POTENTIAL OF BIO-FUEL GEYSERS: CHARACTERISATION AND PERFORMANCE EVALUATION OF THE SHIZA MANZI BIO-FUEL GEYSER

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ABSTRACT

This paper aims to highlight the potential and prospects of bio-fuel geysers in South Africa, notably the *Shiza Manzi* geyser. The geyser is compared to the *imbaula* and an improved *StoveTec* bio-fuel stove using the SeTAR Centre heterogeneous stove testing protocol. The geyser gave a high power of 23 kW and an adequate thermal efficiency of 36%, boiling 20 litres of water in an average of 12-minutes. The CO:CO_2 ratio (indicator of combustion efficiency) was high (12%) during the middle phase of combustion, but averaged 6.9% over the entire burn phase, indicating moderate combustion efficiency. The *imbaula* and *StoveTec* both took on average 20 minutes to bring 5 litres of water to the boil, with average fire-powers of 4 kW and 2 kW, respectively. The *imbaula* had a thermal efficiency of 15% and the *StoveTec* 28%. Information from this paper can be useful in the development, design and dissemination of more efficient bio-fuel hot water geysers. The rollout of bio-fuel hot water heaters has potential as a CO_2 mitigation strategy and such evaluations are needed as part of emerging air quality management strategies to improve quality of life in countries that are still dependent on bio-fuels to meet their domestic and institutional cooking and hot water needs.

Keywords: *Shiza Manzi*, bio-fuels, hot water geyser, heterogeneous testing protocol, thermal performance, emissions, stoves

1. INTRODUCTION

The heating of domestic hot water is an important component of energy consumption in the residential and small institution sectors in many countries [1]. In South Africa, common methods of heating water in the middle-to-upper income households include conventional electrical element geysers, solar heating, heat pumps and gas heating. Although the country has an abundance of solar energy, to date relatively few households have been fitted with solar water heaters and the majority still rely on the use of electrical element geysers. In fact, all policy cases assume near-universal electrification, and yet in the residential sector we find that the share of other commercial fuels (LPG, paraffin and bio-fuels) is increasing [2]. As a result of high unemployment rates and limited socio-economic development most people still live in shacks and other dwellings with insufficient service provision. Even if they have electricity in these dwellings, say in the form of Free Basic Electricity (FBE), they can not afford to use it on water heating, thus they rely on other more readily available and cheaper alternative energy sources.

In the past decade, there have been many calls to develop and implement measures of improved efficiency of electrical geysers, including hot water cylinder (HWC) insulation and load control timers. These have met with limited success, prompting designers to focus on alternate energy sources for domestic hot water consumption. However, the abundance of cheap coal and electricity in South Africa poses a major challenge to the successful implementation of renewable energy technologies [3]. The following are some of the selected technologies that have been advocated.

1.1 SOLAR WATER HEATERS (SWH)

Due to the electricity peak load which is at times greater than the generation capacity of the national electricity grid, it has been suggested that widespread adoption and use of SWHs could be effective in reduction of the peak load. This would only be possible by expanding the SWH market and creating city by-laws to make such installations compulsory. SWHs have not been extensively pursued in South Africa resulting in a weak and fragmented market, despite support from the Department of Energy [2] and a national subsidy programme, administered through Eskom. The project in Lwandle Township near Somerset West has been significant to understanding issues related to the dissemination and adoption of SWH [4–6]. Most of the SWHs that have been installed have been sold by private entrepreneurs to middle-to-high-income households using mortgage financing and sometimes supplier finance [2]. The installation cost of a 1 000 litre system costs about R40 000 with a lifetime of approximately 20 years and that for a 200 litre system is R15 000 with a lifetime of about 10 years. The rebates from Eskom for SWH and heat pumps range from R3 361 to R8 964, depending on the size and type of the system (Taenzana, 2012; Personal communication).

Barriers to installation of SWHs are the high investment costs and the possibility of operational problems. Given the high capital costs of SWHs, such an investment would be more suitable for middle- and upper-income households, primarily those in urban areas. In low-income areas, lack of access to credit sources has limited access to solar water-heaters (SWHs) and conventional electric systems tend to be installed as default heating systems during construction of subsided housing (reconstruction and developing plan - RDP - houses [7]. However, the cost of SWHs is expected to decline over time, with the advent of novel technology more acceptable in the South African market [2]. Lower cost single tank SWH systems are available, but tend to have shorter guarantee and service lifetimes.

1.2 ELECTRIC GEYSER BLANKETS

Electric hot water heater blankets are being used as a demand-side management (DSM) measure to save electricity consumption in residential areas [8]. They have been suggested to be appropriate policy interventions in poor but electrified households [2]. Insulating existing electric storage geysers has been reported to have the potential to save electricity use by up to 12% [9, 10]. Harris *et al*. [11] reported that by properly insulating the hot water cylinder and related pipes, standing losses may be reduced by up to 22%. However, it is assumed that less than 10% of households have geyser blankets (John Ledger, 2012; Personal communication). A study carried out by Bosman *et al*. [8] revealed that using an electric hot water blanket will save 151 kWh per annum with a cost saving of R45.29 per annum (assuming an electricity tariff of R0.30 per kWh).

1.3 HOT WATER LOAD CONTROL

Hot water load control has been suggested to effectively manage load during peak periods. This would in turn reduce electricity cost due to electrical load manipulation by lowering the maximum demand by shifting energy into cheaper, off peak periods [12]. Conventionally, hot water load control and management involved effectively managing peak loads without taking temperature and the demand for hot water at that specific stage into account. Steenkamp and Calmeyer [12] suggested a system of control that took the above concerns into account. The prototype system was implemented at the University of Pretoria to separately control each centralized cylinder in student hostels, based on present volume demand for hot water as well as the timing of the demand, and the maintenance of a minimum useful temperature. It was concluded that hot water load controllers reduced the amount paid for electricity and they also ensured that the temperature of the hot water remained above 42°C. Without the controller the hot water temperature at times dropped to drop to 33°C [12]. The cost of installing such a system is ~R1 300 (www.hitemp.co.za/energysavers). Thus, hot water load controllers can be a reality to households at the lower end of the economic ladder if they are carefully marketed.

1.4 EFFICIENT CLEAN COOK STOVES

The development of domestic stoves *"...is not a recent phenomenon. Within the last one hundred years, wood-burning stoves were adopted by middle and upper-income families*" [13] to meet their basic energy needs, such as cooking and space heating. Improved cook stoves are currently being used in all parts of the world to address issues of health and ease of pressure on forest resources due to the excessive harvesting of fuelwood. It is light of this that a variety of improved cook stoves have been designed, developed, and disseminated world-wide. These include fixed and portable types: metal and clay; single and multiple pots, with chimney and without chimney designs. However, the introduction of improved cook stoves has not yielded the desired the desired impacts especially in developing countries. A variety of reasons which include social barriers, institutional barriers, economic and financial barriers, policy barriers, technical barriers, information barriers and pricing distortions may be attributed to these set-backs [14].

This field has been further revitalised by the introduction of the Global Alliance for Clean Cook stoves - GACC (www.cleancookstoves.org) and the Partnership for Clean Indoor Air – PCIA (http://www.pciaonline.org/).

1.5 RATIONALE OF STUDY

Bio-fuel geysers have been identified as significant in the contribution towards poverty alleviation in terms of improving the general welfare of households as well as the development of activities that offer employment opportunities. However, there is little awareness about the benefits and opportunities of bio-fuel geysers. Bio-diesel fuels are complex to implement due to the issues surrounding energy provision and food security, which often require ministries and stakeholders to sit in endless meetings in-order to reach a consensus. The modest aim of this paper is to present a technical evaluation of an innovative design that was presented for testing at the SeTAR Centre, University of Johannesburg. A secondary aim of the paper is to present the testing capabilities of the SeTAR Centre as a facility to support innovation and sound technical development. The main objective of this paper is to characterise the performance of the *Shiza Manzi* solid bio-fuel geyser and to highlight its potential in a market that is widely dominated by electrical elements and to a lesser extent SWHs, for domestic and small institutional water heating. It is assumed that a new water heating product using solid bio-fuel (wood, agricultural waste) would be competing with other devices using the same fuel types, and not directly with electric hot water devices. Accordingly, the base-line reference devices for this study have been selected as the conventional brazier – *imbaulas,* and the *StoveTec Greenfire Rocket* stove. Hot water services would be obtained by heating smaller quantities (up to 5 litres at a time) in a pot on top of the stove, the default option in many poorer households, on or off-grid.

2. EXPERIMENTAL SET-UP

2.1 HEATING DEVICES TESTED

Three devices were evaluated for thermal and emissions performance and included the *StoveTec Greenfire Wood Rocket Stove*, the *imbaula* and the *Shiza Manzi* bio-fuel geyser.

The imbaula

Imbaula (brazier type) stoves are hand made out of cylindrical metal drums (generally recycled) with perforations of varying sizes around the sides, and a wire grate across the middle of the container to hold the solid fuel. These devices are found in three characteristic sizes, determined by three commonly available metal drums: 20 litre metal paint drums, 70 litre metal dustbins, or sectioned 200 litre oil drums. A typical 20 litre *imbaula* is illustrated in Figure 2. *Imbaula*s commonly have a fuel support grid, made of scrap galvanised wire or a perforated plate, but some are operated without a fire grate. When a fire grate is in place, the rate of burning is increased due to increased air flow.

Figure 2. A typical *imbaula* on a test rig

The *imbaulas* vary greatly in terms of the number and sizes of the side holes, the presence of a grate and its position in the metal drum, making it difficult to standardise them. These metal drum stoves are used widely in the townships of South Africa for space heating, water heating and cooking, especially in winter. The stoves can burn wood, coal, or a combination of both, and often rubbish which includes waste plastic. The stoves are widely used in winter for space heating and cooking.

StoveTec Greenfire Wood Rocket Stove

The stove is comprised of two cylinders forming a right angle (rocket elbow). One end of the elbow is for inserting fuel and drawing in air (Figure 1). The other end is for combusting the gases and smoke from the wood, and emitting heat. The stove has a ceramic lining, which retains enough heat to keep a pot simmering for more than 15 minutes.

Figure 1. *StoveTec* Rocket stove with a fuel stand

The stove is ideal for the backyard, camping or caravanning. It is specifically designed for burning wood. Instead of a grate, a 'stick support' feeds wood into the combustion chamber. The large fuel-opening will admit slightly large pieces of wood. Heat output is controlled by feeding more sticks into the combustion chamber or pulling them back. An optional adjustable wind shield that fits snugly around the pot is used to enhance the efficiency of the system.

The Shiza Manzi Bio-fuel Geyser

Understanding that hot water is an important instrument for social development, Johannes Schonken of Schonken Marketing cc developed the *Shiza Manzi* bio-fuel geyser, which is now in its pilot stages in South Africa. The geyser is made of stainless steel and all other parts are made from copper to ensure the geyser is rust free. The geyser is a 'free-flow' system and it does not require a pressure relieve valve thus making it a safe product to use. It has an internal combustion chamber surrounded by a concentric water jacket. The chimney has a fibre glass insulation sleeve for heat protection (Figure 3). The stove weighs ~15 kg.

Figure 3. Photograph of the *Shiza Manzi* biofuel geyser in a farm house

The stove uses the top-down approach of making a fire, with a downward-migrating draft. Five hundred grams of dry bio-fuel was added into the combustion chamber and lit using a burning piece of paper. Three minutes after ignition, more fuel (600 – 700 g) is added to the combustion chamber. On reaching boiling point, the hot water in the jacket is forced out by opening the cold water inlet half way. To extinguish the fire an airflow regulating plate may be slid over the combustion funnel to cut off the oxygen supply. To remove the ash after a complete burn cycle, an ash removal plate at the base of the geyser is slid open and the ash collected in the ash pan supplied.

2.2 EFFICIENCY TEST

In this experiment, the water temperature was measured using a digital thermocouple. Efficiency was determined using the SeTAR Centre *heterogeneous stove testing* method [15] which required a known quantity of water (5 litres for the *StoveTec* and the *imbaula*, and 20 litres for the *Shiza Manzi* geyser) to be heated on the stove or in the geyser. The devices were loaded with sufficient fuel to be operated at the highest possible power setting. Since water heating was the primary objective of the tests, only the high power test of the protocol was used. The quantity of water evaporated after complete burning of fuel was determined to calculate the efficiency by using the following formula:

$$\eta = \frac{C_p M_w(\Delta T) + M_e L}{\Delta M_f(LHV_f) - M_c(LHV_c)} \qquad \text{Equation 1}$$

where M_w is the mass of the water in the pot at the start of the test (kg), C_p is the specific heat capacity of water (4.186 $Jg^{-1}{}^{o}C^{-1}$), ΔT is the rise in the water temperature (ºC), M_e is the mass of the evaporated water (kg), L is the latent heat of vaporisation of water (2 260 J g^{-1}), ΔM_f is the scale-indicated mass of raw fuel burned (kg), M_c is the mass of charcoal remaining (kg), LHV_f is the lower heating value of the fuel adjusted for moisture content (MJ kg^{-1}), and LHV_c is the lower heating value of the residual charcoal (if any) (MJ kg^{-1}).

2.3 FIRE-POWER

The test procedure for determining the power settings used was similar to that advocated by Prasad *et al.* [16]. The burn rate of a device can be regarded as comparable to fire-power [17]. The mass of a stove was measured by means of a mass balance on which the stove rested. The instantaneous power output of the stove is defined as the mass loss rate multiplied by the lower heating value of the fuel, assuming complete combustion (i.e. products of incomplete combustion are minimal):

$$P = \frac{(LHV \times \Delta m)}{\Delta t} \qquad \text{Equation 2}$$

where P is the fire-power of the stove at a specified power setting (watts); Δt is the time interval (seconds); Δm is the mass loss in a specified time interval (kg); and LHV is the lower heating value of the fuel (MJ kg^{-1}).

2.4 EMISSIONS PERFORMANCE TESTS

The *hood* method was used to capture and sample emissions from the *StoveTec* and the *imbaula*. Since a high extraction rate may influence the combustion characteristics of the stove, an extractor fan was not used for drawing air through the hood and duct. For the *Shiza Manzi* geyser, the gas sampling probe was inserted into the chimney of the geyser. The sampling configuration for gases included, in sequence, a stainless steel probe, a filter, and a flue gas analyser (Testo® 350XL/454). As the heterogeneous testing protocol uses the concentration of gases, including residual oxygen, and the absolute mass loss rate of the stove/fuel to calculate emission factors, the measurement of gas flow rates in the hood or chimney is not required.

The Testo® flue gas analyser was connected to a computer for data logging. Data points were recorded at 10-second intervals. At the end of a complete burn cycle, the data were coded onto an Excel® file for processing and analysis. The Testo® measured CO_2 (NDIR cell), CO, NO, NO_2, H_2, H_2S, SO_2 and O_2 (all electrochemical cells). Tests were run in triplicate for each device to derive means and standard deviations.

An emissions factor is a term given to a gas concentration that has been normalised for any dilution by excess air. In this paper, the term emission factor is defined as concentration of a gas emitted by the stove, expressed in parts per million volume (ppmv), normalised to 0% excess air (oxygen). It is possible to convert this value to other units such as [g MJ^{-1}] of fuel. This provides the concentrations in undiluted air (i.e. sufficient air to provide stoichiometric combustion).

3. RESULTS AND DISCUSSION

Water boiling tests were conducted to determine the suitability of the experimental devices for heating water for an average low-income household. The results showed that the *Shiza Manzi* geyser had a higher fire-power (23 kW) than the *StoveTec* and the imbaula, respectively (Table 1). This is because the *Shiza Manzi* geyser is consisted of a water jacket, which captures radiant heat from the combustion zone and convection heat from the hot gases, thereby rapidly increasing the temperature of water. On the other hand, more fuel was added in the geysers fire hopper compared to the *StoveTec* and the *imbaula,* potentially resulting in increased fire-power of the geyser (Table 1). The *imbaula* shows a fire-power of 4 kW in comparison with the *StoveTec* which showed an average 2 kW fire-power.

Table 1. Stove performance indicators at the high power phase

	Devices Tested		
Parameters	**Stove Tec**	***Imbaula***	***Shiza Manzi***
Mass of water boiled (L)	5	5	20
Fuel consumed (g)	311 ± 23	516 ± 37	1039 ± 40
Time to boil (min) (from ignition)	23.7 ± 3.1	22.7 ± 4.5	11.8 ± 1.6
Firepower (kW)	2.3 ± 0.4	4.1 ± 0.7	23.3 ± 4.2
Thermal efficiency (%)	28.4 ± 1.2	14.9 ± 0.3	36.0 ± 1.4
CO_{EF} (mg MJ^{-1})	2.2 ± 0.4	1.9 ± 0.6	5.2 ± 0.9
Average $CO:CO_2$ ratio (%) over test	7.0 ± 1.2	6.0 ± 2.0	6.9 ± 5.1

The *Shiza Manzi* geyser showed a better thermal efficiency (36%) than the *StoveTec* (28%) and the *imbaula* (15%). The *Shiza Manzi* geyser showed an average $CO:CO_2$ ratio over the entire test of 6.9, the *StoveTec* 7.0 and the *imbaula* 6.0. However, looking at the error bars, there was no significant difference ($p<0.05$) in the $CO:CO_2$ ratio exhibited by all devices tested.

No significant difference was observed ($P<0.05$) in the CO_{EF} between the *imbaula* and the *StoveTec*. However, there was a statistically significant difference in the CO_{EF} between the geyser and the two stoves. The bio-fuel geyser produces twice the amount of CO_{EF} produced by the other stoves. The increase in the CO_{EF} could be due to lack of sufficient oxygen to allow a good fuel-to-air mixture, which in turn favours complete combustion. There is need to lower emissions of incomplete combustion as these have an impact on the local air pollution.

The *Shiza Manzi* geyser is capable of bringing 20 litres cold water to the boil using less than 1.2 kg of dry fuel. The geyser took an average of 12 minutes to bring 20 litres of water to the boil. To bring to the boil 5 litres of water the *StoveTec* and the *imbaula* took on average 23 and 22 minutes, respectively. Due to a high fire-power, the geyser was able to bring to the boil a large volume of water in a short space of time. Thus, the *Shiza Manzi* geyser is recommended for adoption, in terms of time saving, since it can provide enough hot water for an average family within a short period of time, and would be useful for small institutions such as clinics or school hostels. Tests conducted at the SeTAR laboratory, have indicated that 20 litres of water at boiling temperature can provide up to 60 litres of bathing water at 45 ºC when diluted, sufficient for a household of four. On average, 5 litres of boiled water is reported to be sufficient for an individual (yielding up to 12 litres of warm bathing water).

The results exhibited by the *Shiza Manzi* show the importance of iterative designs in creating a balance between high fire-power, high thermal efficiency and low emissions. This fact is often overlooked by many designers and artisans although it is an important part of the design process. This is because iterative designs are expensive to carry out and often need a high injection of capital (to cover for comprehensive tests and material) before the prototype is finalised.

3.1 APPROXIMATE COST OF THE TESTED DEVICES

This section seeks to highlight what the consumer could anticipate paying for the selected and tested devices. It does not describe the economics of the target market as this is beyond the scope of this paper. As an impartial technical performance evaluation Centre, it is not the function or the responsibility of members of the SeTAR Centre to perform an in depth analysis of the costs, economics, and marketing strategies in relation to target markets of the devices presented for evaluation. This discussion gives nominal retail prices as an indication, and hence the likely sectors of market uptake.

The *Shiza Manzi* geyser is a relatively expensive innovation with nominal retail cost of ~R3 700 per unit. This is because the stove is made entirely out of stainless steel, which is a rather expensive alloy to use. The *StoveTec* costs on average less than R400. The imbaula is home made and self fabricated according to individual taste. It is difficult to put a price on this device as it is not sold on the formal market. The only costs incurred by the users are for the purchases of the paint drums; the price of each drum usually does not exceed R30. Some individuals collect the drums free from dump sites (Table 2).

Table 2. Approximate cost of the devices tested including VAT

Device tested	Approximate cost
StoveTec	R300
Imbaula	Home made/self fabricated (R20–R30)
Shiza Manzi	R3 700

Although SWHs were not tested for efficiency and compared to the devices highlighted in this paper, relative prices per system are given in Table 3 to show high start-up costs for these devices.

The high start-up cost for SWHs has forced households to continue relying on paraffin and wood to meet their water heating needs. Table 3 shows a typical quote for different sized high and low pressure units. Low pressure solar water heaters have a potential to replace the costly high pressure systems. Financial savings of adopting solar waters have been reported extensively in literature. The nominal prices for low pressure systems are relatively low compared to high pressure systems and yet poor households struggle to raise the start up capital, which covers the total installation costs. In some cases, there is 'cash payback' if ones gets a system with a total start up cost that is less than the Eskom rebate for that product (see Table 3).

Table 3. An example of a quotation for different sized solar waters heaters and associated Eskom rebates

High pressure unit	Installed price (R)	Rebate (R)	After rebate (R)
200-L high pressure split pumped	23 000	4 700	18 300
200-L high pressure integrated	13 000	0	13 000
150-L high pressure split pumped retrofit	16 000	4 000	12 000
200-L high pressure split pumped retrofit	17 000	4 000	13 000
100-L low pressure Direct-frost resistant	8499	2858	5641
115-L low pressure Direct	6999	4176	2823
100-L low pressure Direct	3592	4233	-641*

-Prices are exclusive of VAT
-* Cash return after claiming rebate
-All prices indicated are a guideline - final pricing to be determined (up or down) by site specific constraints

4. CONCLUSION

The *imbaula* and the *StoveTec* took more than 20 minutes to boil water enough for a single adult to bath. Although the devices are cheap to source, they do not represent a practical or convenient solution for the provision of hot water to an average poor household. They could however present obvious financial and social benefits, for example in cooking (*StoveTec*) and space heating (imbaula). The *Shiza Manzi* could efficiently meet family needs, but cost would be an inhibiting factor. In contrast, the inherent durability of stainless steel construction and high fire power could make the device an attractive investment for small institutional needs, such as rural off-grid clinics.

Test facilities are needed for local innovators and entrepreneurs to develop energy efficient and less polluting combustion devices. In the past, evaluation costs of R100 000 and more for single products has inhibited the potential, growth and promotion of small-to-medium enterprises (SMMEs) in this field. Through the use of an appropriately modified heterogeneous stove testing protocol (HTP), available at a more affordable cost through a university-based testing and technical advice centre, based on solid science and engineering principles, SeTAR Centre his able to give entrepreneurs leverage by assisting them in the design, development and testing of their novel products, thus enabling the clients to make suitable technical and business decisions, including marketing based on objective test results.

5. RECOMMENDATION

We recommend the following**:**

- Further research in social marketing of bio-fuel geysers in South Africa
- Research into life-cycle analysis and benefits of bio-fuel geysers
- Specialised agencies to plan and promote bio-fuel geysers should be created.
- Creation of information channels where product information is disseminated. This also involves engaging communities in developing products. Public understanding of science technology (PUST) is a key tool for the adoption of new technologies.

6. ACKNOWLEDGEMENTS

We wish to acknowledge funding and sponsorship from the following organisations: the CEF, GTZ ProBEC and BECCAP programmes, and the South African National Energy Research Institute (SANERI) who commissioned the SeTAR Centre. We also wish to acknowledge Jannie Schonken for allowing us to evaluate his geyser and furthermore to publish and present the findings at the DUE conference. Lastly, we acknowledge all the researchers at the SeTAR Centre, University of Johannesburg.

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