of fuel	=	350.70	g
$T1_i$	Initial temperature of water	=	31.4	^0C
K	Weight of sand	=	357.46	g
F_f	Weight of un-burned fuel	=	82.72	g
Kc	Weight of sand + char	=	410.09	g
$P1_f$	Weight of pot#1+ water after test	=	2581.05	g
Δt	Time taken to boil	=	21.35	min.sec

4.3.3 Calculation of other parameters

Δt Time to boil in minutes = 21.min 35 sec = 21 + (35/60) = 21.58 min

W_v Mass of water evaporated during the test $= P1_i - P1_f$

$= 2723.63 - 2581.05$

$= 142.58$ g

f_m Fuel consumed (moist) $= F_i - F_f$

$= 350.70 - 82.72$

$= 267.98$ g

ΔC Net change in char during the test $= K_c - K$

$= 410.09 - 357.46$

$= 52.63$ g

W_r Effective mass of water boiled $= P1_f - P1$

$= 2581.05 - 169.91$

$= 2411.14$ g

f_d Equivalent dry fuel consumed can be calculated by following equation;

$f_d = [f_m(LHV_{fuel}(1-MC_{wet}) - MC_{wet}(4.186(T_b-T_a)+2257)) - \Delta C \times LHV_{char}] / LHV_{fuel}$

$= (267.98 (15340.7 (1-.111) - 0.111 (4.186(99.2 -30.5) +2257))-52.63 x29773/15340.7$

$= 131.16$ g

Δt^T Temperature corrected time to boil $= \Delta t75 / (T1_f - T1_i)$

$= 21.58 \times 75 / (99.2 - 31.4)$

$= 23.87$ min

h Thermal efficiency $= (4.186 (T1_f - T1_i)(P1_i - P1) + 2260. w_v) / f_d$ LHV

$= (4.186(99.2 -31.4)(2723.63-169.91)+2260*142) /(131.16*15340.7)$

$= 0.52$

r_b Burning rate $= f_d / \Delta t$

$= 131.16 / 21.58$

$= 6.08$ g/min

SC Specific fuel consumption $= f_d / W_r$

$= 131.16 / 2411.14 = 0.054$

SC^T Temperature corrected specific fuel consumption is given by following equation;

SC^T $= SC \times 75 / (T1_f - T1_i)$

$= 0.054 \times 75 / (99.2 - 31.4) = 0.060$

SE^T Temperature corrected specific energy consumption;

SE^T $= SC^T \times LHV / 1000$

$= 0.060 \times 15340.7 / 1000 = 0.923$ kJ/g

FP Fire power $= f_d \times LHV / (\Delta t \times 60)$

$= 131.16 \times 15340.7 / (21.58 \times 60)$

$= 1553.9$ Watt

4.4 Calculation for the Desha Shakthi pellet stove – trial 1 - hot start

Calculations for the hot start is same as the cold start

4.5 Calculations for the Desha Shakthi pellet stove – trial 1 - simmering

4.5.1 The variables that are constant for the trial 1

LHV_{fuel}	Low heating value of fuel pellet	= 5340.7	kJ/kg
MC_{wet}	Wet basis moisture content of pellet	= 0.111	
LHV_{char}	Low heating value of char of pellet	= 29,773	kJ/kg
T_b	Water boiling temperature	= 99.2	^0C
T_a	Ambient temperature	= 30.5	^0C

4.5.2 The variables that are measured during the trial 1 –simmering

$P1$	Weight of empty pot	=	202.81	g
$P1_i$	Weight of pot + water	=	2646.41	g
F_i	Weight of fuel	=	414.05	g
$T1_i$	Initial temperature of water	=	88.3	^0C
$T1_f$	Final water temp. at end of simmer	=	96.8	^0C
K	Weight of sand	=	347.60	g
F_f	Weight of un-burned fuel	=	0	g
Kc	Weight of sand + char	=	440.25	g
$P1_f$	Weight of pot+ water after test	=	2054.06	g

4.5.3 Calculation of other parameters

Δt Time of simmering in minutes = 45 min

W_v Mass of water evaporated during the test $= P1_i - P_f$

$= 2646.41 - 2054.06$

$= 592.35$ g

f_m Fuel consumed (moist) $= F_i - F_f$

$= 414.05 - 0$

$= 414.05$ g

ΔC Net change in char during the test $= K_c - K$

$= 440.25 - 347.60$

$= 92.65$ g

W_r Effective mass of water simmered $= P1_f - P1$

$= 2054.06 - 202.81$

$= 1851.25$g

f_d Equivalent dry fuel consumed in the simmering is calculated by following equation;

f_d= $[f_m(LHV_{fuel}(1-MC_{wet}) - MC_{wet}(4.186(T_b-T_a)+2257)) - \Delta C \times LHV_{char}] / LHV_{fuel}$

= (414.05(15340.7 (1-0.111) - 0.111(4.186(99.2 - 30.5) + 2257))-52.63 x 29773)/16661

= 180.65 g

h Thermal efficiency = $(4.186(T1_f - T1_i)(P1_i - P1 + wr)/2 + 2260.w_v)/f_d$ LHV

= (4.186(96.8–88.3)(2646.41-202.81+1851.25)/2 +2260*592.35) /(180.65 *15340.7)

= 0.511

r_bBurning rate $= f_d / \Delta t$

= 180.65/ 45

= 4.01g/min

SC Specific fuel consumption $= f_d/W_r$

= 180.65 / 1851.25 = 0.098

SE Specific energy consumption;

SE = SCx LHV / 1000

= 0.098 x15340.7 / 1000 = 1.497 kJ/g

FP Fire power = f_dx LHV /(Δt x 60)

= 180.65 x15340.7 / (45 x 60)

= 1026 Watt

4.6 Calculations for the Spectra pellet stove

Calculations of cold start, hot start and simmer of Spectra pellet cook stove are the same as above Desha Shakthi pellet stove.

4.7 Calculations for the Turbo charcoal stove

Calculations of cold start, hot start and simmer of charcoal stove also same as above. The only difference is that the remaining charcoal is considered as the remaining fuel. Did not used sand to stop the flame.

4.8 Calculations for Semi-enclosed fuel wood stove

Calculations of cold start, hot start and simmer of semi-enclosed wood stove also same as above stoves. Remaining charcoal could be measured directly by separating and weighing and therefore, did not use sand.

4.9 Calculations for Anagi 2 fuel wood stove

Anagi 2 is a two pot stove. Therefore two pots were used for the test. For the calculations of cold start and hot start both pots have been taken in to consideration as give in the protocol. The calculations are the same as Desha Shakthi pellet stove. The calculations for the simmer phase were done only for the main pot (Pot #1) as advised in the protocol.

5 RESULTS AND DISCUSSION

The results of the calculations are given in the Annexure B.

5.1 Temperature Corrected Time to Boil

The results provide indicate that the Anagi 2 stove takes the lowest time to boil while Desha Shakthi stove is the slowest. Turbo charcoal stove also shows lower time when compare with the other stoves.

Table 5.1: Temperature corrected time to boil in minutes

	Cold start min.	Hot start min.	Overall Ave. min.
Semi-enclosed	18.75	19.06	18.91
Anagi-2	14.64	13.34	13.99
Turbo charcoal	15.73	13.69	14.71
Desha Shakthi	23.00	19.35	21.17
Spectra	21.92	17.71	19.82

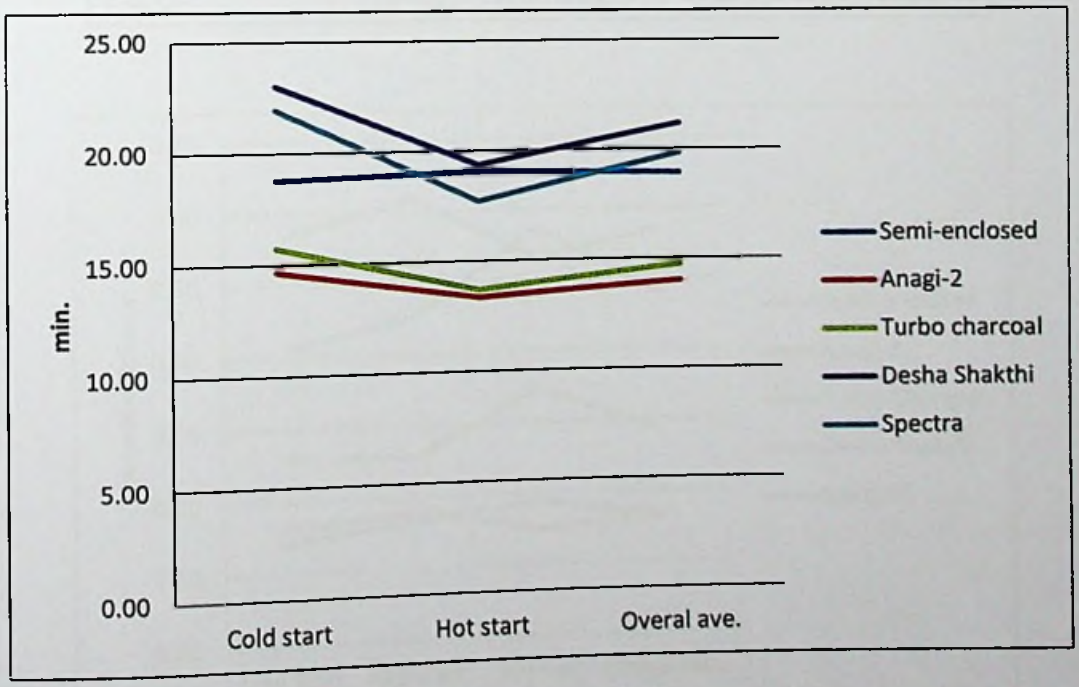

Figure 5.1 : Temperature corrected time to boil

5.2 Thermal Efficiencies of Stoves

Thermal efficiencies of stoves in cold star, hot start, simmer and overall is given below. It can be seen that Desha Shakthi stove shows the highest thermal efficiency in high power (cold start and hot start) while semi-enclosed and Anagi 2 stoves show lower. Spectra stove shown the highest thermal efficiency at low power operation (simmer) while Anagi 2 shows the lowest. All stoves other than Turbo charcoal stove shows higher thermal efficiency in hot start than to cold start while Turbo charcoal stove does not show any difference. When considering the overall average, Anagi 2 stove shows lower efficiency while Desha Shakthi shows the highest efficiency.

Table 5.2: Thermal efficiencies of tested stoves

	Cold Start %	Hot start %	Simmer %	Overall Ave. %
Semi-enclosed	0.14	0.17	0.19	0.17
Anagi 2	0.16	0.18	0.15	0.16
Turbo Charcoal	0.26	0.26	0.35	0.29
Desha Shakthi	0.57	0.62	0.53	0.57
Spectra	0.41	0.45	0.57	0.48

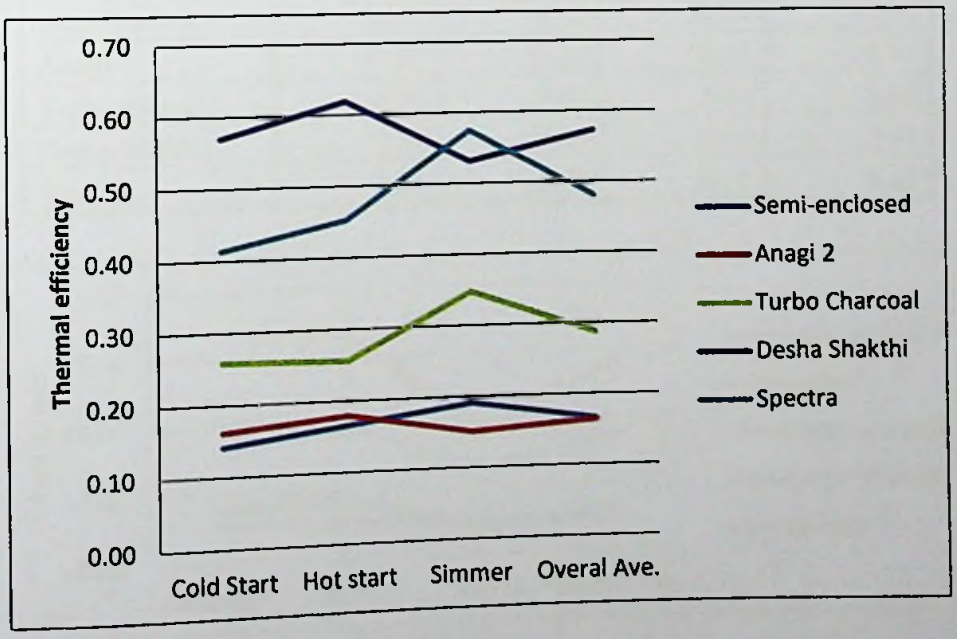

Figure 5.2: Thermal efficiencies of tested stoves

5.2.1 High power thermal efficiency

The following table shows high power efficiency values of stoves

Table 5.3: High power thermal efficiency values.

	Efficiency %
Semi- enclosed	0.15
Anagi-2	0.17
Turbo charcoal	0.26
Desha Shakthi	0.59
Spectra	0.43

5.3 Burning Rate:

Burning rates of stoves are given in the table 5.2. This shows Anagi 2 stove has highest burning rate while Desha Shakthi shows the lowest burning rat in low power as well as high power. Turbo charcoal, Desha Shakthi and Spectra stoves show lower burning rate than rubber wood fired Anagi-2 and semi-enclosed stoves.

Table 5.4: Burning rate of stoves in g/min

	Cold start g/min.	Hot start g/min.	Simmer g/min.	Overall Ave.
Semi-enclosed	21.01	18.87	12.74	17.54
Anagi-2	34.32	33.03	18.61	28.65
Turbo charcoal	8.06	9.02	3.68	6.92
Desha Shakthi	5.58	5.29	4.14	5.00
Spectra	7.34	8.29	4.22	6.62

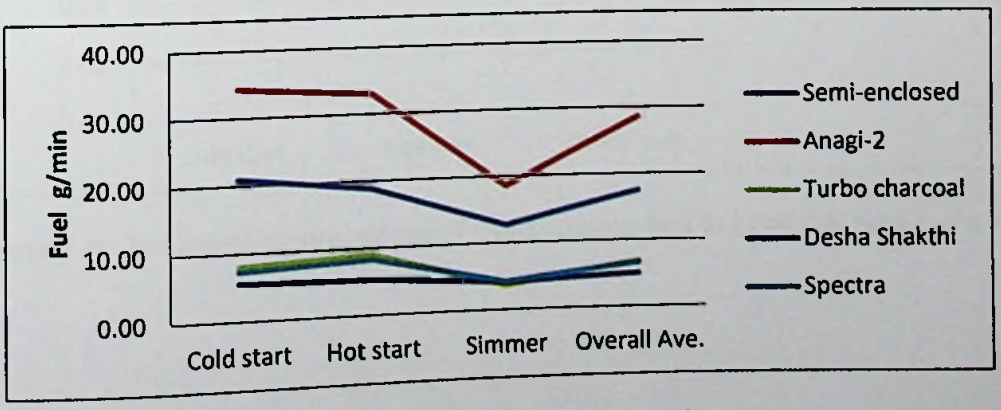

Figure 5.3: Burning rates in g/min

5.4 Temperature Corrected Specific Fuel Consumption

Temperature corrected specific fuel consumption is highest in the semi-enclosed stove and lower in the Turbo charcoal stove and Desha Shakthi stoves. The temperature corrected specific fuel consumption cannot be calculated. The table 5.3 and the figure 5.3 shows the temperature corrected specific fuel consumption of stoves in cold start, hot start and average of cold and hot starts.

Table 5.5: Temperature corrected specific fuel consumption in kg of fuel per kg of water

	Cold start	Hot start	Ave.
Semi-enclosed	0.16	0.15	0.157
Anagi-2	0.15	0.12	0.136
Turbo charcoal	0.05	0.05	0.051
Desha Shakthi	0.06	0.04	0.050
Spectra	0.07	0.06	0.064

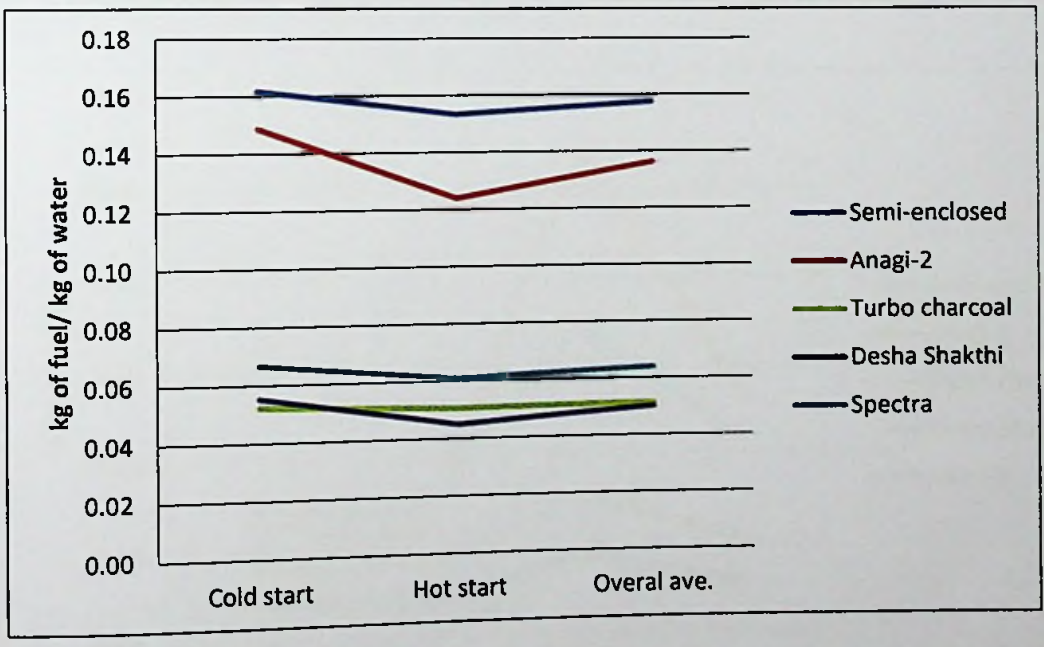

Figure 5.4: Temperature corrected specific fuel consumption in kg of fuel per kg of water

5.5 Temperature Corrected Specific Energy Consumption

Temperature corrected specific fuel consumption at high power operation in semi-enclosed cookstove is the highest while Desha Shakthi stove shows the lowest. For the simmer state, the specific fuel consumption was considered for calculation of specific energy consumption. In all stoves consume more energy in low power operations. Anagi -2 shows the highest specific energy consumption in low power operations. Desha Shakthi stove shows the lowest energy consumption.

Table 5.6: Temperature corrected specific energy consumption in kJ/ kg of water

	Cold start kJ/kg	Hot start kJ/kg	Simmer kJ/kg	Overall Ave. kJ/kg
Semi-enclosed	2.95	2.80	6.95	4.23
Anagi-2	2.71	2.26	10.85	5.27
Turbo charcoal	1.63	1.57	3.10	2.10
Desha Shakthi	0.85	0.69	1.78	1.10
Spectra	1.02	0.93	1.73	1.23

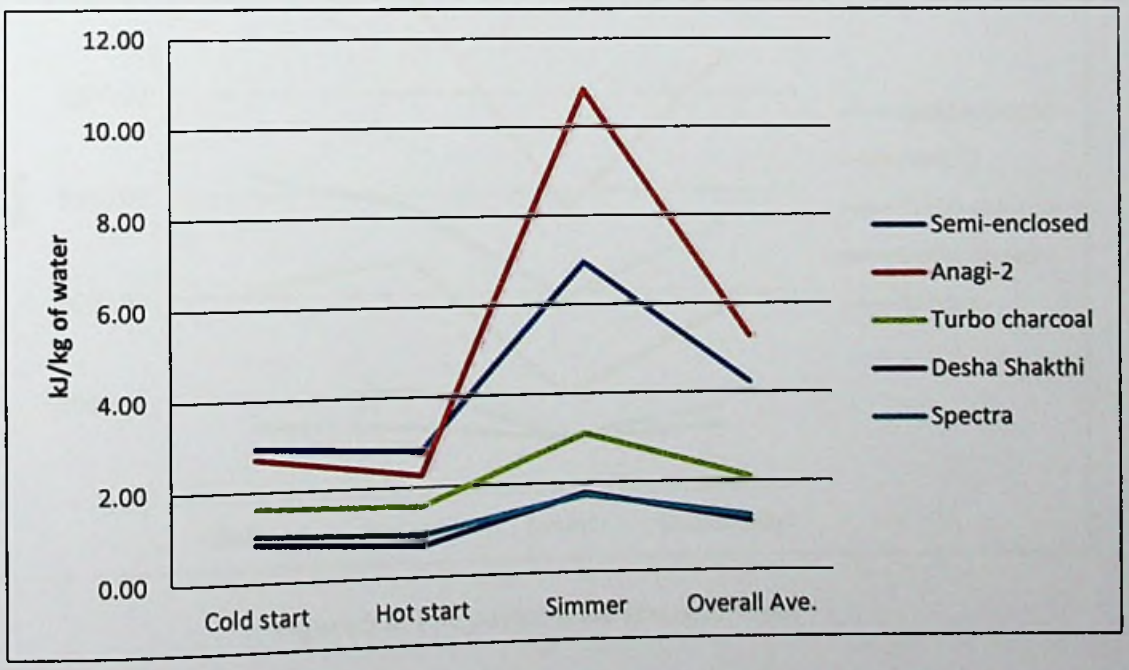

Figure 5.5: Temperature corrected specific energ consumption in kJ/kg of water

5.6 Fire Power

Fire power of the stoves given in the table 5.5 and figure 5.5. Anagi-2 cookstove shows the highest fire power while Desha Shakthi shows the lowest in both high power and low power conditions.

Table 5.7: Fire power of the stoves in Watts

	Cold start	Hot start	Simmer	Overall Ave.
Semi-enclosed	6388.22	5736.82	3875.02	5333.36
Anagi-2	10435.39	10044.35	5658.39	8712.71
Turbo charcoal	4185.52	4682.65	1913.21	3593.79
Desha Shakthi	1426.62	1353.25	1058.87	1279.58
Spectra	1876.49	2120.43	1078.98	1691.97

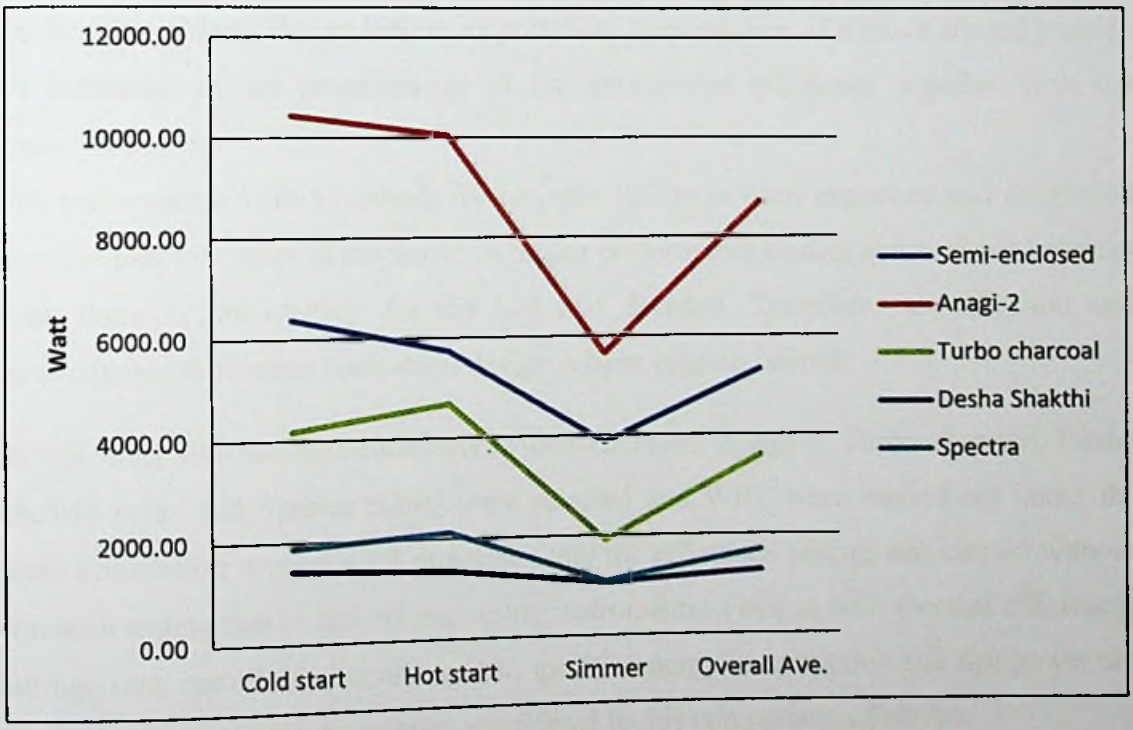

Figure 5.6: Fire power of the stoves in Watts

6 CONCLUTION AND FUTURE WORK

Biomass is the main source of energy in Sri Lanka and major share of it is consumed in cookstoves in domestic sector. Although, ICS dissemination programs have been conducted by the government and NGOs, the most of the cookstoves are inefficient and fuel wood is consumed in traditional way with high moisture content. A continuous decrease can be observed when considering the past biomass consumption data of the country. This is due to low popularity of biomass as a source of energy when compared with fossil fuels. This provides an importance of converting the biomass in to a convenient form like pellatization and etc. There are companies produce pellets out of saw dust for combustion in cookstoves but are in small scale because of the low demand.

The improvement of low emission cookstoves are becoming very important factor due to the health problems due to indoor air pollution. Performance of a stove should provide an indication of the improvement of the combustion efficiency together with the emission factors.

The performance testing methods for biomass ICS have been improved and developed over the past few years in the world. A proper performance testing and analysis have not been done in the country for the last two decades. Therefore, identification and encouragement of better cook stove design is been lagging behind.

In this study five biomass cookstoves (semi-enclosed, Anagi 2, Turbo charcoal, Desha Shakthi pellet and Spectra pellet) were selected and WBT were carried out under the Shell Foundation version 4.2.3 protocol. Only the efficiency testing was carried without emission testing due to lack of measuring instruments. Time to boil, thermal efficiency, burning rate, specific fuel consumption, specific energy consumption and fire power are the performance testing parameters considered in this comparison of stoves.

The time taken to boil water for both hot and cold start (high power state) is higher in Semi-enclosed, Spectra and Desha Shakthi than Turbo charcoal and Anagi-2 stoves. The lower time is very important because stove users may not have an interest in using a stove that heats slowly and lengthen their cooking time.

In reality the cooking process is a combination of cold start, hot start and simmering. Therefore consideration of overall average of parameters provides closer simulation to the real cooking practices. For the overall average of thermal efficiency was higher for Desha Shakthi and Spectra pellet cookstoves and lowest for Anagi-2 and semi-enclosed firewood cookstoves.

Overall specific fuel consumption was lowest for Desha Shakthi and Turbo charcoal cook stove and higher for Anagi-2 and semi-enclosed stoves. Overall specific energy consumption was lower for Desha Shakthi and Spectra cookstoves and higher in Anagi-2 and semi-enclosed stoves.

In conclusion, considering the findings (other than the time to boil) of the study the Desha Shakthi pellet cookstove design is the best among other stoves. The performance of the Spectra stove also shows better performance when compared to other stoves. When compared to other stoves the gap between pot and stove of Spectra stove is high as 35 mm where as others having about 10mm. therefore lot of energy is wasted by radiation can be observed. Therefore performance can be improved further by lowering the gap. And also by improving the insulation around the outer chamber may reduce the heat dissipation by convection. The Turbo charcoal stove shows average performance and less time to boil.

According to the IWA performance matrix these cookstoves can be categorized as follows.

Table 6.1: IWA performance categorization on thermal efficiency of stoves tested.

Semi- enclosed stove	0.15	tier 1
Anagi-2	0.17	tier 1
Turbo charcoal stove	0.26	tier 2
Desha Shakthi	0.59	tier 4
Spectra	0.43	tier 4

Further to categorize the performance of the stoves it is needed to do complete study on the emissions of the stove together with WBT.

6.1 Major Conclusions

- *The time taken to boil water* for both hot and cold start (high power state) is higher in Semi-enclosed, Spectra and Desha Shakthi cookstoves.
- Desha Shakthi and Spectra pellet cookstoves show highest *thermal efficiency* and lowest in Anagi-2 and semi-enclosed firewood cookstoves.
- *Overall specific fuel consumption* was lowest for Desha Shakthi and Turbo charcoal cook stove and higher for Anagi-2 and semi-enclosed stoves.
- *IWA performance categorization on thermal efficiency*, Semi-enclosed stove and Anagi-2 are in tier 1, Turbo charcoal stove is in tier2 and Spectra and Desha Shakthi stoves are in maximum tier 4.

6.2 Future work

- This study on biomass cookstoves was done without consideration of emissions. To categories stove emissions and safety under IWA performance matrix, the emission tests should be done during the WBT. Emission testing while WBT needs more instruments such as CO and PM emission measuring instrument as well a hood to collect emissions. Since this type of comprehensive WBT have not been done for Sri Lankan biomass stoves.
- When comparing Spectra pellet and Desha Shakthi pellets stoves Desha Shakthi stove shows better performance but it forms black soot in the pots than Spectra stove. The gap between the pot and the stove top of Spectra stove is high as 35 mm where as other stoves are having about 10mm. There is a possibility of improving the performance of Spectra stove by introducing design modification to the Spectra stove.
- There are agricultural waste energy sources like paddy husk, sugarcane tops, maize residues, and etc are less popular due to difficulties in collection, transportation due to poor handling and high moisture content. A study can be

carried out to see the possibility of convert these waste in to pellet at the field and use as a fuel other than burning in the field.

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APPENDIX A

DATA COLLECTION SPREAD SHEETSAND OTHER DATA

1 Water Boiling Data Collection Spread Sheets

Water Boiling Test–Desha Shakthi Pellet stove Trial Number: 01

Atm. Temperature :30.5^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	169.91g	202.81g	202.81g
Weight of pot + water	2723.63 g	2748.22 g	2646.41 g
Weight of fuel	350.70g	347.30 g	414.05g
Weigh of kerosene	3 ml	3 ml	3 ml
Initial temperature of water	31.4^{0}C	27.3^{0}C	88.3 ^{0}C
Weight of sand	357.46 g	361.00 g	347.60 g
Weight of un-burned fuel	82.72 g	113.67 g	0 g
Weight of sand + char	410.09 g	408.61 g	440.25 g
Weight of pot+ water after the boiling	258.05 g	2646.19g	2054.06 g
Time taken to boil	21.35 min.	19.54 min.	-
Water temperature Boiling/ end of simmering	99.2 ^{0}C	99.2 ^{0}C	96.8

Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C
1	31.4	28.1	88.0	25	-	-	96.3
2	32.5	29.3	87.5	26	-	-	95.4
3	34.8	30.2	87.2	27	-	-	95.4
4	36.5	31.2	88.7	28	-	-	95.5
5	38.5	32.6	90.2	29	-	-	96.1
6	41.7	35.1	91.0	30	-	-	95.6
7	43.5	37.5	93.7	31	-	-	95.7
8	48.6	40.4	97.7	32	-	-	96.2
9	50.3	45.3	97.8	33	-	-	94.6
10	53.3	49.9	96.8	34	-	-	97.2
11	60.2	54.9	96.0	35	-	-	96.8
12	64.9	60.6	94.3	36	-	-	96.9
13	66.9	65.7	93.0	37	-	-	96.5
14	68.6	71.9	94.2	38	-	-	95.2
15	72.5	77.4	95.4	39	-	-	93.8
16	77.6	83.1	95.8	40	-	-	95.8
17	81.4	87.2	96.0	41	-	-	96.7
18	84.8	91.3	95.9	42	-	-	97.7
19	89.6	95.3	96.4	43	-	-	97.4
20	93.9	-	96.9	44	-	-	97.9
21	98.0	-	96.8	45	-	-	96.8
22	-	-	96.2				
23	-	-	95.8				
24	-	-	95.7				

Water Boiling Test – Desha Shakthi Pellet stove Trial Number: 02

Atm. Temperature :27.3^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.54g	169.91g	169.91g
Weight of pot + water	2638.21g	2554.10 g	2465.29g
Weight of fuel	351.80 g	253.83g	408.62g
Weigh of kerosene	3 ml	3 ml	3 ml
Initial temperature of water	26.0 ^{0}C	25.3 ^{0}C	88.0 ^{0}C
Weight of sand	434.86 g	409.65 g	383.26 g
Weight of un-burned fuel	90.65 g	44.37 g	0 g
Weight of sand + char	486.81 g	454.37g	482.02
Weight of pot+ water after the boiling	2460.87 g	2465.43 g	1826.12 g
Time taken to boil	23.42 min. sec	19.34 min. sec	-
Water temperature Boiling/ end of simmering	99.2 ^{0}C	99.2 ^{0}C	96.7

Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C
1	27.9	28.2	86.5	25	-	-	97.4
2	29.9	29.6	87.5	26	-	-	97.9
3	31.9	31.7	88.1	27	-	-	98.0
4	34.8	33.7	89.3	28	-	-	97.7
5	37.0	36.3	90.1	29	-	-	97.3
6	40.1	39.5	91.3	30	-	-	97.3
7	42.3	41.5	91.4	31	-	-	96.6
8	44.8	43.4	91.5	32	-	-	97.7
9	46.8	46.1	93.5	33	-	-	97.3
10	47.9	49.1	95.2	34	-	-	97.2
11	50.6	52.2	97.0	35	-	-	98.1
12	53.6	56.0	97.3	36	-	-	97.9
13	58.3	59.9	96.3	37	-	-	98.2
14	63.1	70.2	96.3	38	-	-	97.7
15	68.8	76.9	96.2	39	-	-	98.0
16	74.3	83.4	97.3	40	-	-	98.0
17	78.7	90.3	97.3	41	-	-	98.3
18	84.0	96.9	97.3	42	-	-	97.6
19	87.1	98.2	97.5	43	-	-	98.1
20	90.3	-	97.2	44	-	-	97.8
21	93.7	-	95.6	45	-	-	96.7
22	96.5	-	97.0				
23	98.0	-	97.9				
24	-	-	97.2				

Water Boiling Test – Desha Shakthi Pellet stove Trial Number: 03

Atm. Temperature :29.7^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	170.78g	203.17g	203.17g
Weight of pot + water	2580g	2402g	2295g
Weight of fuel	351.62 g	255.52g	521.9g
Weigh of kerosene	4g	4g	3g
Initial temperature of water	26.3 ^{0}C	27.0 ^{0}C	89.5 ^{0}C
Weight of sand	347.1 g	336.31 g	332.87 g
Weight of un-burned fuel	125.75 g	54.61 g	24.3 g
Weight of sand + char	392.87 g	379.59g	445.6g
Weight of pot+ water after the boiling	2469 g	2305 g	1625 g
Time taken to boil	20.15 min.	16.47 min.	-
Water temperature, boiling/ end of simmering	99.0 ^{0}C	99.0 ^{0}C	98.6

Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C
1	27.3	27.7	90.9	25	-	-	97.9
2	27.6	29.6	91.0	26	-	-	97.8
3	27.9	31.7	91.8	27	-	-	96.4
4	28.7	34.2	92.6	28	-	-	97.1
5	29.9	39.3	94.2	29	-	-	98.3
6	30.6	45.3	94.0	30	-	-	97.0
7	33.0	49.1	94.8	31	-	-	97.1
8	34.7	53.6	96.7	32	-	-	95.1
9	37.4	59.7	97.2	33	-	-	97.6
10	41.5	65.0	95.7	34	-	-	97.0
11	46.2	72.0	96.0	35	-	-	97.1
12	53.1	78.9	97.4	36	-	-	96.9
13	59.0	83.0	95.8	37	-	-	97.8
14	66.1	89.0	97.2	38	-	-	97.2
15	71.6	94.5	98.6	39	-	-	96.0
16	80.3	98.2	97.4	40	-	-	97.6
17	86.6	99.0	97.3	41	-	-	97.3
18	91.7	-	98.2	42	-	-	97.3
19	97.5	-	98.2	43	-	-	96.7
20	98.7	-	98.0	44	-	-	97.1
21	99.0	-	96.9	45	-	-	98.6
22	-	-	98.5				
23	-	-	97.6				
24	-	-	96.5				

Water Boiling Test – Spectra Pellet stove Trial Number: 01

Atm. Temperature :29.7^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.21g	170.11g	203.21g
Weight of pot + water	2708.21g	2678.93g	2589.42g
Weight of fuel	380.11 g	351.03g	562.94g
Weigh of kerosene	3 ml	3 ml	3 ml
Initial temperature of water	27.0^{0}C	26.7^{0}C	88.0^{0}C
Weight of sand	374.21 g	0	383.11 g
Weight of un-burned fuel	71.02 g	59.32 g	54.05 g
Weight of sand + char	428.92 g	53.78 g	503.21g
Weight of pot+ water after the boiling	2618.94 g	2590.65 g	1874.89g
Time taken to boil	22.47 min.	17.31 min.	-
Water temperature, boiling/ end of simmering	99.2^{0}C	99.2^{0}C	98.6

Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold start Temp. ^{0}C	Hot start Temp. ^{0}C	Simmer Temp. ^{0}C
1	28.4	31.5	90.9	25	-	-	97.9
2	29.5	33.0	91.0	26	-	-	97.8
3	30.2	35.2	91.8	27	-	-	96.4
4	32.1	37.2	92.6	28	-	-	97.1
5	33.5	40.5	94.2	29	-	-	98.3
6	35.4	44.5	94.0	30	-	-	97.0
7	39.7	49.8	94.8	31	-	-	97.1
8	34.7	54.9	96.7	32	-	-	95.1
9	46.8	62.4	97.2	33	-	-	97.6
10	51.1	67.1	95.7	34	-	-	97.0
11	55.7	74.1	96.0	35	-	-	97.1
12	60.4	79.7	97.4	36	-	-	96.9
13	66.4	85.2	95.8	37	-	-	97.8
14	70.9	90.8	97.2	38	-	-	97.2
15	76.8	96.1	98.6	39	-	-	96.0
16	80.0	98.2	97.4	40	-	-	97.6
17	85.9	99.0	97.3	41	-	-	97.3
18	90.2	-	98.2	42	-	-	97.3
19	94.1	-	98.2	43	-	-	96.7
20	97.0	-	98.0	44	-	-	97.1
21	97.7	-	96.9	45	-	-	98.6
22	98.8	-	98.5				
23	-	-	97.6				
24	-	-	96.5				

Water Boiling Test – Spectra Pellet stove Trial Number: 02

Atm. Temperature :29.5^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.21g	170.11g	170.11g
Weight of pot + water	2706.11g	2672g	2564.12g
Weight of fuel	350.41g	360.11g	488.32g
Weigh of kerosene	3 ml	3 ml	3 ml
Initial temperature of water	28.7^{0}C	27.5^{0}C	88.5^{0}C
Weight of sand	380.21 g	0	331.22 g
Weight of un-burned fuel	71.40 g	101.23 g	14.37 g
Weight of sand + char	421.57 g	45.81g	444.51g
Weight of pot+ water after the boiling	2612.22 g	2565.79g	1850.19 g
Time taken to boil	19.35 min.	16.03 min.	-
Water temperature, boiling/ end of simmering	99.2^{0}C	99.2^{0}C	98.0

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	29.7	29.5	88.2	25	-	-	99.0
2	31.3	31.4	88.2	26	-	-	98.2
3	32.6	33.3	87.6	27	-	-	98.4
4	34.9	36.3	89.9	28	-	-	98.3
5	37.6	40.0	91.6	29	-	-	96.6
6	40.5	44.0	94.2	30	-	-	98.5
7	44.4	49.0	96.5	31	-	-	97.6
8	47.5	53.7	98.1	32	-	-	98.5
9	51.5	60.0	98.0	33	-	-	98.2
10	55.1	66.7	98.5	34	-	-	98.6
11	59.6	72.1	98.5	35	-	-	97.4
12	65.3	78.0	98.0	36	-	-	98.7
13	70.0	82.9	98.6	37	-	-	96.5
14	75.2	88.4	98.0	38	-	-	97.8
15	79.9	94.9	98.6	39	-	-	96.1
16	83.8	99.0	99.0	40	-	-	96.7
17	89.0	-	98.7	41	-	-	98.5
18	94.0	-	97.8	42	-	-	98.5
19	98.2	-	98.8	43	-	-	97.9
20	-	-	98.1	44	-	-	97.8
21	-	-	97.9	45	-	-	98.0
22	-	-	96.3				
23	-	-	97.7				
24	-	-	97.9				

Water Boiling Test – Spectra Pellet stove Trial Number: 03

Atm. Temperature :31.1^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.21g	170.11g	170.11g
Weight of pot + water	2708.72g	2675.32 g	2561.22g
Weight of fuel	350.17g	344.43 g	490.88g
Weigh of kerosene	3 ml	3 ml	3 ml
Initial temperature of water	30.0^{0}C	29.1^{0}C	90.0^{0}C
Weight of sand	350.13 g	353.32 g	316.41 g
Weight of un-burned fuel	82.67 g	94.32 g	60.44g
Weight of sand + char	397.75 g	396.72 g	423.43g
Weight of pot+ water after the boiling	2604.28g	2578.54 g	1883.43 g
Time taken to boil	19.38min.	17.02 min.	-
Water temperature, boiling/ end of simmering	99.2^{0}C	99.2^{0}C	97.3

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	30.9	31.3	90.2	25	-	-	96.7
2	31.6	32.5	89.6	26	-	-	98.4
3	32.8	34.5	89.7	27	-	-	97.9
4	33.6	36.4	88.8	28	-	-	97.8
5	35.3	38.5	89.9	29	-	-	96.6
6	36.2	41.1	91.7	30	-	-	97.4
7	39.7	44.3	93.0	31	-	-	96.8
8	42.9	49.7	95.1	32	-	-	96.2
9	47.2	55.4	97.3	33	-	-	98.9
10	52.0	61.7	98.2	34	-	-	98.4
11	56.7	66.9	98.6	35	-	-	96.6
12	62.1	74.2	98.7	36	-	-	98.1
13	65.2	80.9	98.4	37	-	-	98.5
14	73.3	85.7	97.8	38	-	-	97.1
15	78.6	92.9	98.3	39	-	-	96.4
16	84.3	96.9	97.8	40	-	-	98.2
17	89.5	99.0	97.3	41	-	-	96.8
18	94.4	-	98.5	42	-	-	96.1
19	98.1	-	97.3	43	-	-	97.2
20	-	-	97.9	44	-	-	98.5
21	-	-	97.3	45	-	-	97.3
22	-	-	98.2				
23	-	-	98.0				
24	-	-	96.5				

Water Boiling Test – Charcoal stove Trial Number: 01

Atm. Temperature :29.8^{0}C, Atm. pressure: 767.5 mmHg

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.21g	170.11g	170.11g
Weight of pot + water	2730.28 g	2715.94g	2629.04g
Weight of fuel	177.27g	210.68g	251.86g
Weigh of saw dust	10 g	10 g	10 g
Initial temperature of water	27.5^{0}C	27.5^{0}C	92.3^{0}C
Weight of un-burned fuel	45.21 g	82.79 g	81.02 g
Weight of pot+ water after the boiling	2615.79 g	2629.22 g	1808.32 g
Time taken to boil	14.35 min	12.36 min	-
Water temperature, boiling/ end of simmering	99.2^{0}C	99.2^{0}C	98.9

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	28.9	29.0	91.7	25	-	-	98.8
2	31.0	32.1	95.0	26	-	-	98.5
3	34.5	36.0	98.6	27	-	-	98.5
4	41.4	43.0	98.2	28	-	-	98.4
5	47.9	49.5	98.1	29	-	-	98.2
6	56.4	60.1	98.6	30	-	-	98.4
7	63.6	69.8	98.2	31	-	-	97.1
8	71.3	77.1	98.1	32	-	-	98.2
9	78.1	88.4	98.8	33	-	-	98.0
10	84.0	93.4	98.9	34	-	-	97.7
11	91.1	95.7	98.4	35	-	-	98.2
12	96.2	98.5	98.6	36	-	-	98.8
13	98.3	-	98.1	37	-	-	98.1
14	99.0	-	98.9	38	-	-	98.8
15	-	-	98.0	39	-	-	98.4
16	-	-	96.0	40	-	-	98.0
17	-	-	96.1	41	-	-	98.1
18	-	-	98.3	42	-	-	97.5
19	-	-	98.6	43	-	-	98.9
20	-	-	98.1	44	-	-	97.7
21	-	-	98.0	45	-	-	98.9
22	-	-	98.1				
23	-	-	98.5				
24	-	-	97.8				

Water Boiling Test – Charcoal stove Trial Number: 02

Atm. Temperature :31.3^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.21g	170.11g	170.11g
Weight of pot + water	2707.85g	2670.04 g	2569.42 g
Weight of fuel	177.27g	172.76 g	250.06g
Weigh of saw dust	10 g	10 g	10 g
Initial temperature of water	27.7^{0}C	27.7^{0}C	91.3^{0}C
Weight of un-burned fuel	55.05g	56.03 g	90.01 g
Weight of pot+ water after the boiling	2611.04g	2592.01g	1815.43g
Time taken to boil	14.22 min	13.41 min	-
Water temperature, boiling/ end of simmering	99.2^{0}C	99.2^{0}C	97.1

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	30.3	30.1	92.6	25	-	-	97.4
2	32.6	32.8	97.2	26	-	-	97.5
3	34.7	35.0	98.4	27	-	-	97.3
4	38.0	36.1	98.2	28	-	-	96.8
5	42.8	39.1	98.1	29	-	-	98.5
6	49.4	45.0	98.2	30	-	-	97.7
7	56.9	52.7	98.4	31	-	-	97.5
8	67.8	62.7	98.7	32	-	-	97.5
9	76.3	72.3	98.0	33	-	-	98.0
10	84.0	80.4	98.4	34	-	-	97.3
11	90.5	86.8	98.6	35	-	-	97.5
12	94.8	94.4	98.5	36	-	-	97.3
13	98.4	98.5	98.2	37	-	-	97.0
14	98.9	-	97.8	38	-	-	98.6
15	-	-	98.8	39	-	-	98.4
16	-	-	98.1	40	-	-	97.6
17	-	-	98.6	41	-	-	97.6
18	-	-	98.2	42	-	-	97.5
19	-	-	98.3	43	-	-	97.5
20	-	-	97.8	44	-	-	97.1
21	-	-	98.0	45	-	-	97.1
22	-	-	97.1				
23	-	-	97.0				
24	-	-	96.9				

Water Boiling Test – Charcoal stove Trial Number: 03

Atm. Temperature :29.5^{0}C, Atm. pressure: 767.5 mmHg.

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.21g	170.11g	170.11g
Weight of pot + water	2708.43g	2679.23g	2585.03g
Weight of fuel	192.87g	181.57g	258.96g
Weigh of saw dust	10 g	10 g	10 g
Initial temperature of water	27.5^{0}C	27.7^{0}C	88.5^{0}C
Weight of un-burned fuel	73.13 g	57.43 g	70.10 g
Weight of pot+ water after the boiling	2631.21 g	2603.91g	1874.94g
Time taken to boil	16.07 min	12.57 min	-
Water temperature, boiling/ end of simmering	99.2^{0}C	99.2^{0}C	98.4

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	28.9	30.1	89.5	25	-	-	97.7
2	30.9	32.3	90.4	26	-	-	97.2
3	32.6	34.3	90.8	27	-	-	98.6
4	35.6	36.2	94.0	28	-	-	98.1
5	37.8	41.2	97.9	29	-	-	98.2
6	41.4	49.2	98.0	30	-	-	98.0
7	46.3	57.8	97.5	31	-	-	97.4
8	52.2	67.0	98.2	32	-	-	98.5
9	61.2	77.1	98.2	33	-	-	97.5
10	71.4	84.1	97.1	34	-	-	97.4
11	80.4	92.6	98.1	35	-	-	97.5
12	87.6	97.3	97.3	36	-	-	97.7
13	91.8	-	98.2	37	-	-	97.1
14	97.6	-	97.1	38	-	-	98.1
15	98.8	-	98.6	39	-	-	98.0
16	99.1	-	98.1	40	-	-	97.9
17	-	-	98.0	41	-	-	98.1
18	-	-	98.0	42	-	-	98.3
19	-	-	97.8	43	-	-	97.9
20	-	-	98.2	44	-	-	98.1
21	-	-	97.4	45	-	-	98.4
22	-	-	98.1				
23	-	-	97.9				
24	-	-	98.0				

Water Boiling Test – Anagi 2 stove Trial Number: 01

Atm. Temperature :29.7^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot #1	203.20g	203.20 g	203.20g
Weight of pot #1 + water	2715.32g	2717.96 g	2564.71g
Weight of empty pot #2	170.11g	170.11 g	170.11g
Weight of pot #2 + water	2676.68g	2695.45 g	2697.38g
Weight of fuel	1462.13g	1758.33g	1386.16g
Weigh of kerosene + coconut leaves	10g	10 g	10 g
Initial temperature of water at pot #1	29.3 ^{0}C	29.0 ^{0}C	79.9 ^{0}C
Initial temperature of water at pot #2	29.0 ^{0}C	29.0 ^{0}C	65.0 ^{0}C
Weight of un-burned fuel	852.19 g	1241.11 g	396.38 g
Weight of char	55.24 g	55.24 g	134.22 g
Weight of pot#1 + water after the boiling	2454.42 g	2570.57 g	1572.32 g
Weight of pot #2 + water after the test	2652.94 g	2700.16 g	2468.29 g
Time taken to boil	14.35 min	13.12 min	
Water temperature, boiling/ end of simmering	99.2 ^{0}C	99.2^{0}C	98.4
Final water temperature of water at pot#2	63.5 ^{0}C	65.4^{0}C	76.1 ^{0}C

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	33.5	36.5	89.5	25	-	-	97.5
2	35.5	43.2	95.2	26	-	-	98.0
3	38.6	48.2	96.8	27	-	-	98.4
4	44.5	53.8	97.3	28	-	-	98.3
5	48.2	59.7	97.9	29	-	-	98.2
6	56.5	65.8	98.1	30	-	-	98.4
7	66.4	71.6	97.9	31	-	-	97.9
8	76.8	77.3	98.4	32	-	-	98.3
9	85.2	82.1	98.3	33	-	-	98.1
10	90.2	87.7	97.8	34	-	-	97.7
11	94.4	92.6	98.4	35	-	-	97.7
12	95.5	96.4	97.9	36	-	-	97.9
13	96.5	98.3	98.6	37	-	-	98.1
14	98.9	-	98.9	38	-	-	98.1
15	-	-	98.6	39	-	-	97.6
16	-	-	98.2	40	-	-	97.0
17	-	-	97.8	41	-	-	94.9
18	-	-	97.7	42	-	-	98.4
19	-	-	97.8	43	-	-	98.1
20	-	-	98.1	44	-	-	98.6
21	-	-	97.8	45	-	-	98.4
22	-	-	97.6				
23	-	-	98.2				
24	-	-	97.5				

Water Boiling Test – Anagi 2 stove Trial Number: 02

Atm. Temperature :29.5^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot #1	203.21g	203.21g	203.21g
Weight of pot #1 + water	2705.76g	2710.21g	2570.34g
Weight of empty pot #2	170.11g	170.11 g	170.11g
Weight of pot #2 + water	2670.11g	2686.29 g	2613.76g
Weight of fuel	1004.87 g	1020.22 g	1410.43g
Weigh of kerosene + coconut leaves	10g	10 g	10 g
Initial temperature of water at pot #1	29.1^{0}C	29.1^{0}C	85.7^{0}C
Initial temperature of water at pot #2	29.1^{0}C	29.1^{0}C	57.0 ^{0}C
Weight of un-burned fuel	540.47 g	605.67 g	500.39 g
Weight of char	43.11 g	43.11 g	82.23 g
Weight of pot#1 + water after the boiling	2592.24 g	2610.45 g	1610.05 g
Weight of pot #2 + water after the test	2662.56 g	2615.02 g	2482.16 g
Time taken to boil	12.30 min	11.59 min	
Water temperature, boiling/ end of simmering	99.2 ^{0}C	99.2^{0}C	98.2
Final water temperature of water at pot#2	52.5^{0}C	57.5 ^{0}C	72.0^{0}C

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	40.4	32.2	94.1	25	-	-	98.2
2	40.6	37.2	95.1	26	-	-	98.1
3	42.1	42.4	98.8	27	-	-	98.4
4	49.1	49.8	98.8	28	-	-	97.9
5	62.0	55.3	98.8	29	-	-	97.8
6	69.7	63.0	98.2	30	-	-	97.7
7	72.0	70.2	98.7	31	-	-	98.0
8	75.3	77.1	97.6	32	-	-	97.9
9	83.3	84.4	97.9	33	-	-	97.5
10	88.3	91.0	98.3	34	-	-	97.9
11	94.4	96.2	98.2	35	-	-	97.3
12	98.5	-	98.0	36	-	-	97.8
13	-	-	98.6	37	-	-	98.3
14	-	-	98.2	38	-	-	97.9
15	-	-	98.0	39	-	-	97.8
16	-	-	98.9	40	-	-	97.6
17	-	-	98.2	41	-	-	98.1
18	-	-	97.2	42	-	-	97.9
19	-	-	98.0	43	-	-	98.3
20	-	-	98.2	44	-	-	98.4
21	-	-	98.0	45	-	-	98.2
22	-	-	98.1				
23	-	-	97.9				
24	-	-	97.5				

Water Boiling Test – Anagi 2 stove Trial Number: 03

Atm. Temperature :30.5^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot #1	203.21g	203.21 g	203.21g
Weight of pot #1 + water	2707.94g	2702.76g	2597.54g
Weight of empty pot #2	170.11g	170.11 g	170.11g
Weight of pot #2 + water	2674.06g	2675.4 g	2666.76g
Weight of fuel	1404.15 g	1447.85 g	1503.23g
Weigh of kerosene + coconut leaves	10g	10 g	10 g
Initial temperature of water at pot #1	30.1 ^{0}C	30.1 ^{0}C	85.9^{0}C
Initial temperature of water at pot #2	30.1 ^{0}C	30.1 ^{0}C	62.7^{0}C
Weight of un-burned fuel	874.23 g	954.98 g	580.08 g
Weight of char	68.17 g	68.17 g	79.87 g
Weight of pot#1 + water after the boiling	2678.42 g	2603.57 g	1652.39 g
Weight of pot #2 + water after the test	2601.87 g	2669.36 g	2516.21 g
Time taken to boil	13.43 min	12.04 min	
Water temperature, boiling/ end of simmering	99.2 ^{0}C	99.2^{0}C	98.8
Final water temperature of water at pot#2	58.1^{0}C	63.2^{0}C	74.2^{0}C

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	34.5	34.8	86.2	25	-	-	98.9
2	36.6	36.9	88.5	26	-	-	98.6
3	38.9	41.5	90.2	27	-	-	98.5
4	46.1	46.4	94.9	28	-	-	98.1
5	57.4	57.9	98.1	29	-	-	97.9
6	69.4	69.5	98.4	30	-	-	97.6
7	70.7	71.8	98.6	31	-	-	98.0
8	74.5	76.6	97.9	32	-	-	98.2
9	78.9	82.1	98.2	33	-	-	98.5
10	84.8	88.6	98.1	34	-	-	97.9
11	90.4	96.5	98.5	35	-	-	97.2
12	97.5	98.9	98.1	36	-	-	97.7
13	98.6	-	98.0	37	-	-	98.1
14	-	-	97.9	38	-	-	97.8
15	-	-	98.2	39	-	-	97.5
16	-	-	98.9	40	-	-	97.6
17	-	-	98.1	41	-	-	98.2
18	-	-	97.9	42	-	-	97.8
19	-	-	97.5	43	-	-	98.1
20	-	-	98.1	44	-	-	98.6
21	-	-	98.6	45	-	-	98.8
22	-	-	98.9				
23	-	-	98.3				
24	-	-	98.7				

Water Boiling Test – Semi-enclosed stove Trial Number: 01

Atm. Temperature :30.1^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.52g	170.11g	170.52g
Weight of pot + water	2748.21g	2672.75g	2508.96g
Weight of fuel	1088.11g	1022.46g	1079.42g
Weigh of kerosene + coconut leaves	10g	10 g	10 g
Initial temperature of water at pot	27.6^{0}C	27.6^{0}C	87.5^{0}C
Weight of un-burned fuel	489.19 g	454.07g	308.73 g
Weight of char	80.21 g	80.21 g	93.42 g
Weight of pot+ water after the boiling	2639.03 g	2540.51 g	1603.46g
Time taken to boil	16.23 min	18.12 min	
Water temperature, boiling/ end of simmering	99.2 ^{0}C	99.2^{0}C	98.9

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	32.4	31.2	87.5	25	-	-	98.4
2	34.5	33.2	86.2	26	-	-	98.6
3	37.4	35.1	87.8	27	-	-	98.4
4	43.3	40.6	89.3	28	-	-	98.2
5	47.1	43.5	92.9	29	-	-	97.1
6	54.3	47.3	96.1	30	-	-	98.2
7	64.2	50.1	97.9	31	-	-	98.9
8	75.9	52.9	98.3	32	-	-	98.3
9	84.2	56.2	98.9	33	-	-	97.1
10	89.2	64.7	97.9	34	-	-	97.6
11	93.1	68.6	98.2	35	-	-	97.9
12	94.4	74.3	98.2	36	-	-	98.1
13	95.5	80.5	98.5	37	-	-	98.3
14	97.9	85.8	98.9	38	-	-	96.5
15	98.4	89.1	97.9	39	-	-	97.4
16	99.0	90.4	98.7	40	-	-	97.1
17	-	98.3	98.8	41	-	-	98.0
18	-	99.1	96.9	42	-	-	98.4
19	-	-	97.8	43	-	-	98.3
20	-	-	98.3	44	-	-	98.6
21	-	-	97.6	45	-	-	98.9
22	-	-	97.9				
23	-	-	98.1				
24	-	-	98.5				

Water Boiling Test – Semi-enclosed stove Trial Number: 02

Atm. Temperature :31.0^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.52g	170.11 g	170.11g
Weight of pot + water	2711.32g	2672.31 g	2565.78 g
Weight of fuel	1128.54g	1097.32g	1023.43g
Weigh of kerosene + coconut leaves	10g	10 g	10 g
Initial temperature of water at pot	27.8 ^{0}C	27.5 ^{0}C	91.5 ^{0}C
Weight of un-burned fuel	512.32 g	556.54g	116.34 g
Weight of char	83.27 g	83.27g	103.76 g
Weight of pot+ water after the boiling	2650.54 g	2569.23 g	1780.22g
Time taken to boil	18.22 min	18.08 min	
Water temperature, boiling/ end of simmering	99.2 ^{0}C	99.2^{0}C	98.9

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	31.3	33.1	91.8	25	-	-	98.4
2	33.1	33.2	93.9	26	-	-	98.6
3	35.2	34.3	96.9	27	-	-	98.4
4	41.8	39.5	97.2	28	-	-	98.2
5	44.6	42.4	98.2	29	-	-	98.5
6	48.2	46.2	96.1	30	-	-	98.0
7	54.8	51.1	97.9	31	-	-	98.6
8	64.8	53.7	98.3	32	-	-	98.0
9	78.3	56.2	98.9	33	-	-	98.6
10	83.2	63.9	97.9	34	-	-	99.0
11	92.3	67.8	98.2	35	-	-	98.3
12	93.4	73.2	98.2	36	-	-	98.9
13	95.0	79.4	98.5	37	-	-	97.9
14	96.9	84.7	98.9	38	-	-	98.1
15	97.1	88.1	97.9	39	-	-	97.4
16	97.9	90.6	98.7	40	-	-	97.1
17	98.4	98.7	98.8	41	-	-	98.0
18	99.1	99.0	98.5	42	-	-	98.4
19	-	-	97.8	43	-	-	98.3
20	-	-	98.3	44	-	-	98.6
21	-	-	97.6	45	-	-	98.9
22	-	-	97.9				
23	-	-	98.1				
24	-	-	98.5				

Water Boiling Test – Semi-enclosed stove Trial Number: 03

Atm. Temperature :29.5^{0}C, Atm. pressure: 767.5 mmHg,

	Cold start	Hot start	Simmering (45 mints)
Weight of empty pot	203.52g	170.11 g	170.11g
Weight of pot + water	2709.43g	2608.87 g	2453.26 g
Weight of fuel	1189.91g	1097.68g	1275.12g
Weigh of kerosene + coconut leaves	10g	10 g	10 g
Initial temperature of water at pot	26.3 ^{0}C	27.0 ^{0}C	89.5 ^{0}C
Weight of un-burned fuel	540.28 g	456.19g	298.1 g
Weight of char	98.47 g	98.47g	106.65 g
Weight of pot+ water after the boiling	2598.08 g	2455.61 g	1643.32g
Time taken to boil	19.56 min	18.57 min	
Water temperature, boiling/ end of simmering	99.2 ^{0}C	99.2^{0}C	98.3

Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C	Time (min)	Cold Temp. ^{0}C	Hot Temp. ^{0}C	Simmer Temp. ^{0}C
1	30.2	32.7	90.8	25	-	-	98.0
2	32.5	33.6	92.4	26	-	-	98.1
3	34.1	34.8	94.8	27	-	-	98.4
4	40.8	39.4	96.8	28	-	-	98.6
5	43.5	41.2	97.9	29	-	-	98.4
6	47.1	45.3	98.1	30	-	-	98.6
7	51.5	51.7	98.9	31	-	-	98.8
8	63.8	52.6	98.3	32	-	-	98.0
9	76.5	55.5	97.9	33	-	-	97.6
10	78.2	62.8	97.8	34	-	-	98.8
11	86.3	66.9	98.1	35	-	-	98.2
12	89.4	74.3	98.2	36	-	-	98.5
13	93.5	78.1	98.9	37	-	-	97.2
14	94.9	84.3	98.8	38	-	-	98.3
15	96.9	88.6	98.9	39	-	-	98.5
16	97.9	90.7	97.7	40	-	-	98.1
17	98.4	98.7	97.5	41	-	-	98.3
18	98.9	99.0	98.2	42	-	-	98.2
19	99.0	-	98.6	43	-	-	98.5
20	-	-	98.5	44	-	-	98.5
21	-	-	98.6	45	-	-	98.3
22	-	-	98.0				
23	-	-	97.8				
24	-	-	97.5				

2 Moisture Content

2.1 Pellet

The moisture content of pellets was tested using standard oven test and the result is 11.1 % wet basis (Appendix D)

2.2 Rubber Wood

Moisture content of rubber wood was tested by ASTM 873 using standard oven test and the result is 14.5 % (Appendix D)

2.3 Coconut shell Charcoal

Moisture content of rubber wood was tested by BSTM 1860 using standard oven test and the result is 6.24 % (Appendix D)

APPENDIX B

CALCULATION RESULTS

Semi-enclosed Cookstove - Water Boiling Test Results

	units	Trial 1			Trial 2			Trial 3		
		cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Weight of empty pot	g	203.52	170.11	170.11	203.52	170.11	170.11	203.52	170.11	170.11
Weight of pot + water	g	2748.21	2672.75	2508.96	2711.32	2672.31	2565.78	2709.43	2608.87	2453.26
Weight of fuel	g	1088.11	1022.46	1079.42	1128.54	1097.32	1023.43	1189.91	1097.68	1275.12
Weight of kerosene +coconut leaves	g	10	10	10	10	10	10	10	10	10
Initial temperature of water	^{0}C	27.6	27.6	87.5	27.8	27.5	91.5	26.3	27	89.5
Weight of un-burned fuel	g	489.19	454.07	308.73	512.32	556.54	116.34	540.28	456.19	298.1
Weight of char	g	80.21	80.21	93.42	83.27	83.27	103.76	98.47	98.47	106.65
Weight of pot+ water after boiling	g	2639.03	2540.51	1603.46	2650.54	2569.23	1780.22	2598.08	2455.61	1643.32
Time taken to boil	min.sec	16.23	18.12		18.22	18.08		19.56	18.57	
Water temperature, boiling/ end of simmering	^{0}C	99.2	99.2	98.9	99.2	99.2	98.9	99.2	99.2	98.3
Ambient Temperature (Ta)	^{0}C	30.1	30.1	30.1	31	31	31	29.5	29.5	29.5

LHV_{fuel}	Low heating value of Fuel wood (rubber)	kJ/kg	18244.4
MC_{wet}	Wet basis moisture content		0.145
LHV_{char}	Low heating value of char	kJ/kg	29,773
T_b	Water boiling temperature	^{0}C	99.2

		units	Trial 1			Trial 2			Trial 3		
			cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	16.23	18.12	45	18.22	18.08	45	19.56	18.57	45
wv	Mass of water vaporized	g	109.18	132.24	905.5	60.78	103.08	785.56	111.35	153.26	809.94
f_m	Fuel consumed (moist)	g	598.92	568.39	770.69	616.22	540.78	907.09	649.63	641.49	977.02
ΔC	Net changed in char during the test	g	80.21	80.21	93.42	83.27	83.27	103.76	98.47	98.47	106.65
W_r	Effective mass of water boiled	g	2435.51	2370.4	1433.35	2447.02	2399.12	1610.11	2394.56	2285.5	1473.21
f_d	Equivalent dry fuel consumed	g	369.08	343.60	490.92	378.53	315.55	587.91	381.62	374.82	641.57
Δt^T	Temperature corrected time to boil	min	17.00	18.98		19.14	18.91		20.12	19.29	
h	Thermal efficiency		0.150	0.167	0.239	0.128	0.171	0.171	0.146	0.158	0.162
r_b	Burning rate	g/min	22.74	18.96	10.91	20.78	17.45	13.06	19.51	20.18	14.26
SC	Specific fuel consumption		0.152	0.145	0.342	0.155	0.132	0.365	0.159	0.164	0.435
SC^T	Temp. corrected specific fuel consumption		0.159	0.152		0.162	0.138		0.164	0.170	
SE^T	Temp. corrected specific energy consumption	kJ/kg	2.896	2.770	6.249	2.965	2.510	6.662	2.991	3.108	7.945
FP	Fire power	W	6915	5766	3317	6317	5307	3973	5932	6137	4335

			Average				Standard deviation		
		units	cold start	hot start	simmer	overall test average	cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	18.00	18.26	45.00	18.13	1.68	0.27	
wv	Mass of water vaporized	g	93.77	129.53	833.67		28.59	25.20	63.39
f_m	Fuel consumed (moist)	g	621.59	583.55	884.93		25.78	52.04	104.93
ΔC	Net changed in char during the test	g	87.32	87.32	101.28		9.78	9.78	6.96
W_r	Effective mass of water boiled	g	2425.70	2351.67	1505.56		27.57	59.08	92.71
f_d	Equivalent dry fuel consumed	g	376.41	344.66	573.47		6.53	29.65	76.36
Δt^T	Temperature corrected time to boil	min	18.75	19.06		18.91	1.60	0.20	
h	Thermal efficiency		0.14	0.17	0.19	0.17	0.01	0.01	0.04
r_b	Burning rate	g/min	21.01	18.87	12.74	17.54	1.63	1.37	1.70
SC	Specific fuel consumption		0.16	0.15	0.38	0.23	0.004	0.016	0.05
SC^T	Temperature corrected specific fuel consumption		0.16	0.15		0.16	0.003	0.016	
SE^T	Temperature corrected specific energy consumption	kJ/kg	2.95	2.80	6.95	4.23	0.05	0.30	0.88
FP	Fire power	W	6388.22	5736.82	3875.02	5333.36	495.01	415.98	515.97

Anagi 2 Cookstove - Water Boiling Test Results

	units	Trial 1			Trial 2			Trial 3		
		cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Weight of empty pot #1	g	203.20	203.20	203.20	203.21	203.21	203.21	203.21	203.21	203.21
Weight of pot#1 + water	g	2715.32	2717.96	2564.71	2705.76	2710.21	2570.34	2707.94	2702.76	2597.54
Weight of pot#2	g	170.11	170.11	170.11	170.11	170.11	170.11	170.11	170.11	170.11
Weigh of pot#2+water	g	2676.68	2695.45	2697.38	2670.11	2686.29	2613.76	2674.06	2675.40	2666.76
Weight of fuel	g	1462.13	1758.33	1386.16	1004.87	1020.22	1410.43	1404.15	1447.85	1503.23
Weigh of kerosene +coconut leaves	g	10	10	10	10	10	10	10	10	10
Initial temperature of water of pot#1	^{0}C	29.3	29.0	79.9	29.1	29.1	85.7	30.1	30.1	85.9
Initial temperature of water of pot#2	^{0}C	29.0	29.0	65.0	29.1	29.1	57.0	30.1	30.1	62.7
Weight of un-burned fuel	g	852.19	1241.11	396.38	540.47	605.67	500.39	874.23	954.98	580.08
Weight of char	g	55.24	55.24	134.22	43.11	43.11	82.23	68.17	68.17	79.87
Weight of pot#1+ water after the boiling	g	2454.42	2570.57	1572.32	2592.24	2610.45	1610.05	2678.42	2603.57	1652.39
Weight of pot#2 +water end of the test	g	2652.94	2700.16	2468.29	2662.56	2615.02	2482.16	2601.87	2669.36	2516.21
Time taken to boil	min.,sec	14.35	13.12		12.30	11.59		13.43	12.04	
Water temperature, boiling/ end of simmering	^{0}C	99.2	99.2	98.4	99.2	99.2	98.2	99.2	99.2	98.8
final water temperature of water at pot #2	^{0}C	63.5	65.4	76.1	52.5	57.5	72.0	58.1	63.2	74.2
Ambient temperature (Ta)		29.7	29.7	29.7	29.5	29.5	29.5	30.5	30.5	30.5

LHV_{fuel}	Low heating value of Fuel wood (rubber)	kJ/kg	18,244
MC_{wet}	Wet basis moisture content		0.04
LHV_{char}	Low heating value of char	kJ/kg	29,773
T_b	Water boiling temperature	^{0}C	99.2

			Trial 1			Trial 2			Trial 3		
		units	cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	14.58	13.2	45	12.5	11.98	45	13.72	12.07	45
wv	Mass of water vaporized	g	284.64	142.68	992.39	89.78	104.47	960.29	101.71	105.23	945.15
f_m	Fuel consumed (moist)	g	609.94	517.22	989.78	464.4	414.55	910.04	529.92	492.87	923.15
ΔC	Net changed in char during the test	g	26.24	26.24	69.22	14.01	14.01	25.23	38.07	38.07	17.17
W_r	Effective mass of water boiled	g	3460.80	3679.25	1369.12	3221.03	3397.76	1406.84	3460.58	3597.54	1449.18
f_d	Equivalent dry fuel consumed	g	539.32	450.83	831.71	420.37	372.79	827.39	443.64	408.28	853.06
Δt^T	Temperature corrected time to boil	min	15.64	14.10		13.37	12.82		14.89	13.10	
h	Thermal efficiency		0.177	0.176	0.157	0.154	0.187	0.150	0.154	0.176	0.144
r_b	Burning rate	g/min	36.99	34.15	18.48	33.63	31.12	18.39	32.34	33.83	18.96
SC	Specific fuel consumption		0.156	0.123	0.607	0.131	0.110	0.588	0.128	0.113	0.589
SC^T	Temp. corrected specific fuel consumption		0.167	0.131		0.140	0.117		0.139	0.123	
SE^T	Temp. corrected specific energy consumption	kJ/kg	3.051	2.388	11.083	2.547	2.142	10.730	2.539	2.247	10.740
FP	Fire power	W	11248	10385	5620	10226	9462	5591	9832	10286	5764

		units	Average			overall test average	Standard deviation		
			cold start	hot start	simmer		cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	13.60	12.42	45.00	13.01	1.05	0.68	0.00
wv	Mass of water vaporized	g	158.71	117.46	965.94		109.22	21.84	24.12
f_m	Fuel consumed (moist)	g	534.75	474.88	940.99		72.89	53.65	42.76
ΔC	Net changed in char during the test	g	26.11	26.11	37.21		12.03	12.03	28.02
W_r	Effective mass of water boiled	g	3380.81	3558.18	1408.38		138.37	144.81	40.05
f_d	Equivalent dry fuel consumed	g	467.78	410.63	837.39		63.04	39.07	13.74
Δt^T	Temperature corrected time to boil	min	14.64	13.34		13.99	1.16	0.68	
h	Thermal efficiency		0.16	0.18	0.15	0.16	0.01	0.01	0.01
r_b	Burning rate	g/min	34.32	33.03	18.61	28.65	2.40	1.67	0.31
SC	Specific fuel consumption		0.14	0.12	0.59	0.28	0.02	0.01	0.01
SC^T	Temperature corrected specific fuel consumption		0.15	0.12		0.14	0.02	0.01	
SE^T	Temperature corrected specific energy consumption	kJ/kg	2.71	2.26	10.85	5.27	0.29	0.12	0.20
FP	Fire power	W	10435.39	10044.35	5658.39	8712.71	730.61	506.62	92.86

Turbo Charcoal Cookstove - Water Boiling Test Results

	Units	Trial 1			Trial 2			Trial 3		
		cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Weight of empty pot	g	203.21	170.11	170.11	203.21	170.11	170.11	203.21	170.11	170.11
Weight of pot + water	g	2730.28	2715.94	2629.04	2707.85	2670.04	2569.42	2708.43	2679.23	2585.03
Weight of fuel	g	177.27	210.68	251.86	181.25	172.76	250.06	192.87	181.57	258.96
Weigh of saw dust	g	10	10	10	10	10	10	10	10	10
Initial temperature of water	^{0}C	27.5	27.5	92.3	27.7	27.7	91.3	27.5	27.5	88.5
Weight of sand	g	0	0	0	0	0	0	0	0	0
Weight of un-burned fuel	g	45.21	82.79	81.02	55.05	56.03	90.01	73.13	57.43	70.1
Weight of char	g	0	0	0	0	0	0	0	0	0
Weight of pot+ water after the boiling	g	2615.79	2629.22	1808.32	2611.04	2592.01	1815.43	2631.21	2603.91	1874.94
Time taken to boil	min. sec	14.35	12.36		14.22	13.41		16.07	12.57	
Water temperature, boiling/ end of simmering	^{0}C	99.2	99.2	98.9	99.2	99.2	97.1	99.2	99.2	98.4
Ambient temperature (Ta)	^{0}C	29.8	29.8	29.8	31.3	31.3	31.3	29.5	29.5	29.5

LHV_{fuel}	Low heating value of fuel charcoal	kJ/kg	31,165
MC_{wet}	Wet basis moisture content		0.04
T_b	water boiling temperature	^{0}C	99.2

			Trial 1			Trial 2			Trial 3		
		units	cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	14.58	12.6	45	14.37	13.68	45	16.12	12.95	45
wv	Mass of water vaporized	g	114.49	86.72	820.72	96.81	78.03	753.99	77.22	75.32	710.09
f_m	Fuel consumed (moist)	g	132.06	127.89	170.84	126.2	116.73	160.05	119.74	124.14	188.86
W_r	Effective mass of water boiled	g	2412.58	2459.11	1638.21	2407.83	2421.9	1645.32	2428	2433.8	1704.83
f_d	Equivalent dry fuel consumed	g	126.35	122.36	163.45	120.74	111.68	153.13	114.56	118.77	180.69
Δt^T	Temperature corrected time to boil	min	15.25	13.18		15.07	14.35		16.86	13.55	
h	Thermal efficiency		0.258	0.252	0.375	0.257	0.266	0.367	0.259	0.249	0.300
r_b	Burning rate	g/min	8.67	9.71	3.63	8.40	8.16	3.40	7.11	9.17	4.02
SC	Specific fuel consumption		0.052	0.050	0.100	0.050	0.046	0.093	0.047	0.049	0.106
SC^T	Temperature corrected specific fuel consumption		0.055	0.052		0.053	0.048		0.049	0.051	
SE^T	Temperature corrected specific energy consumption	kJ/kg	1.707	1.622	3.109	1.639	1.507	2.900	1.538	1.591	3.303
FP	Fire power	W	4501	5044	1887	4364	4240	1767	3691	4764	2086

			Average			Overall test average	Standard deviation		
		units	cold start	hot start	simmer		cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	15.02	13.08	45.00	14.05	0.96	0.55	
wv	Mass of water vaporized	g	96.17	80.02	761.60		18.64	5.96	55.71
f_m	Fuel consumed (moist)	g	126.00	122.92	173.25		6.16	5.68	14.56
W_r	Effective mass of water boiled	g	2416.14	2438.27	1662.79		10.54	19.00	36.58
f_d	Equivalent dry fuel consumed	g	120.55	117.60	165.75		5.90	5.43	13.92
Δt^T	Temperature corrected time to boil	min	15.73	13.69		14.71	0.99	0.60	
h	Thermal efficiency		0.26	0.26	0.35	0.29	0.001	0.01	0.04
r_b	Burning rate	g/min	8.06	9.02	3.68	6.92	0.83	0.79	0.31
SC	Specific fuel consumption		0.05	0.05	0.10	0.07	0.003	0.002	0.01
SC^T	Temperature corrected specific fuel consumption		0.05	0.05		0.05	0.003	0.002	
SE^T	Temperature corrected specific energy consumption	kJ/kg	1.63	1.57	3.10	2.10	0.09	0.06	0.20
FP	Fire power	W	4185.52	4682.65	1913.21	3593.79	433.47	407.86	160.73

Desha Shakthi Pellet Cookstove - Water Boiling Test Results

	units	Trial 1			Trial 2			Trial 3		
		cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Weight of empty pot	g	169.91	202.81	202.81	203.54	169.91	169.91	170.78	203.17	203.17
Weight of pot + water	g	2723.63	2748.22	2646.41	2638.21	2554.10	2465.29	2580.34	2402.27	2295.36
Weight of fuel	g	350.70	347.30	414.05	351.80	253.83	408.62	351.62	255.52	521.90
kerosene (ml)	ml	3	3	3	3	3	3	3	3	3
Initial temperature of water	^{0}C	31.4	27.3	88.3	26	25.3	88	26.3	27	89.5
Weight of sand	g	357.46	361	347.6	434.86	409.65	383.26	347.1	336.31	332.87
Weight of un-burned fuel	g	82.72	113.67	0	90.65	44.37	0	125.75	54.61	24.3
Weight of sand + char	g	410.09	408.6	440.25	486.81	454.37	482.02	392.87	379.59	445.6
Weight of pot+ water after the boiling	g	2581.05	2646.19	2054.06	2460.87	2465.43	1826.12	2468.34	2305.61	1625.32
Time taken to boil	min.sec	21.35	19.54		23.42	19.34		20.15	16.47	
Water temperature, boiling/ end of simmering	^{0}C	99.2	99.2	96.8	99.2	99.2	96.7	99.2	99.2	98.6
Ambient temperature (Ta)	^{0}C	30.5	30.5	30.5	27.3	27.3	27.3	29.7	29.7	29.7

LHV_{fuel}	Low heating value of fuel pellet	kJ/kg	15340.7
MC_{wet}	Wet basis moisture content		0.111
LHV_{char}	Low heating value of char	kJ/kg	29,773
T_b	water boiling temperature	^{0}C	99.2

		units	Trial 1			Trial 2			Trial 3		
			cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	21.58	19.90	45	23.7	19.57	45	20.25	16.78	45
wv	Mass of water vaporized	g	142.58	102.03	592.35	177.34	88.67	639.17	112	96.66	670.04
f_m	Fuel consumed (moist)	g	267.98	233.63	414.05	261.15	209.46	408.62	225.87	200.91	497.6
ΔC	Net changed in char during the test	g	52.63	47.6	92.65	51.95	44.72	98.76	45.77	43.28	112.73
W_r	Effective mass of water boiled/simmered	g	2411.14	2443.38	1851.25	2257.33	2295.52	1656.21	2297.56	2102.44	1422.15
f_d	Equivalent dry fuel consumed	g	131.16	111.01	180.65	126.51	95.54	164.03	107.81	90.91	214.41
Δt^T	Temperature corrected time to boil	min	23.87	20.76		24.28	19.86		20.83	17.43	
h	Thermal efficiency		0.520	0.585	0.511	0.591	0.640	0.603	0.598	0.633	0.481
r_b	Burning rate	g/min	6.08	5.58	4.01	5.34	4.88	3.65	5.32	5.42	4.76
SC	Specific fuel consumption		0.054	0.045	0.098	0.056	0.042	0.099	0.047	0.043	0.151
SC^T	Temperature corrected specific fuel consumption		0.060	0.047		0.057	0.042		0.048	0.045	
SE^T	Temperature corrected specific energy consumption	kJ/kg	0.923	0.727	1.497	0.881	0.648	1.519	0.741	0.689	2.313
FP	Fire power	W	1554	1426	1026	1365	1248	932	1361	1385	1218

		units	Average			Overall test average	Standard deviation		
			cold start	hot start	simmer		cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	21.84	18.75	45.00	20.30	1.74	1.71	
wv	Mass of water vaporized	g	143.97	95.79	633.85		32.69	6.72	39.12
f_m	Fuel consumed (moist)	g	251.67	214.67	440.09		22.60	16.97	49.88
ΔC	Net changed in char during the test	g	50.12	45.20	101.38		3.78	2.20	10.29
W_r	Effective mass of water boiled	g	2322.01	2280.45	1643.20		79.77	170.97	214.85
f_d	Equivalent dry fuel consumed	g	121.82	99.16	186.36		12.36	10.53	25.67
Δt^T	Temperature corrected time to boil	min	23.00	19.35		21.17	1.88	1.72	
h	Thermal efficiency		0.57	0.62	0.53	0.57	0.04	0.03	0.06
r_b	Burning rate	g/min	5.58	5.29	4.14	5.00	0.43	0.36	0.57
SC	Specific fuel consumption		0.05	0.04	0.12	0.07	0.005	0.002	0.03
SC^T	Temperature corrected specific fuel consumption		0.06	0.04		0.05	0.01	0.003	
SE^T	Temperature corrected specific energy consumption	kJ/kg	0.85	0.69	1.78	1.10	0.10	0.04	0.46
FP	Fire power	W	1426.62	1353.25	1058.87	1279.58	110.28	93.24	145.85

Spectra Pellet Cookstove – Water Boiling Test results

	units	Trial 1			Trial 2			Trial 3		
		cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Weight of empty pot	g	203.21	170.11	203.21	203.21	170.11	170.11	203.21	170.11	170.11
Weight of pot + water	g	2708.21	2678.93	2589.42	2706.11	2672.06	2564.12	2708.72	2675.32	2561.22
Weight of fuel	g	380.11	351.03	562.94	350.41	360.11	488.32	350.17	344.43	490.88
kerosene (ml)	ml	3	3	3	3	3	3	3	3	3
Initial temperature of water	^{0}C	27.0	26.7	88.0	28.7	27.5	88.6	30.0	29.1	90.0
Weight of sand	g	374.21	0	383.11	380.21	0	331.22	350.13	353.32	316.41
Weight of un-burned fuel	g	71.02	59.32	54.05	71.40	101.23	14.37	82.67	94.32	60.44
Weight of sand + char	g	428.92	53.78	503.21	427.57	45.81	444.51	397.75	396.72	423.43
Weight of pot+ water after the boiling	g	2618.94	2590.65	1874.89	2612.22	2565.79	1850.19	2604.28	2578.54	1883.43
Time taken to boil	min. sec	22.47	17.31		19.35	16.03		19.38	17.02	
Water temperature, boiling/ end of simmering	^{0}C	99.2	99.2	98.6	99.2	99.2	98.0	99.2	99.2	97.3
Ambient temperature (Ta)	^{0}C	29.7	29.7	29.7	29.5	29.5	29.5	31.1	31.1	31.1

LHV_{fuel}	Low heating value of fuel pellet	kJ/kg	15340.7
MC_{wet}	Wet basis moisture content		0.111
LHV_{char}	Low heating value of char	kJ/kg	29,773
T_b	water boiling temperature	^{0}C	99.2

		units	Trial 1			Trial 2			Trial 3		
			cold start	hot start	simmer	cold start	hot start	simmer	cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	22.78	17.52	45	19.58	16.05	45	19.63	17.03	45
wv	Mass of water vaporized	g	89.27	88.28	714.53	93.89	106.27	713.93	104.44	96.78	677.79
f_m	Fuel consumed (moist)	g	309.09	291.71	508.89	279.01	258.88	473.95	267.5	250.11	430.44
ΔC	Net changed in char during the test	g	54.71	53.78	120.1	47.36	45.81	113.29	47.62	43.4	107.02
W_r	Effective mass of water boiled/ simmered	g	2415.73	2420.54	1671.68	2409.01	2395.68	1680.08	2401.07	2408.43	1713.32
f_d	Equivalent dry fuel consumed	g	162.90	149.58	209.93	150.98	136.46	192.73	140.47	133.52	167.04
Δt^T	Temperature corrected time to boil	min	23.66	18.12		20.83	16.79		21.28	18.22	
h	Thermal efficiency		0.384	0.419	0.529	0.411	0.473	0.573	0.446	0.466	0.622
r_b	Burning rate	g/min	7.15	8.54	4.67	7.71	8.50	4.28	7.16	7.84	3.71
SC	Specific fuel consumption		0.067	0.062	0.126	0.063	0.057	0.115	0.059	0.055	0.097
SC^T	Temperature corrected specific fuel consumption		0.070	0.064		0.067	0.060		0.063	0.059	
SE^T	Temperature corrected specific energy consumption	kJ/kg	1.075	0.981	1.927	1.023	0.914	1.760	0.973	0.910	1.496
FP	Fire power	W	1828	2183	1193	1972	2174	1095	1830	2005	949

		units	Average			Overall test average	Standard deviation		
			cold start	hot start	simmer		cold start	hot start	simmer
Δt	Time taken to boil /simmering	min	20.66	16.87	45	18.77	1.83	0.75	0.00
wcv	Mass of water vaporized	g	95.87	97.11	702.08		7.78	9.00	21.04
f_{cm}	Fuel consumed (moist)	g	285.20	266.90	471.09		21.47	21.93	39.30
ΔC_c	Net changed in char during the test	g	49.90	47.66	113.47		4.17	5.43	6.54
W_r	Effective mass of water boiled / simmered	g	2408.60	2408.22	1688.36		7.34	12.43	22.02
f_d	Equivalent dry fuel consumed	g	151.45	139.85	189.90		11.23	8.55	21.59
Δt^T	Temperature corrected time to boil	min	21.92	17.71		19.82	1.52	0.80	
h	Thermal efficiency		0.41	0.45	0.57	0.48	0.03	0.03	0.05
r_b	Burning rate	g/min	7.34	8.29	4.22	6.62	0.32	0.39	0.48
SC	Specific fuel consumption		0.06	0.06	0.11	0.08	0.004	0.003	0.01
SC^T	Temperature corrected specific fuel consumption		0.07	0.06		0.06	0.003	0.003	
SE^T	Temperature corrected specific energy consumption	kJ/kg	1.02	0.93	1.73	1.23	0.05	0.04	0.22
FP	Fire power	W	1876.49	2120.43	1078.98	1691.97	82.29	100.45	122.64

APPENDIX C

FUEL TEST RESULTS

INDUSTRIAL TECHNOLOGY INSTITUTE (ITI)
P. O. Box, 787, 363, Bauddhaloka Mawatha, Colombo 7, Sri Lanka.
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120/4 A, Vidya Mawatha, Colombo 7, Sri Lanka.
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TEST REPORT

Report No. SS 1704804

Report to :

Ms. R. I. K. Chandrasene,
No. 59/L/15, Padmaperuma Mawatha,
Galahitiyawa, Ganemulla.

Issued By:

Materials Laboratory,
Industrial Technology Institute,
363, Bauddhaloka Mawatha,
Colombo 07.

2017-04-11

... Continuation Sheet

TEST REPORT

Report No. – SS 1704804

Customer : Ms. R. I. K. Chandrasene, No. 59/L/15, Padmaperuma Mawatha, Galahitiyawa, Ganemulla.	**Test Item :** Biomass **Service Requested :** Customer's request dated 2017-03-27
Description : Three (03) test items Following information was given in the customer's letter. Samples : 1. Charcoal 2. Fuel wood (Rubber) 3. Sawdust pellets	**Identification of Test Item :** Test items were not labelled. **Date of Receipt of Test Item :** 2017-03-27
Test Dates : From 2017-04-06 to 2017-04-07	

TEST RESULTS :

Test / Unit	Test Method	Results
		Charcoal
Moisture Content (as received) / %	BS EN 1860 - 2 : 2005	6.24

Test / Unit	Test Method	Results
		Fuel wood (Rubber)
Moisture Content (as received) / %	ASTM E 871 - 82	14.5

Test / Unit	Test Method	Results
		Sawdust pellets
Moisture Content (as received) / %	ASTM E 871 - 82	11.1
Calorific Value (on dry basis) / kcal/kg	ASTM D 5865	3982

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Authorized Signatory
K.H.R. Sajeewani
Research Engineer
Materials Laboratory

2017-04-11
-/ss.

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Gihan Bandara
Assistant Research Technologist