Centre for sustainable Energy Services

Final Report on Testing Performance of a SeTa Mkaa Stove

Prepared by:

Tanzania Industrial Research and
Development Organization (TIRDO)
P. O. Box 23235
Dar es Salaam, Tanzania
Tel: +255-22-266 88 22
Fax: +255-22-2666 034
Email: info@tirdo.or.tz
http://tirdo.or.tz/index.php

March 2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

Tanzania Industrial Research and Development Organization (TIRDO) wishes to acknowledge TaTEDO’s efforts specifically Eng. Estomih Sawe for promoting and implementing out sustainable energy development projects, example scaling up Supply of Improved Cook stoves in Tanzania.

Eng. Shima Sago, is specifically acknowledged for his hand in hand support in accomplishing the stoves efficiency tests and for his support in providing technical information of the tested firewood and charcoal stoves.

Lastly, a team from TIRDO who participated in completion of the test and technical report for testing efficiency of firewood and charcoal stoves in TaTEDO premises and TIRDO laboratory 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
Ohm	Unit for electrical resistance
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 stoves and briquetting production. They are available for sale to the public and there by disseminating renewable energy technologies that conserve the environment. Periodically as the need may be, these products are subjected to tests that forms a basis for improvement and technology documentation.

In the current work, stove test was carried out to Charcoal cooking stove of the type designated as SeTa Mkaa Stove that included various temperature measurements to perform evaporation test. From these tests it was possible to establish fire power and thermal efficiency of both cooking stove. Results are;

SN	Stove name	Efficiency (%)	Fire Power (kW)
		Evaporation Test	
1	SeTa Mkaa STOVE	50.88	1.11

After performance tests of these stoves, results show SeTa Mkaa lies within Class 1 Biomass stove with Cooking efficiency more than 50% and surpass performance requirements in terms of efficiency that is above 20% in accordance to Biomass Cook Stove standard developed by TBS. 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 fiber 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, safety and durability factor of the stove.
- Perform Deep assessment of impact of manufacturing defaults and their impact on thermal efficiency results.

1 INTRODUCTION

1.1 BACKGROUND

TaTEDO: Is Centre for Sustainable Energy Services committed to facilitating access to sustainable energy services for all in Tanzania; through different approaches depending on a number of factors i.e. social economic and cultural context. The Organization is a non-governmental, non-profitable devoted for spearheading the development of renewable energy technologies and conservation of the environment.

Prototypes of cook stoves that have been developed were categorized in the following group(s):-

a) SeTa –Mkaa stove

In ongoing efforts to improve efficiency of cook stoves, TaTEDO came up with a ceramic fibre blanket insulated cook stove that uses less charcoal and cooks fast as compared to other charcoal stove. The stove is portable and durable, and it is ideal for family use. The stove design is meant to reduce the quantity of charcoal used, reduce heat losses to the surrounding and improve combustion of charcoal.

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:-

- Assessment of 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 METHODOLOGY

Investigations of the fire power and thermal efficiency of the charcoal stove was done at laboratory condition at TIRDO premises. The approach to determine efficiency and firepower was done by conducting evaporation tests at cold and hot start conditions. A team of two engineers and two technicians was deployed to conduct those tests that were led by Eng. Atupele Kilindu.

2 DESCRIPTION

SeTa Mkaa Stove use charcoal to generate heat for cooking purposes.

2.1 SeTa MKAA STOVE

There is a chamber for air inlet which also serves as an outlet for ash and remained charcoal, this ensures a clean operation of the stove. TaTEDO has designed these prototypes with capacities of reducing heat loss through insulator material (Ceramic Fibre Blanket) of dimensions 50mm x 610mm. This particular stove has air inlet with air inlet opening of dimensions 50mm x 145mm

Figure 2.1: SeTa Mkaa stove

2.2 STOVE DESIGN

SeTa Mkaa Stove details of parts and dimensions are described as shown in Appendix 2 and 3.

2.3 FUEL

Charcoal fuel was provided by TaTEDO with specifications of the stove and also taking into account condition where the stove testing took place. About 1kg of Charcoal were weighed on the weigh balance and placed on the combustion chamber of cook stove. Charcoal fuel were prepared accordingly depending on the design specifications of the stoves and oven.

2.3.1 Fuel Size

Charcoal fuel comprised of mostly small charcoal briquettes of less than 50mm diameter. Big charcoal lumps were crumpled into small size of irregular sphere of about 50mm diameter or less.

2.3.2 Proximate Analysis

Proximate analysis using simple methods were carried out to estimate main constituents of charcoal 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 the moisture contents of biomass have a strong influence on its calorific value.

The proximate analysis started by determination of the moisture content. The moisture content of wood fuel or charcoal was determined by taking a 50 g 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 continued until the weight became constant. The moisture content [m] in percent of the biomass on dry basis was then calculated as: -

$$[m]=\frac{Mi - Mc}{Mc} \times 100\%$$

Where: -

[m] = moisture content of biomass

Mi = initial mass of sample

Mc = constant mass of sample

Next was determination of volatile matter. The amount of volatile matter was determined by heating a dried ground sample of charcoal/woodfuel in an oven with a temperature of 600°C for six minutes and followed by heating the sample in another oven with a temperature of 900°C for another six minutes. The amount of volatile matter in the biomass is calculated as: -

$$[u] = \frac{Mi - Mf}{Mf} \times 100\%$$

Where: -

μ = volatile matter in percent

Mi = Initial mass of the sample

Mf = final mass of the sample

After, the volatile matter, the amount of ash was determined. The higher the value of ash content the lower is the calorific value of the type of fuel. The amount of ash was determined by heating a dry sample of charcoal/woodfuel in a crucible in a furnace which was kept at 900°C. The amount of residue left was weighed and amount of ash calculated as follows: -

$$[a] = \frac{Mi - Mf}{Mf} \times 100\%$$

Where: -

a = amount of ash in percentage

Mi = initial mass of the sample

Mf = final mass of the sample

The final step in the proximate analysis was the determination of the amount of fixed carbon content using mass balance calculations given as: -

$$[c]\% = 100\% - \{[m]\% + [a]\% + \mu\%\}$$

Where: -

[c] = amount of fixed carbon content

[m] = moisture content

[a] = ash content

μ = volatile matters

2.3.3 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 cooled to a standard temperature of 298°K. The calorific value of charcoal/wood fuel depends on 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 in a 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.

2.4 OPERATIONS

2.4.1 Fuel Quantity

Measured sufficient fuel was filled in combustion chamber of tested stove. 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 water.

2.4.2 Amount of Water

TZS 473: 2019 Biomass Cook stoves Standard developed by TBS gave a guidance on amount of water required in accordance to the cooking power. .

2.4.3 WATER QUALITY

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

2.4.4 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.

2.4.5 Pot type and Size

Shiny mild steel pot of diameters between 180mm and 275mm and 1mm thick were used in thermal efficiency tests. These pots are typical of those used in household sector. The selection of pot size depended on stove pot holder dimensions. This was adopted in order to maximize heat absorption and allow draft to pass along pot walls.

2.4.6 Heat Transfer

Same pot was used throughout the testing period. The pot was cleaned by steel wool to remove black tar after each test to ensure that heat transfer rates to the water remained consistent.

2.4.7 Pot Lid

No pot lids were used during these tests to avoid errors associated with goodness of fit of the lid and with lid orientation in trays as per VITA standards (1985:1).

2.4.8 Ignition Method

About 30 cc of kerosene was used for starting fire using a matchstick. The stove inlet doors were left open and kindling continued. According to VITA standard simulation applicable in households’ condition is required and this was adopted.

2.4.9 Stacking of fuel

An operator with good experience in using charcoal stoves was a key person in operating devices. Stacking of wood fuel and shaking off ash from burning charcoal was carried out in the same manner done in households.

2.4.10 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 temperature measurement range of –120°C to 1700°C and anemometer for wind velocity measurement. Temperature measurement was facilitated by a type K thermocouple that is manufactured by Alpha Wire Corporation, USA.

2.4.11 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 two minutes. In case of pots, a thermocouple was immersed in the pot. Temperatures were recorded to a point of water boiling, and continued to evaporate until the fuel were completely burnt out. Remaining water was weighted. 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.

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 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

The proximate analysis for wood fuel and charcoal are given in Table 3.1 below.

Table 3-1: Proximate analysis results

Biomass Type	Constituents			
	Ash content %	Volatile matter %	Moisture content %	Fixed carbon %
Charcoal	2.72	20.01	5.00	72.27

3.3 CALORIFIC VALUE (CV)

The calorific values of the two types of biomass are given below.

Table 3-2: Calorific values of wood fuel and charcoal

Biomass Type	*CV* (Kcal/kg)
Charcoal	5340

3.4 Kerosene Data

The properties of Kerosene were collected from *Technical Data on Fuel* by J.W Rose and J.R. Cooper and are shown below.

Table 3.3: Useful parameters for Kerosene.

Density at 1 atm. and 15.6°C. (g/cm3)		0.78
Calorific value at 15°C (MJ/Kg)		
	(i) Gross	46.5
	(ii) Net	43.5

3.4 ENVIRONMENT CONDITION

The test were carried out in TIRDO laboratory for portable charcoal stove.

3.4.1 Laboratory Condition

The laboratory conditions were kept as practiced in households. The following parameters were measured: -

Laboratory inside temperature: 31°C

Airflow rate in the lab: 0.1 km/h

Draft at the hood: 0

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

Evaporation test was 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), ΔT = 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 evaporation test was calculated.

Table 4-1: Thermal efficiencies of the SeTa Mkaa cook stove

S/N	TEST AND CONDITION	TEST DATE	EFFICIENCY (%)	FIRE POWER (kW)
1.	Evaporation	Saturday 27 /02 /2021	50.08	1.11

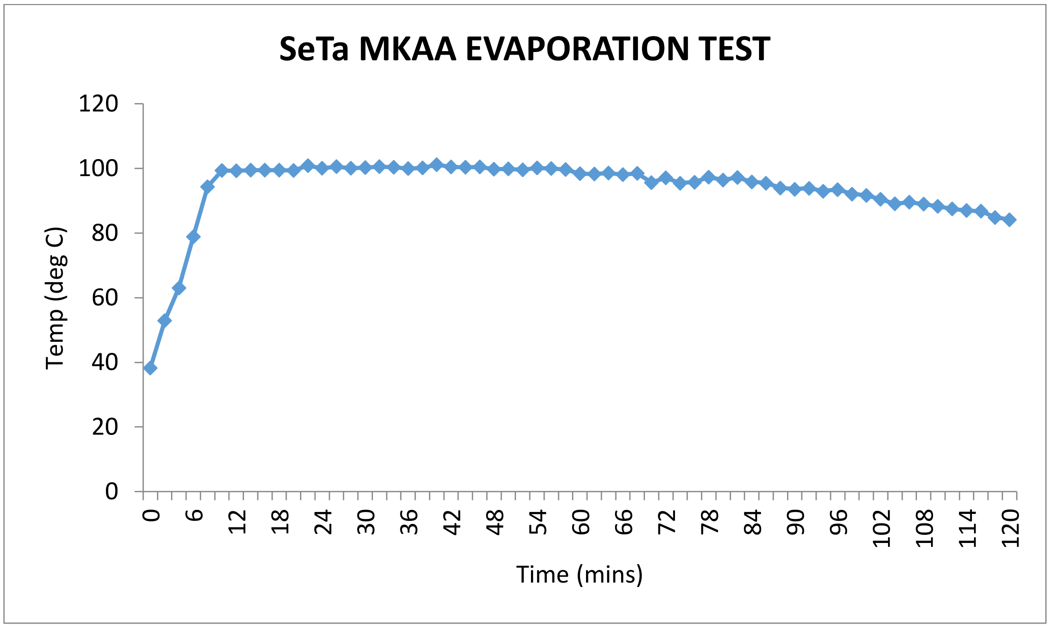


Figure 4.1: Evaporation Test

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 insulation gap and material used for insulation, size of combustion chamber cross sectional area, combustion chamber material, charcoal magazine and air inlet.

- Insulation gap and insulation material.

It is obtained by dividing cross sectional area of the combustion chamber to edge circumference of the stove (SeTa Mkaa Stove), which gives a 5.0 cm gap. Insulation gap and material used on SeTa Mkaa Stove were not selected basing on theoretical calculation for heat loss as a result the insulation did not perform per expectancy.

-Geometrical relationship of combustion chamber, charcoal 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 both stoves, slight deviation from design standard can be observed and they cannot be ignored when looking at factors affecting thermal efficiency of these stoves.

- Air inlet (damper).

Design of these stoves allows entrance of air through air inlet and Ash 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.

In these stoves, are well designed that combustion results in less smoke.

5.2 HEAT LOSS

Insulation is a primary method used in preventing heat loss, the SeTa Mkaa stove has insulation in the combustion chamber. Heat loss at combustion chamber area is insulated by an insulation gap and a 5 cm thick ceramic fiber blanket. Conclusively with all this insulation, temperature rise on the surfaces of the stove were observed and it can be accounted that thermal efficiency is affected.

5.3 RESULTS

For SeTa Mkaa Stove;

- Evaporation test.

Plots in fig. 4.1 depict temperature against time. Fig. 4.1 for hot start boiled at 18 min. time and remain constant at highest temperature about until 60 min then start to drop to 85 °C at 120 min. time. This happened because of surrounding ambient temperature and wind speed conditions, hot start began at 12:05 PM with ambient temperature of 30.8 °C and wind at 0.4 Km/h.

6 CONCLUSION

TaTEDO has developed a design of stoves for domestic and institutional purposes. After performance test of this stove, it should be noted that these stoves have good efficiencies and have improved much from traditional stove efficiencies. TaTEDO should work out on the improvement of these stoves by considering various factors such as social-economic covering acceptability, price, engineering concept (proper designs, materials science concept), and environmental and health aspects covering emissions levels, health problems to operators.

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 fuel consumption.
- Deep assessment of impact of manufacturing defaults and their impact on thermal efficiency results.
- Carry out a detail design showing calculations for optimum performances of stove and technical drawings
- Study materials which can be used for insulating combustion chamber such as vermiculite, ceramic wool and their contribution to production cost

8 APPENDICES

8.1 APPENDIX 1: COOKING EFFICIENCY AND FIRE POWER CACLULATIONS

Identification:	**Seta Mkaa Stove**
Type:	**Charcoal Stove**
Size:	**230mm**

Data I (Input)

a)	Mass of water, **M**w:	4	kg
b)	Water temp., **T**w:	29.8	oC
c)	Room temp., **RT**:	30.8	oC
d)	Mass of charcoal, **M**f:	0.7	kg
e)	Time to start, **t**s:	13:18:56	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 charcoal, **CV**f:	22 343 000	J/kg

Data III (Output)

I)	End of test, te:	15:18:56	hrs.
j)	Mass of water left, **M**wl:	1.002	kg
k)	Duration of test, tD:	7 200	s

Calculations:

Thermal efficiency, n_{th}

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

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

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

$$= \boxed{50.88}\ \%$$

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

$$= \frac{M_w \cdot C_{pw}(100 - T_w) + M_e \cdot L_w}{t_D}$$

$= 1\,105.14$ Watts

$\boxed{1.11}$ kW

8.2 APPENDIX 2: SPECIFICATIONS FOR SETA MKAA STOVE

- Outside diameter = 300mm GS Sheet, t = 1.2mm
- Combustion chamber diameter = 190mm
- Combustion chamber materials = Stainless Steel, t= 2mm
- Stove top cover = stainless steel, t =2mm
- Depth of combustion chamber = 100mm
- Stove body height = 200mm GS sheet
- Insulation thickness = 50mm
- Air inlet opening = 50mm x 145mm
- Number of Pot support = 4
- Insulation material = Ceramic Fibre Blanket (50mm x 610mm)
- Grate Material = Stainless Steel, t= 3mm
- Ash guide to ash tray = Frustum of a cone (D=190mm, d=125mm, h=35mm)
- Overall stove height = 230mm
- Weight of charcoal stove = 5.5 Kg

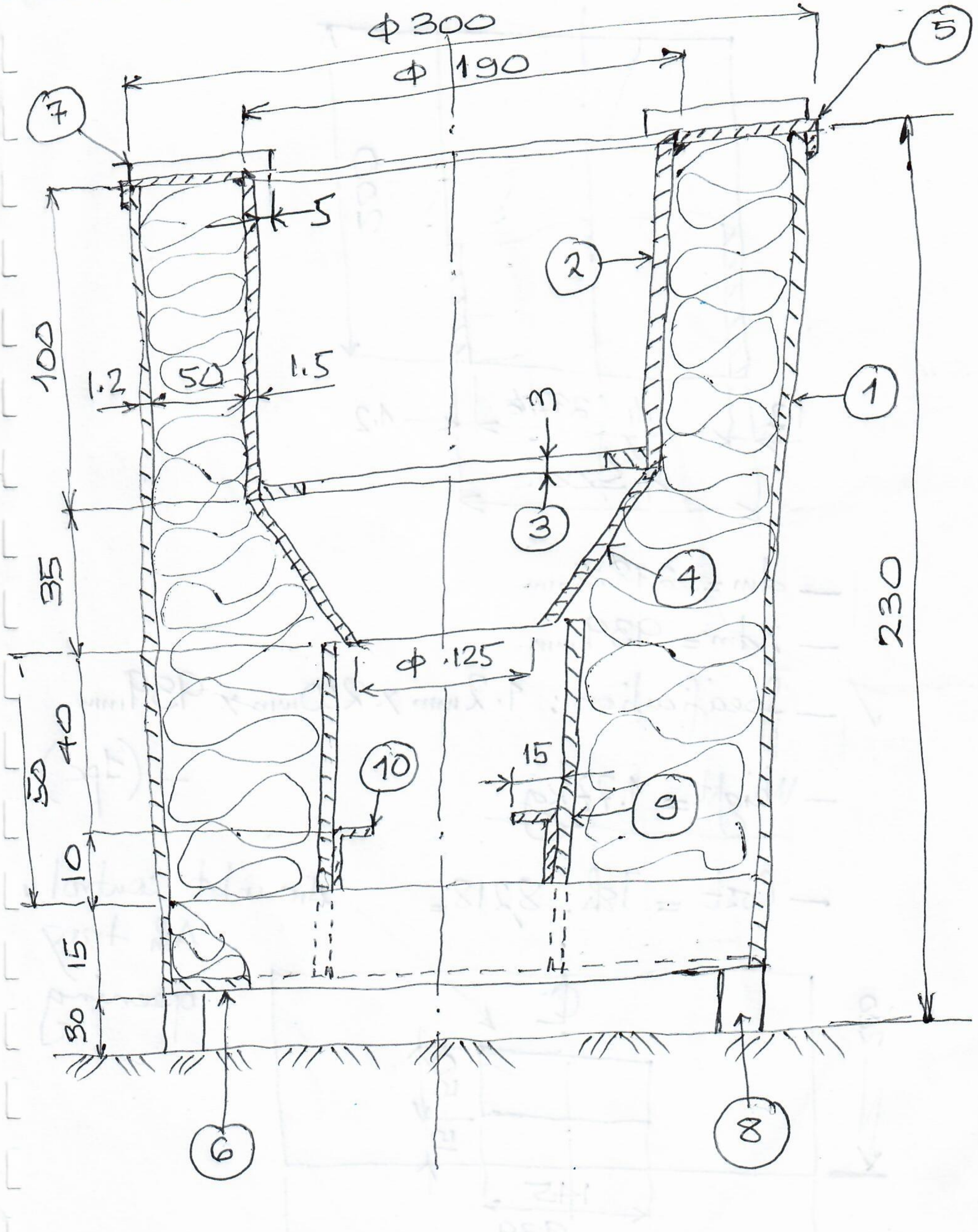
8.3 SeTa MKAA STOVE PARTS DETAILS

2.0 Proposed new Stove design

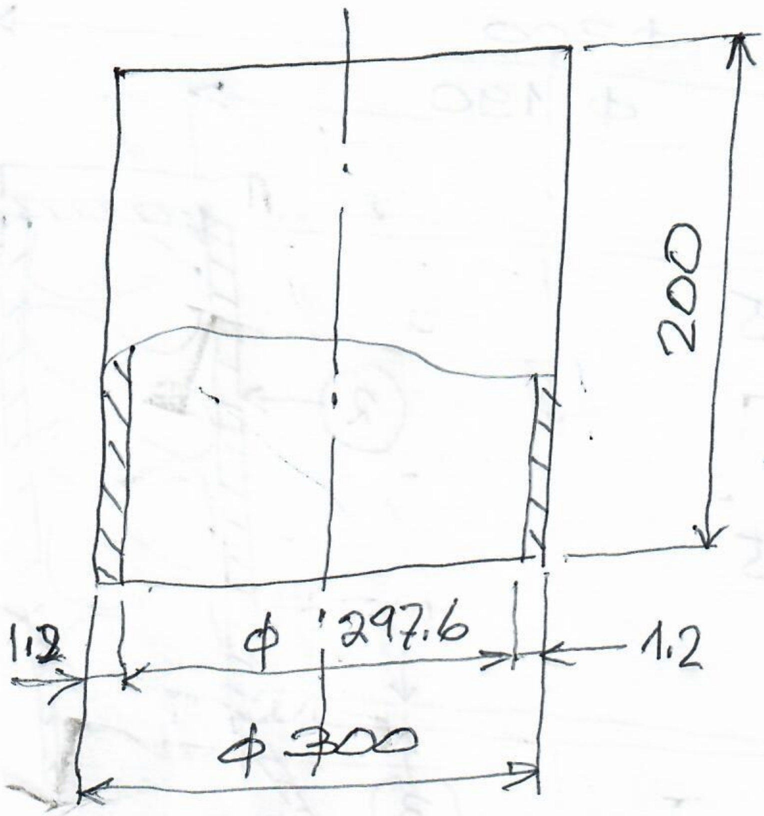
The proposed improved Stove has the following parameters:

- Outside diameter = 300 mm — GS sheet, t = 1.2 mm
- Combustion chamber diameter = 190 mm
- Combustion chamber material — Stainless Steel 1.5 mm
- Depth of combustion chamber = 100 mm
- Stove body height = 200 mm — GS sheet
- Insulation thickness = 50 mm
- Air inlet opening = 50 mm x 145 mm
- Number of pot supports = 4
- Insulation material = Ceramic Fibre Blanket (50 mm x 610 mm)
- Grate material = Stainless steel, t = 3 mm
- Ash guide to ash tray ⇒ Frustum of a cone [D = 190 mm, d = 125 mm, h = 35 mm]
- Overall stove height = 230 mm.

2.1 Stove sketch and details of parts



2.1.1 Stove cylinder – GS Sheet, $t = 1.2mm$



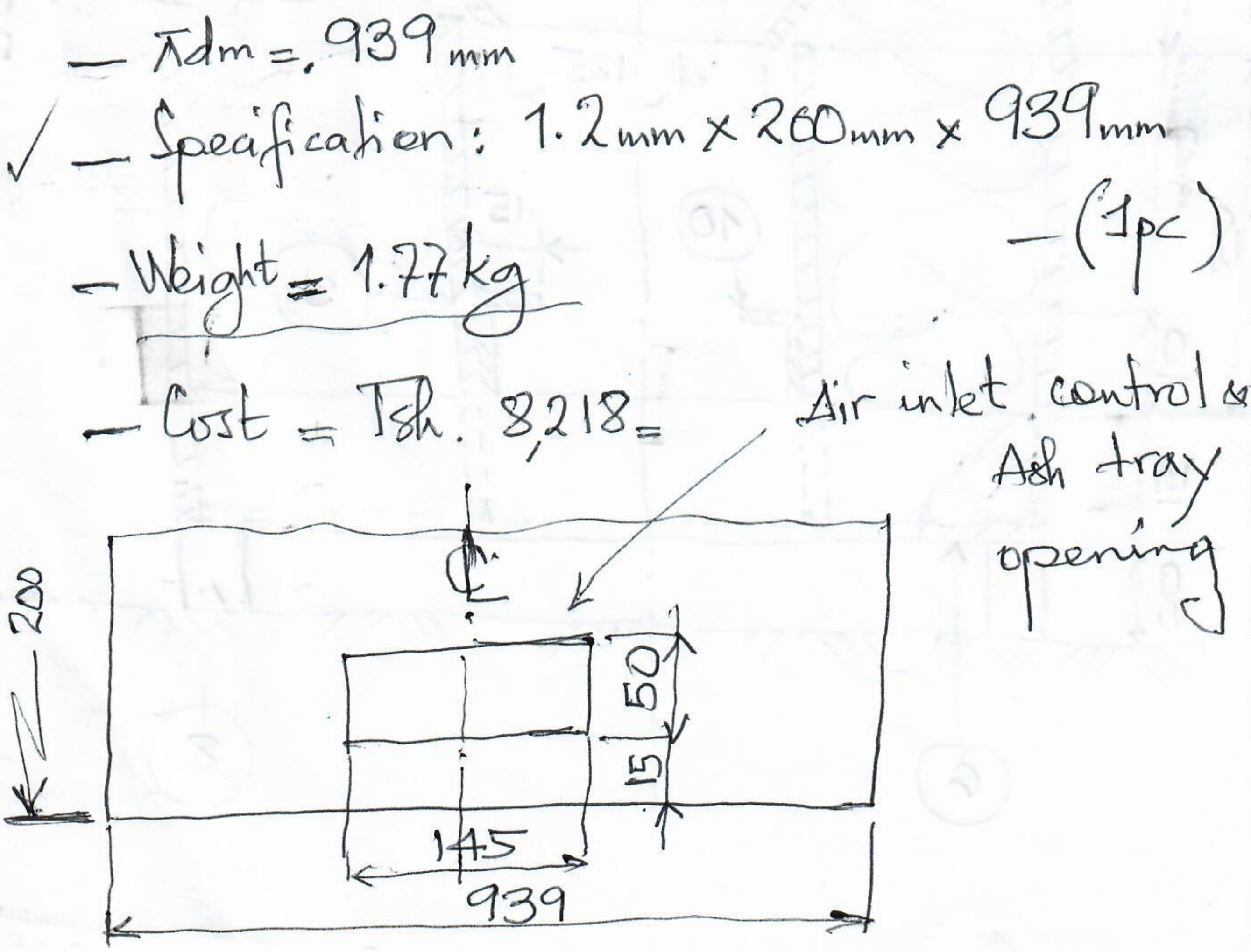
– $d_m = 298.8mm$

– $\pi d_m = 939mm$

✓ – Specification: 1.2mm x 200mm x 939mm – (1pc)

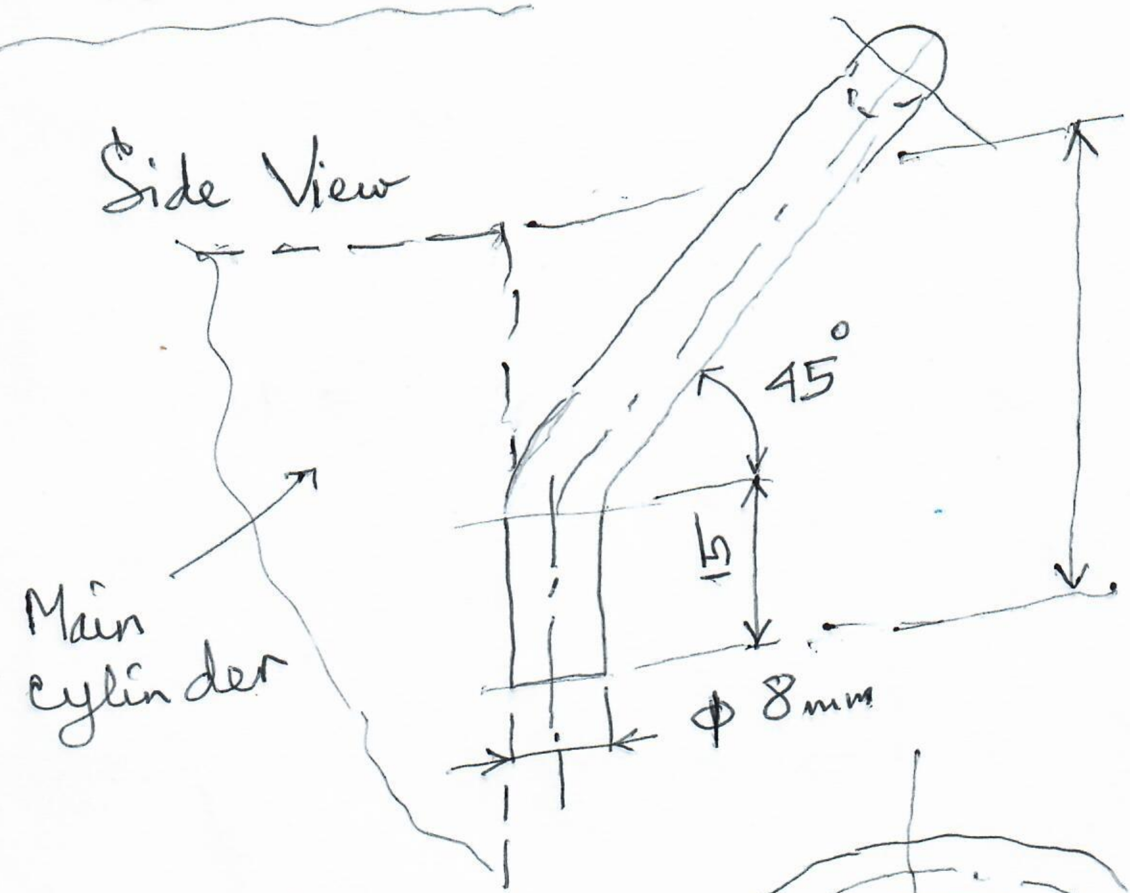
– Weight = 1.77 kg

– Cost = Tsh. 8,218=

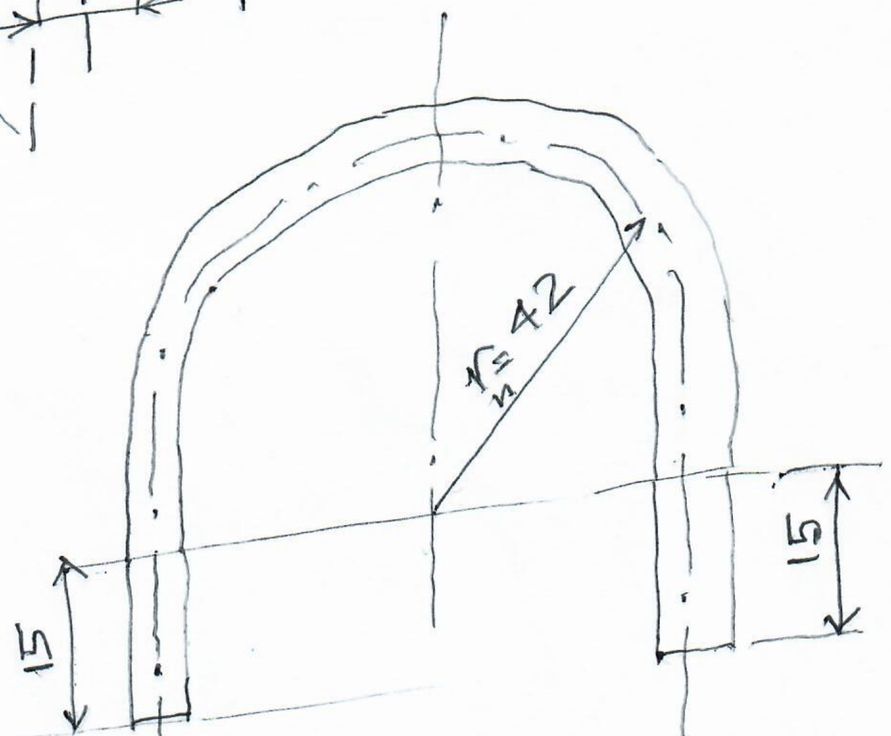


2.1.1 Stove Handles

Side View



Front View

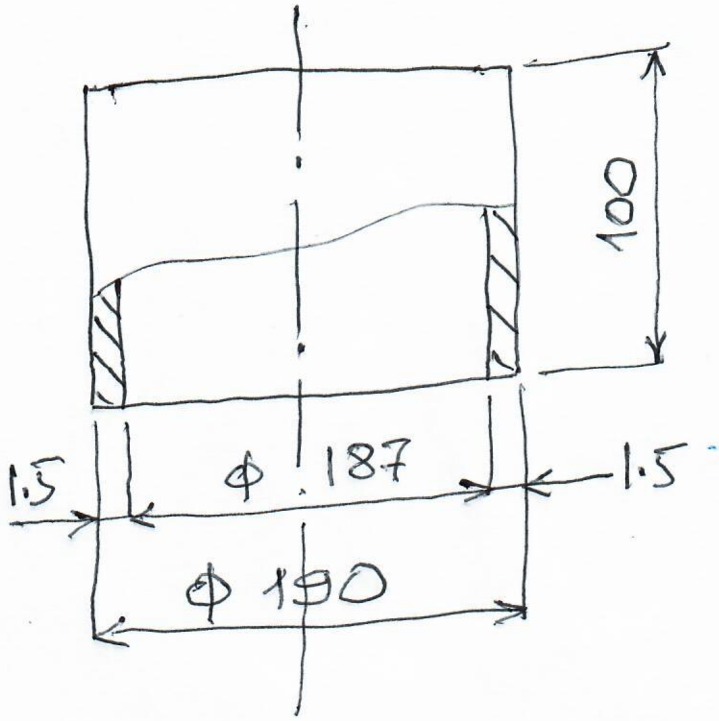


- Developed length ≈ 162mm

⇒ Specification: ϕ 8mm x 162 mm — 2pcs

- Weight = 0.128kg
- Cost = Tsh. 567=

2.1.2 Combustion chamber cylinder – Stainless $t = 1.5mm$



– $d_m = 188.5mm$

– $\pi d_m = 592$ mm

✓ – Specification: 1.5mm x 100mm x 592 mm → 1pc

– Weight = 0.7 kg

– Cost = Tsh. 5,800=