Centre for sustainable Energy Services

Report on Testing Performance of a 50 Litre Institutional Firewood Cook Stove

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Tanzania Industrial Research and Development Organization (TIRDO) wishes to acknowledge TaTEDO's efforts of promoting and implementing outsustainable energy development projects, example Scaling up Supply of Improved Cookstoves in Tanzania.

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Lastly, a team from TIRDO who participated in completion of the test and technical report for testing efficiency of firewood cooking stove in TaTEDO are acknowledged.

ABBREVIATIONS

TaTEDO	Tanzania Traditional Energy Development Organization
TIRDO	Tanzania Industrial Research and Development Organization
ToR	Terms of reference
CV	Calorific Value
mm	Millimeter
kW	kilowatt
VITA	Volunteers In Technical Assistance
USA	United States of America
SD	Secure Digital
Ohm	Unit for electrical resistance
Pt	Platinum resistance thermometer
MJ/Kg	Mega Joule per kilogram
Km/h	Kilometer per hour
KJ/Kg	Kilo Joule per kilogram
g	gram
L	Litre
Min	Minute

EXECUTIVE SUMMARY

TaTEDO is developing, fabricating and promoting various improved bioenergy technologies such as ovens, stoves and briquetting production. They are available for sale to the public and thereby disseminating renewable energy technologies that conserve theenvironment. Periodically as the need may be, these products are subjected to tests thatforms a basis for improvement and technology documentation.

In the current work, two types of tests were carried out to institutional base 50 Litre firewood cooking stove of the type designated as SeTa – IS 50 that included various temperature measurements to perform boiling and evaporation test. From these tests it was possible to establish fire power and thermal efficiency of the cooking stove. Results are;

i) Evaporation tests:-

- Cold start (thermal efficiency, 49.46% with fire power, 4.53kW).
- Hot start (thermal efficiencies, 54.82% and 48.42% with fire power, 4.63kW and 4.46kW respectively).

ii) Boiling tests

- Cold start (thermal efficiency, 44.83% with fire power, 4.06kW)
- Hot start (thermal efficiency, 48.57% with fire power, 5.76kW)

After performance tests of the stove, results show a relatively high efficiency as above. High efficiency is attributed by; good design for heat transfer, increased surface area for heat exchange, high efficiency of the combustion chamber and reduction of heat energy loss by application of ceramic fibre blanket to areas where useful heat exchange take place.

Based on the results observed after the test for thermal efficiency, it recommended to:-

- Conduct further tests to determine quality level of emission by the stove, this will help in quantification of combustion chamber efficiency.

- Carry out tests to determine optimum operating parameters of the stove for establishment of optimum wood fuel consumption.
- Deep assessment of impact of manufacturing defaults and their impact on thermal efficiency results.
- Since insulation is a key component in improving efficiency, design should be focused on better insulation practices

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1 INTRODUCTION

1.1 BACKGROUND

Tanzania Traditional Energy Development Organization (TaTEDO) is a Sustainable Energy Developmentorganization with and collaborating with Social enterprisesinvolved in the development and promotion ofrenewable energy technologies. The Organization is a non-governmental, non-profitabledevoted for spearheading the development of renewable energy technologies andconservation of the environment.

Prototypes of cook stoves that have been developed were categorized in the following groups:-

a) Improved charcoal stove
b) Improved charcoal ovens
c) Improved woodstoves
    - Ceramic portable woodstove
    - Ceramic fixed woodstove
    - Brick fixed woodstove
    - Msafiri stove
    - Kunichachestove
    - Sazawa charcoal stove
    - SeTa –Mkaakidogo, charcoal stove
    - SeTa institutional improved firewood cook stoves
d) Bio-waste stoves

Tests on efficiencies of improved woodstoves carried out by the University of Dar es Salaam in 1995 shows maximum efficiency of 25% while the one done by TIRDO in 2001 reveals 24.33% of the Msafiri woodstove.

In ongoing efforts to improve efficiency of cook stoves, TaTEDO has come up with a ceramic fibre blanket insulated metal cook stove that uses wood fuel and designated to be used for institutional based needs like schools and prisons.

The stove design is meant to reduce the quantity of wood fuel used, reduce heat losses to the surrounding, improve combustion of wood fuel and reduce smoke. However, the design did not leave aesthetics attributes to chance by designing a cook stove that burns quietly and smoke has only one outlet which is the chimney, a firewood magazine allows for firewood to be stacked in and closed unlike other woodstoves whereby this chamber is relied for air inlet. There is a chamber for air inlet which also serves as an outlet for ash and remained charcoal from burnt firewood, this ensures a clean operation of the stove. TaTEDO has designed these prototypes with capacities of 25L, 50 L, and 100 L.

1.2 OBJECTIVES

The main objective is to determine thermal efficiency of the SeTa institutional improved firewood cook stove.

1.3 SCOPE OF WORK

The work covers:-

- Assessmentof cook stove, surrounding environment for experiment and taking measurements of cook stove along with pots.
- Performing experiments of the cook stove to obtain data to efficiency calculation.
- Reporting to the client for output as stipulated in ToR.

1.4 TERMS OF REFERENCE

The contract signed between the Consultant and TaTEDO provided the terms of reference (ToR). The terms required the Consultant to;

i. Perform water boiling and evaporation tests at warm and cold conditions to determine power and efficiency of the firewood cook stove.

ii. Prepare a detailed report with the findings of the tests conducted.

iii. Asses and advice the client on requirements needed prior to the tests and to improve the stove if any.

2 METHODOLOGY

Laboratory investigations for power and thermal efficiencies of the firewood cooking stove were carried out at TaTEDO while testing of fuel quality was done at TIRDO laboratory. As guided by the terms of reference, a team of 3 engineers were deployed to TaTEDO for onsite testing of the cook stove, the team was led by Mr. AtupeleKilindu.

2.1 SAMPLING AND DESCRIPTION

At TaTEDO, there are different types and sizes of cook stoves. The sample stove for testing is not a normal domestic type of known cook stoves, it is designed to cater for public needs like schools, hospitals, prisons and others in similar need resemblance.

i. Sampling of a cook stove.

From a stack pile of public need based firewood cook stoves 25, 50 and 100 litres capacity cook stoves, a 50 litre was singled out for testing. The choice was made by TaTEDO as stated in terms of reference. The stove measures; height = 74.5 cm, diameter = (inner = 62.5 cm; outer = 68 cm), circumference = 200 cm, chimney height = 163 cm, chimney diameter = 10.2 cm, pot skirt height = 32.5 cm, pot skirt diameter = 56.5 cm.Stove is made of galvanizedsteel and combustion chamber made of high heat resistant stainless steel.

ii. Control.

This particular stove has firewood magazine measuring; H = 38 cm, L = 11 and W = 15.5 cm at 45 degree angle to a horizontal air inlet and also making a 45 degree angle with a vertical combustion chamber, air inlet with a tray for ash collection and combustion chamber measure H = 40 cm, L = 16 cm, W = 16 cm and H = 43.5 cm, L = 15 cm, 7.8 cm respectively. Firewood magazine has a rectangular grate with rectangular holes (measuring; L = 20 cm and W = 1.5 cm) which can be removed for cleaning purposes and measures L = 29 cm, W = 14.5 cm and a 3 mm thickness.

a b c

Figure 2-1: SeTa IS – 50 firewood cook stove

2.2 FUEL

Wood fuel was prepared accordingly depending on the design specifications of the stove. The wood fuel was prepared and provided by TaTEDO with specifications of the stove and also taking into account conditions where the stove testing took place.

2.2.1 FUEL SIZE

Large woodfuel were split by axe into irregular shapes of approximate dimensions of 45mm by 30mm by 15mm.

2.2.2 PROXIMATE ANALYSIS

Proximate analysis using simple methods were carried out to estimate main constituentsof charcoal and woodfuel which have direct influence on the combustion characteristics.For instance, the contribution of flaming and glowing combustion in a biomass burning process depend on the proportion of volatile matter and fixed carbon in it, while themoisture contents of biomass has a strong influence on its calorific value.

The proximate analysis started by determination of the moisture content. The moisture content of woodfuel or charcoal was determined by taking a 50g pre-weighed sample. The sample was placed in a drying oven in which a temperature of 105°C was maintained. After every 6 hours the change in mass was noted and the process continueduntil the weight became constant.

2.2.3 CALORIFIC VALUE

The calorific value of a fuel is defined as the amount of heat evolved when a unit weight of fuel is completely burnt and the combustion products such as CO_2 and H_2O are cooledto a standard temperature of 298°K. The calorific value of charcoal/woodfuel dependson species, age of the tree, moisture content and density. The calorific value was determined by an adiabatic bomb calorimeter using D2015-96 standard method. A sample of air dried biomass with known mass was burnt in an atmosphere of oxygen in a stainless steel high-pressure vessel. This bomb was placed ina calorimeter which was highly polished outer vessel containing a known amount of water with a known temperature. The combustion products CO_2 and H_2O were allowed to cool to the standard temperature. The resulting heat of combustion is measured from the accurate measurements of the rise the temperature of water in calorimeter, the calorimeter itself and the bomb.

2.3 OPERATIONS

2.3.1 FUEL QUANTITY

Sufficient fuel was filled in combustion chamber of tested stove after measuring its mass and remained fuel was measured to obtain the amount used. After the first test it was established for amount of fuel needed for a given amount of water so then the fuel in the chamber was filled regarding weight of firewood.

2.3.2 AMOUNT OF WATER

The ISO 19867 – 1:2018 Clean cook stoves and clean cooking solutions – Harmonized laboratory test protocols – Part 1: Standard test sequence for emissions and performance, safety and durability. This standard is applicable to cook stoves used in domestic, small scale enterprises and institutional applications, typically with fire power of less than 20 kW and cooking vessel of volume less than 150 litres.

2.3.3 WATER QUALITY

Water used was from a supply water tap and assumptions were quality of water remained consistent throughout the testing period.

2.3.4 POWER LEVELS

The power levels were adopted from VITA standards (1985:2,3). High power was reached by leaving the air inlet openings wide open. Woodfuel were frequently arranged to give maximum burning characteristics.During the tests wood fuel were added tomaintain high power phase.

2.4 POTS

2.4.1 TYPE AND SIZE

A 50 litre capacity stainlesssteel potwith diameter of 50.0 cm, height of 35.0 cm,bottom thickness of 2mm and body cylinder thickness of 1.5 mm made by TaTEDO. The pot fit into the cook stove with a one inch collar that rests on outer ring of the stove to prevent heat and unburnt gases escaping when cooking. They are a design specific for the stove and were usedin thermal efficiency tests. No pot lids were used in the tests to avoid errors associated with goodness of fit of lids to the pots.

2.4.2 HEAT TRANSFER

The same pots were used throughout the testing period. The pots were not cleaned off black soot after each test to encompass real cooking conditions. Design of the stove is such that, heat transfer is made maximum throughout the surface of the cooking pot. Pot’s bottom gets in direct contact with the fire while cylindrical surface area is heated by the unburnt gases before exiting through the chimney.

2.5 OPERATOR

2.5.1 IGNITION METHOD

A firewood out of measured wood fuel was chopped into very small pieces that were lit by a matchstick. The stove inlet doors were left open and kindling continued. According to VITA standard simulationapplicable in household’s condition is required and this was adopted.

2.5.2 STACKING OF FUEL

TaTEDO provided an operator with good experience in using wood fuel stoves and was a key person in operating the firewood cook stove.

2.6 DATA COLLECTION

DT4947SD a portable 4 - channel thermometer with data logging SD card manufactured by GENERAL Specialty Tools & Instruments, USA, was utilized for data collection. The equipment supports type K/J/R/E/T/S and Pt 100 ohm thermocouple for temperaturemeasurement range of –120°C to 1700°C and anemometer for wind velocitymeasurement. Temperature measurement was facilitated by a type K thermocouplethat is manufactured by Alpha Wire Corporation, USA.

2.6.1 EVAPORATION TEST

Weight of wood fuel was determined and recorded. Similarly, weight of water in pots were determined together with corresponding temperatures. The time of starting the experiment was noted and temperatures were recorded at intervals of five minutes. In case of pots, a thermocouples was immersed in the pot. Temperatures were recorded to a point of water boiling, it continued until water temperature dropped to 85 °C from 99 °C. Remainingwater was weighted together with remaining fuel in the stove. For cold start condition, the stove was left to cool to ambient temperature before another test. However, for hot start condition the test were carried on right after clean the stove off ash and remains from wood fuel.

2.6.2 BOILING TEST

The same procedure as evaporation test was carried out except when water in the pot reaches 98 °C boiling point, it was taken out and another pot placed on stove. This continued until maximum water temperature reached was recorded.

3 ENVIRONMENTAL CONDITION AND FUEL DATA

By using standard biomass analytical methods fuel data for biomass were established. Further environment conditions that were used to test the stoves and oven are given.

3.1 FUEL DATA

The fuel data for biomass are based on procedural for proximate analysis and the calorific value was determined as per D2015-96 Standard Test Method for Gross Calorific Value of Coal.

3.2 PROXIMATE ANALYSIS

Proximate analysis for wood fuel was done on woods that were visually distinctive and so tests were carried separately for the fire woods, results are tabulated in Table 3-1

Table 3-1: Proximate analysis results

Biomass Type	Constituents		
	Ash content %	Volatile matter %	Moisture content %
Wood fuel A	0.5652	94.2093	4.5746
Wood fuel B	0.6	94.9498	5.0403

3.3 CALORIFIC VALUE (CV)

The calorific values of the two woods tested are given in Table 3-2

Table 3-2: Calorific values for woods

Biomass Type	CV (MJ/Kg)
Wood fuel A	18.773
Wood fuel B	17.472

3.4 ENVIRONMENT CONDITION

3.4.1 LABORATORY CONDITION

The laboratory conditions were kept under normal ambient temperature. The following parameters were measured; laboratory inside temperature: 31°C, and airflow in the lab: 0 Km/h.

3.4.2 TaTEDO SITE

The cook stove was tested at TaTEDO Dar es Salaam office on Friday 15 /02 /2019 and Monday 18 /02/ 2019 at outdoor conditions and the following parameters were recorded;

Table 3-3: Environment conditions of the test

Test Parameter	Test Result	Equipment used and specifications
Ambient temperature	30 to 32 °C	4-channel thermometer type DT4947SD-4, Range -100 to 1700°C
Weather condition	Sunny	Visual
Wind direction	Optimal	Hot wire anemometer
Wind speed	0.7 to 10.3 Km/h	Hot wire anemometer

4 STOVE'S PERFORMANCE

4.1 COMBUSTION CHARACTERISTICS

In this section the burning characteristics of the cook stove is described. Furthermore, smoke formation and how proper burning and less smoky operation could be attained is also described. Though smoke formation is dependent on fuel wood/charcoal type but this description is based on the same type of fuel source.

4.2 TEST RESULTS

Boiling and evaporation tests were carried out to determine the overall thermal efficiency of the cook stove. The efficiency of the cook stove is calculated by formula given below.

$$\eta = \sum_{k=1}^{K} \frac{C_p m_k k(\Delta T)_k k + h_e m_{wv}}{m_f h_f} \qquad \text{Equation 1}$$

Where; $\boldsymbol{\eta}$ = Efficiency (%), k = pot number, K = number of pots, $C_p =$ Specific Heat Capacity of water (KJ/Kg), $m_k =$ mass of water in each pot (Kg), $\Delta T =$ rise in water temperature (K), $h_e =$ latent heat of vaporization of water (KJ/Kg), $m_{wv} =$ mass of vaporized water (Kg), $m_f =$ mass of fuel (Kg), $h_f =$ calorific value of biomass (KJ/Kg).

With the equation given efficiency values for boiling and evaporation tests were calculated.

Table 4-1: Thermal efficiencies of the cook stove

S/N	TEST AND CONDITION	TEST DATE	EFFICIENCY (%)	FIRE POWER (kW)
1.	Evaporation (cold start)	Friday 15 /02 /2019	49.46	4.39
2.	Evaporation (hot start)	Friday 15 /02 /2019	54.82	3.77
3.	Evaporation (hot start)	Friday 15 /02 /2019	48.42	3.05
4.	Boiling (cold start)	Monday 18 /02/ 2019	44.83	4.0
5.	Boiling (hot start)	Monday 18 /02/ 2019	48.57	5.67

Boiling test on other hand gave low efficiencies than evaporation due to the fact that towards the tail out of charcoal the energy dissipated by burning charcoal was not considered and water evaporated was equally not taken into account. Furthermore, a considerable amount of heat energy is lost while exchanging the pots. Figure 4-1to Figure 4-5shows typical graphs of boiling tests for five tested stoves.

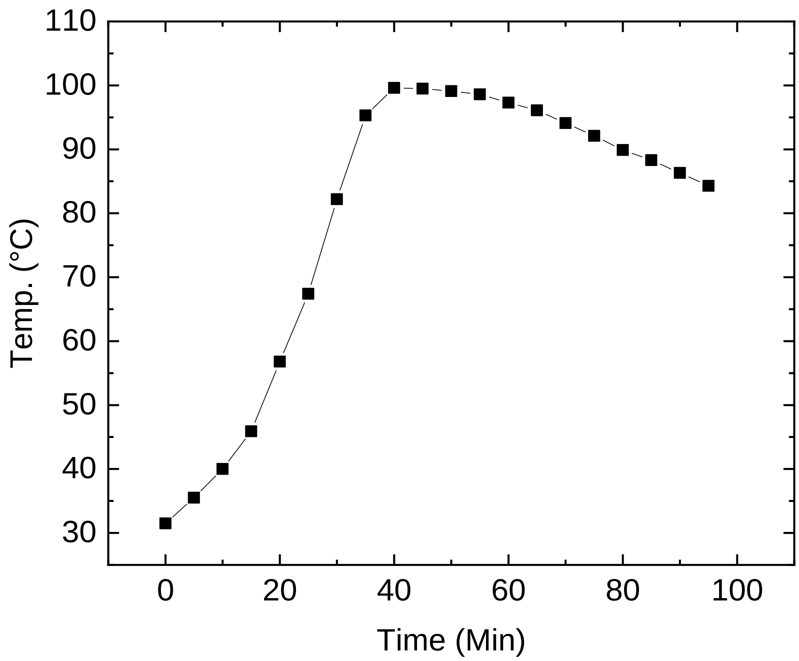

Figure 4-1: Evaporation test (cold start)

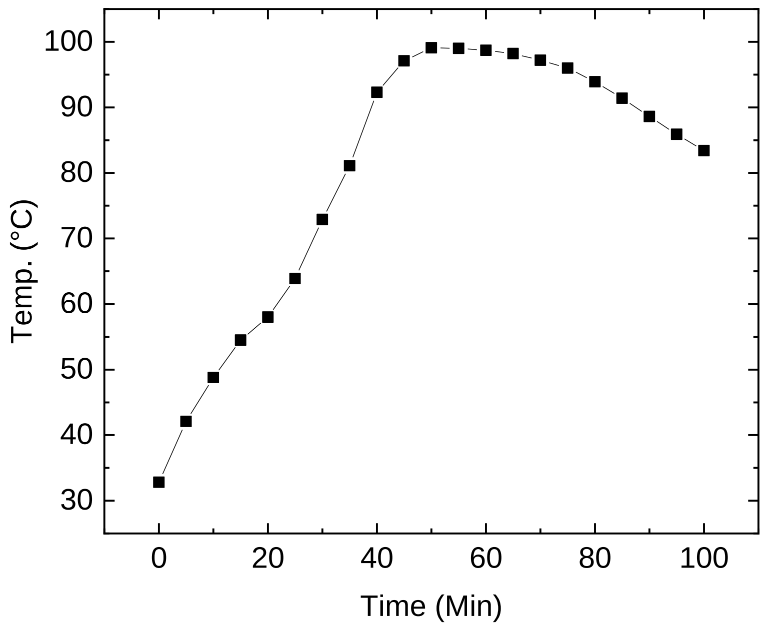

Figure 4-2: Evaporation test (hot start)

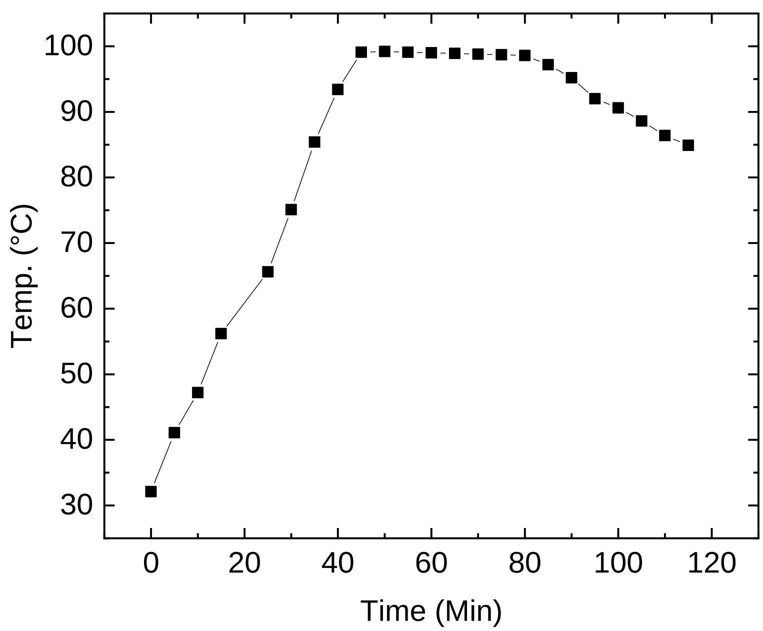

Figure 4-3: Evaporation test (hot start)

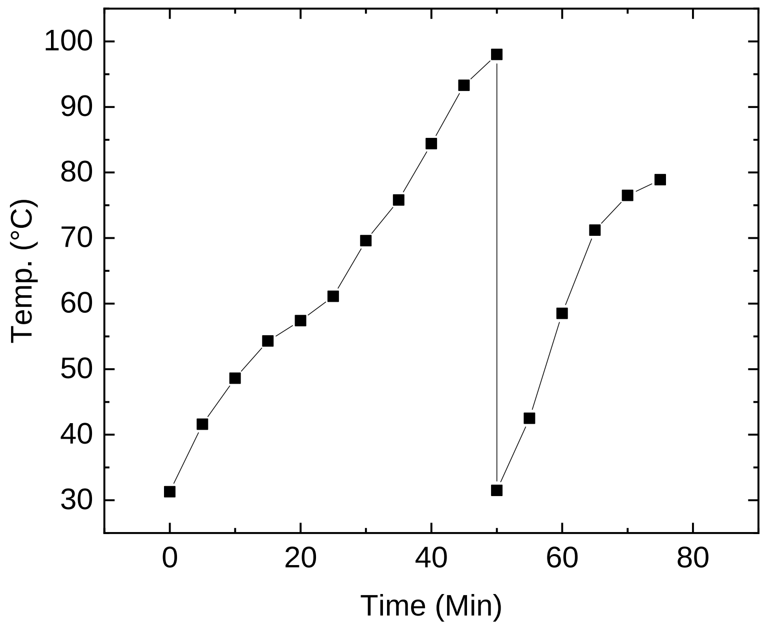

Figure 4-4: Boiling test (cold start)

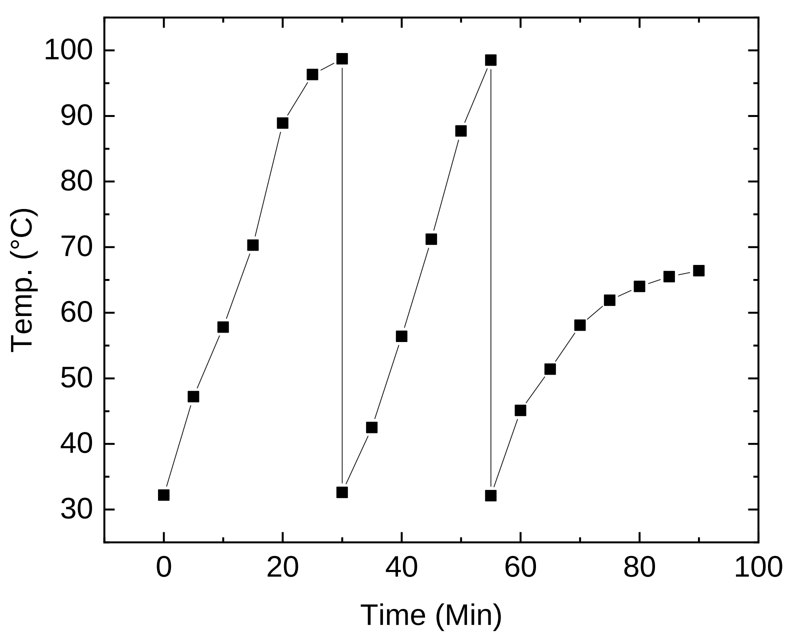

Figure 4-5: Boiling test (hot start)

4.3 SURFACE HEAT TEMPERATURES

The cooks stove was examined for heat losses due to strength of the insulation material used on outer surfaces of the combustion chamber and insulation along the inner wall of stove. Insulation around the combustion chamber has a thickness of 5.0 cm and of the inner wall is 2.5 cm, temperatures were highest near the firewood magazine and recorded lowest on the upper outer surface of the stove. Ranges at points measured were 36.2 to 106 °C and the apparent measured temperatures reached by the stove's open fire were in 1200 °C.

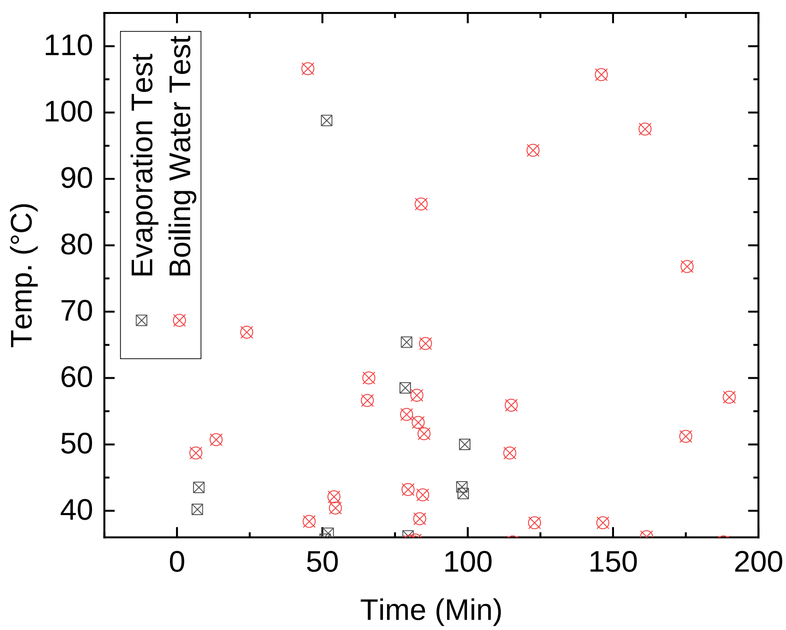

Figure 4-6: Stove's surface temperature

5 DISCUSSION

Efficiency of any cook stove is a function of stove design and heat loss to the surrounding. The discussion will be focused on the mentioned parameters.

5.1 STOVE DESIGN

Design geometrics used for stove design are; size of the gap between pot and pot skirts, gap between pot and combustion chamber cross sectional area, geometrical relationship among combustion chamber, firewood magazine and air inlet (damper), cooking pot geometry and grate.

- Gap between pot and pot skirt.

It is obtained by dividing cross sectional area of the combustion chamber to edge circumference of the pot, which gives a 1.63 cm gap.

- Gap between pot and combustion chamber cross sectional area.

This is obtained through dividing cross sectional area of the combustion chamber by circumference or perimeter of the combustion chamber, in this stove it gives 4.0 cm.

- Geometrical relationship of combustion chamber, firewood magazine and air inlet.

Air inlet is to be one third of combustion chamber and firewood magazine should be two third of combustion chamber. Looking at the design of the stove, slight deviation from design standard can be observed and they cannot be ignored when looking at factors affecting thermal efficiency of this stove.

- Air inlet (damper).

Design of this stove allows entrance of air through air inlet and firewood magazine (if lid left open), if both air inlets are left open fire power increases resulting in high rates of heat transfer. It as well results into high fuel consumption.

- Cooking pot geometry

There is a relationship between cooking pot height and its diameter, as the ratio increases beyond unit efficiency drops rapidly, in this case the stove has a ratio of 0.7.

- Grate.

It might be regarded as component which function is only to hold wood fuel while burning. If poorly designed it can result to combustion issues related with proper air – fuel mixing.

In this stove, is well designed that combustion results in less smoke.

5.2 HEAT LOSS

Insulation is a primary method used in preventing heat loss, the stove has insulation in two main areas; the combustion chamber and area around the pot skirt. Heat loss at combustion chamber area is insulated by a 5 cm thick ceramic fibre blanket and at pot skirt is insulated by a 2.5 cm thickness.

With all this insulation, temperature rise on the surfaces of the stove were recorded and it can be accounted that thermal efficiency is affected.

5.3 RESULTS

- Evaporation test.

Plots in fig. 4.1 to 4.3 depict temperature against time. Fig. 4.1 for cold start boiled at 40 min. time and dropped to 85 °C at 95 min. time while for hot condition (fig. 4.2) boiling was at 45 min. time and dropped to 85 °C at 100 min. time. This happened because of surrounding ambient temperature and wind speed conditions, cold start began at 11:27 AM with ambient temperature of 33.4 °C and wind at 3.3 Km/h. hot start was around 01:30 PM and the weather had cooled down to 31 °C with wind blowing up to 7 Km/h.

- Boiling test.

Plots in fig. 4.4 and 4.5 depict cold and hot start conditions for boiling tests respectively, thermal efficiencies range difference is not very much. It was observed that for cold start one pot boiled and for hot start two ports boiled.

6 CONCLUSION

TaTEDO has developed a design of stove for institutional purposes. After performance tests of the stove, results show a relatively high efficiency. High efficiency is attributed by; good design for heat transfer, increased surface area for heat exchange, high efficiency of the combustion chamber for reduction of harmful emission and reduction of heat energy loss by application of ceramic fibre blanket to areas where heat useful heat exchange take place.

Material used to make the combustion chamber is high heat resistant stainless steel, choice of this material gives durability to the cook stove.

7 RECOMMENDATIONS

The following are recommendations based on the results observed after the test for thermal efficiency:-

- Conduct further tests to determine quality level of emission by the stove, this will help in quantification of combustion chamber efficiency.
- Carry out tests to determine optimum operating parameters of the stove for establishment of optimum wood fuel consumption.
- Deep assessment of impact of manufacturing defaults and their impact on thermal efficiency results.
- Since insulation is a key component in improving efficiency, design should be focused on better insulation practices.

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APPENDICES

APPENDIX 1: Evaporation test Calculations

EVAPORATION TEST

Identification:	**1**			
Type:	**SeTa - IS 50**			
Size:				

Data I (Input)

a)	Mass of water, **M**w:	41.912	kg
b)	Water temp., **T**w:	31.5	oC
c)	Room temp., **RT**:	33.4	oC
d)	Mass of charcoal, **M**f:	2.861	kg
e)	Time to start, **t**s:	1127	hrs

Data II (Constants)

f)	Water spec. heat capacity, **C**pw:	4,200	J/kg K
g)	Water latent heat of Vapour. **L**w:	2,260,900	J/kg
h)	Calorific Value of firewood, **CV**f:	18,125,090	J/kg

Data III (Output)

I)	End of test, te:	1304	hrs.
j)	Mass of water left, **M**wl:	35.824	kg
k)	Duration of test, tD:	5,700	s

Calculations:

Thermal efficiency, η_{th}

$$\eta_{th} = \frac{\text{Useful Energy}}{\text{Energy Input}} \cdot 100\%$$

$$= \frac{\text{Energy used to boil water + latent heat}}{\text{Energy supplied by Jatropha oil}} \cdot 100\%$$

$$= \frac{Mw \cdot Cpw(99 - Tw) + Me \cdot Lw}{Mf \cdot CVf} \cdot 100\%$$

$$= 49.46 \quad \%$$

$$\text{Power} = \frac{\text{Useful Energy}}{\text{Time}}$$

$$= \frac{Mw \cdot Cpw(100 - Tw) + Me \cdot Lw}{t_D}$$

$$= 4{,}530.25 \quad \text{Watts} \quad 4.53 \quad \text{kW}$$

EVAPORATION TEST

Identification:	**2**
Type:	**SeTa - IS 50**
Size:	

Data I (Input)

a)	Mass of water, M_w:	41.8	kg
b)	Water temp., T_w:	31.5	oC
c)	Room temp., **RT**:	30	oC
d)	Mass of charcoal, M_f:	2.78	kg
e)	Time to start, t_s:	1314	hrs

Data II (Constants)

f)	Water spec. heat capacity, C_{pw}:	4,200	J/kg K
g)	Water latent heat of Vapour. L_w:	2,260,900	J/kg
h)	Calorific Value of firewood, CV_f:	18,125,090	J/kg

Data III (Output)

I)	End of test, t_e:	1521	hrs.
j)	Mass of water left, M_{wl}:	34.824	kg
k)	Duration of test, t_D:	6,000	s

Calculations:

Thermal efficiency, n_{th}

$$n_{th} = \frac{\text{Useful Energy}}{\text{Energy Input}} \cdot 100\%$$

$$= \frac{\text{Energy used to boil water + latent heat}}{\text{Energy supplied by Jatropha oil}} \cdot 100\%$$

$$= \frac{Mw \cdot Cpw(99 - Tw) + Me \cdot Lw}{Mf \cdot CVf} \cdot 100\%$$

$$= 54.82 \quad \%$$

$$\text{Power} = \frac{\text{Useful Energy}}{\text{Time}}$$

$$= \frac{Mw \cdot Cpw(100 - Tw) + Me \cdot Lw}{t_D}$$

$$= 4{,}632.98 \quad \text{Watts}$$

$$4.63 \quad \text{kW}$$

EVAPORATION TEST

Identification:	**3**
Type:	**SeTa - IS 50**

Size:

Data I (Input)

a)	Mass of water, **M**w:	41.912	kg
b)	Water temp., **T**w:	32	oC
c)	Room temp., **RT**:	32.6	oC
d)	Mass of charcoal, **M**f:	3.64	kg
e)	Time to start, **t**s:	1348	hrs

Data II (Constants)

f)	Water spec. heat capacity, **C**pw:	4,200	J/kg K
g)	Water latent heat of Vapour. **L**w:	2,260,900	J/kg
h)	Calorific Value of firewood, **CV**f:	18,125,090	J/kg

Data III (Output)

I)	End of test, te:	1542	hrs.
j)	Mass of water left, **M**wl:	33	kg
k)	Duration of test, tD:	7,200	s

Calculations:

Thermal efficiency, n_{th}

n_{th} = Useful Energy . 100%

$$\frac{\quad}{\text{Energy Input}}$$

$$= \frac{\text{Energy used to boil water + latent heat}}{\text{Energy supplied by Jatropha oil}} \cdot 100\%$$

$$= \frac{Mw \cdot Cpw(99 - Tw) + Me \cdot Lw}{Mf \cdot CVf} \cdot 100\%$$

$$= 48.42 \quad \%$$

$$\text{Power} = \frac{\text{Useful Energy}}{\text{Time}}$$

$$= \frac{Mw \cdot Cpw(100 - Tw) + Me \cdot Lw}{t_D}$$

$$= 4{,}461.00 \quad \text{Watts}$$

$$4.46 \quad \text{kW}$$

APPENDIX 2 Boiling test Calculations

BOILING TEST

Identification:	**10C**

Type: **SeTa - IS 50**

Size:

Boiling Test NO. 1

Data I (Input)

a)	Mass of water, Mw:	31.928	kg
b)	Water temp., Tw:	31.2	oC
c)	Room temp., RT:	31.2	oC
d)	Mass of Charcoal, Mf:	3	kg
e)	Time to start, ts:	1040	hrs
f)	Definition of boiling, BP	98	oC

Data II (Constants)

g)	Water spec. heat capacity, Cpw:	4,200	J/kg K
h)	Calorific Value of Charcoal, CVf:	18,125,090	J/kg

Data III (Output)

j)	End of test, t_e:	1220	hrs.
j)	Number of boiling, Nb:	2	
k)	Final water temp., Tf	79.4	oC
m)	Duration of test, t_D:	6,000	s

Calculations:

Thermal efficiency, n_{th}

$$n_{th} = \frac{\text{Useful Energy}}{\text{Energy Input}} \cdot 100\%$$

$$= \frac{\text{Energy used to boil water + Sensible heat}}{\text{Energy supplied by charcoal}} \cdot 100\%$$

$$= \frac{Nb \cdot Mw \cdot Cpw(98 - Tw) + Mw \cdot Cpw(Tf - Tw)}{Mf \cdot CVf} \cdot 100\%$$

$$= 44.83 \quad \%$$

$$\text{Power} = \frac{\text{Useful Energy}}{\text{Time}}$$

$$= \frac{Nb \cdot Mw \cdot Cpw(80 - Tw) + Mw \cdot Cpw(Tf - Tw)}{t_D}$$

= 4,063.16 Watts

4.06 kWatts

BOILING TEST

Identification:	**12C**
Type:	**SeTa - IS 50**
Size:	

Boiling Test NO. 2

Data I (Input)

a)	Mass of water, Mw:	31.928	kg
b)	Water temp., Tw:	32.1	oC
c)	Room temp., RT:	31.3	oC
d)	Mass of Charcoal, Mf:	3.534	kg
e)	Time to start, ts:	1221	hrs
f)	Definition of boiling, BP	98	oC

Data II (Constants)

g)	Water spec. heat capacity, Cpw:	4,200	J/kg K
h)	Calorific Value of Charcoal, CVf:	18,125,090	J/kg

Data III (Output)

j)	End of test, te:	1351	hrs.
j)	Number of boiling, Nb:	3	
k)	Final water temp., Tf	66.4	oC
m)	Duration of test, tD:	5,400	s

Calculations:

Thermal efficiency, n_{th}

$$n_{th} = \frac{\text{Useful Energy}}{\text{Energy Input}} \cdot 100\%$$

$$= \frac{\text{Energy used to boil water + Sensible heat}}{\text{Energy supplied by charcoal}} \cdot 100\%$$

$$= \frac{Nb \cdot Mw \cdot Cpw(98 - Tw) + Mw \cdot Cpw(Tf - Tw)}{Mf \cdot CVf} \cdot 100\%$$

$$= 48.57 \ \%$$

$$\text{Power} = \frac{\text{Useful Energy}}{\text{Time}}$$

$$= \frac{Nb \cdot Mw \cdot Cpw(80 - Tw) + Mw \cdot Cpw(Tf - Tw)}{t_D}$$

$$= 5{,}761.23 \ \text{Watts}$$

5.76 kWatts