Evaluation and comparison of the performance characteristics of improved firewood stove for rural households of Rwanda

Jean de Dieu Iyakaremye[1], Leonce Harerimana[1], Deepak Das[1], Francois Mugwaneza[1] and Jean Bosco Ndikubwimana[2]

[1] Department of Agricultural Mechanization, University of Rwanda

[2] Department of Applied Statistics, University of Rwanda, Nyagatare Campus, Po Box 57 Nyagatare

Corresponding Author: Jean de Dieu Iyakaremye, Email: iyakjdd@gmail.com

Abstract

Fire wood is the dominant energy source used for cooking, heating and other activities in rural households in Rwanda. One of the solutions to overcome the shortage of fuel wood and environmental degradation is the use of fuel efficient stoves. Development and promotion of energy technologies improves living standard by contributing to poverty. This paper is about the evaluation and comparison of the developed types of burnt clay stoves so as to find out the fuel efficient stove to recommend to rural households. The stove developed has the characteristics of reduced consumption of firewood and thus reduce deforestation rate and additionally reduces harmful indoor air pollution. five different stove models were developed by College of Agriculture, Animal Sciences and Veterinary Medicine (CAVM), have been taken for this study together with a local three stone open fire stove serving as a control. During this research cooking test of different food stuffs and boiling test were carried out to determine the thermal efficiency of stoves. The results showed that Model 5 was the best performing among others tested and only 25% of firewood is needed in model 5 when compared to local stove model. The thermal efficiency of the model 5 stove found to be 27.61% while the efficiency of local stove is only 8.46%. The statistical analysis showed that there is significant difference in boiling time and cooking time of various food items at the 95% confidence level. The same is true with the wood consumption. Through the mean separation Model 5 emerges to be outstanding in all the aspect. It is concluded to adopt and promote Model 5 stove especially for rural households for cooking since it is the most ecofriendly to environment among the tested models and can contribute to poverty reduction and generating income to the Rwandan society through more fuel and time saving.

Key words: Fuel stoves, firewood, improved stoves, fuel wood, efficient stove

1. Introduction

Fire wood is the dominant energy source for the most fuel-consuming jobs done by the rural population in Rwanda, including cooking, keeping warm, heating water for washing, smoking food and brewing beer (NISR 2008a). Firewood collection is perceived as an increasingly difficult task, and many people are walking lengthy distances for wood (Okorio et al, 2003). In Rwanda firewood alone accounts for more than 80% (MININFRA, 2009). Biomass is already in short supply with the country facing a biomass deficit of over 4 million m^3 per year. The collection of firewood is typically the responsibility of women and minors and can take up to several hours per day in less forested countries (Steve, 2014). Fuel wood problem is acute in almost all areas of Rwanda.

The total opportunity cost of time lost to avoidable cooking drudgery and fuel collection tasks globally is over 60 million person years annually. Researchers have suggested that up to one-half of this time could be redeployed to economically productive activities (World Bank, 2015).

The conventional three stone stoves used in Rwanda have the problems of wasteful use of fuel (Laan et al, 2010).

Research over the last few years has clearly proven that improved stoves can reduce both particulate matter and carbon monoxide by 24 % – 70 % (Steve, 2014).

Development and use of improved stoves can also reduce the use of wood for fuel and thus reduce deforestation rate and can increase carbonization efficiency while additionally reducing greenhouse gas emissions (Steve, 2014).

Improved stoves are not only time saving in cooking but also improved stove would reduce time utilized in fetching firewood and avail the same to other development activities (Boy E *et al*, 2000).

The demand for energy in Rwanda is substantially higher than the supply from domestic production. In this context this research is an attempt made to evaluate the efficiency of 6 stoves to address the above stated problems. The study has been undertaken with the following objectives:

- To evaluate and compare the thermal efficiency of 6 different stoves
- To determine the firewood and time saving by the improved stove over the local stove

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

2. Methodology

2.1 Area of the study

The study was conducted in conditions of Busogo Sector, Musanze District of the Northern Province, in Rwanda. This region surrounds the Volcanoes National Park with a lightly undulating slope of about 15 %. The area has a tropical climate, high altitude with an average temperature of 20ºC. The annual rainfall varies between 1400 mm and 2000 mm. The altitude varies from 2,500 m to 2,700 m and wind velocity varies between 0 to 4 m/s. (Annual Report, District of Musanze, 2006)

The different improved stoves studied in comparison with local stove have been designed and developed in College of Agriculture, Animal Sciences and Veterinary Medicine (CAVM).

The materials such as sauce pans were used as cooking vessels, measuring cylinder to measure water before and after boiling, thermometer for recording temperature during cooking and boiling test, stop watch for recording time, different food stuff (rice, potatoes, beans, oil, and salt), cutting tools(knife) and balance for measuring different quantity(wood, food stuff) used. The type of wood fuel used was eucalyptus saligna for this particular study.

The methodology that was used consisted of cooking test, the boiling test and the calculation of the wood reduction by improved stoves.

2.2. Description of the tested stove

Improved firewood stove development originated from the conventional clay stove made by the village potters. Commonly, all five improved and smokeless stoves are made of a mixture of clay at 92%, sand 6% and wheat ash at 2%. Their specifications are shown in table below

Table 1: Specification of CAVM Model stoves

Specification	Model–1	Model–2	Model–3	Model–4	Model–5
Fire wood gate, cm x cm	20 x 15	20 x 15	20 x 15	20 x 15	20 x 15
Height, cm	22	22	22	22	22
Length, cm	50	45	70	50	50
Width, cm	30	--	Right:50 Left : 50 Front 30	30	50
Primary pot-hole dia, cm	24	24	25	24	24
Secondary pot-hole dia, cm	21	21	21	21	21

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

The different stoves are specified by the respective photographs for each stove hereunder.

Fig 1: photograph for each stove developed at CAVM

The main purpose of the study is to determine thermal efficiency of all the cooking stoves, and estimate the time and wood saving over the three stone stove.

2.3. Data collection and analysis for various tests

2.3.1. Cooking test

In this test, only the time for cooking, temperature rises and fire wood consumption were recorded. The temperature rise was recorded by immersing the thermometer having the provision of measuring up to 130°C in the food stuff under cooking. The temperature is read every 10 minutes from the starting time to the end time of cooking. The quantity of firewood consumed during the cooking were also considered by measuring the quantity of fire wood before and after complete cooking of each food items and for each stove.

2.3.2. Boiling test and stove efficiency determination

Boiling test has been carried out to measure the performance of different cooking stoves involved in the study in terms of overall thermal efficiency of cooking stove which is the ratio of energy content in the fuel.

To determine the thermal efficiency of various model of stove the boiling test was carried out. Boiling of 3 liters of water in each stove was carried out. In this method, efficiency (n_c) is defined as the ratio of useful heat energy used to the input heat energy.

$$n_c = \frac{Useful\ heat\ energy}{Input\ heat\ energy} \times 100 \qquad (3)$$

Useful heat energy is the sensible and latent heat absorbed by boiled water whereas input heat energy is the one, which is released from the burning of fire wood in each stove. With this definition, the useful heat energy efficiency of fire wood is expressed mathematically as:

$$n_c = \frac{Mw\ Cpw\ (Tb - Ti) + Mwe\ Lv}{Mfwu\ Cvfw} \qquad (4)$$

Where

- Mw = The initial mass of water in kg
- Cpw = Specific heat capacity of water = $4.2 \times 10^3 Jkg^{-1}$

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

- Tb = Boiling temperature of water in degree centigrade
- Ti = Initial temperature of water in degrees centigrade.
- Mwe = Mass of water lost due to evaporation

= Mass of container with water before boiling – Mass of water with container after boiling in kg.

- Lv = Latent heat of vaporisation of water = $2.258 \times 10^6 Jkg^{-1}$
- Mfw = Mass of fire wood used

= Mass of fire wood before combustion – Mass of fire wood after combustion.

- Cvfw = Calorific value of fire wood = $1.68 \times 10^7 Jkg^{-1}$

During the experiment, four experiments have been done successively by boiling 3 liters of water and the arithmetic mean of four values obtained in 4 experiments has been taken as average thermal efficiency of each stove.

2.3.3. Computation of the time saved in using improved stove

The cooking test was carried out for a complete menu of food required for a Rwandan family of 3 members per day. It included rice, beans, potatoes and tea. The following formulas are used to compute the saving in cooking time per cent.

$$Time\ saved\ in\ cooking\ by\ improved\ stove = Time\ in\ local\ stove - Time\ in\ improved\ stove \quad (1)$$

$$Saving\ Time\ (\%) = \frac{Time\ saved}{Time\ in\ local\ stove} \times 100 \quad (2)$$

The time taken for cooking is recorded using a digital watch.

With the experiment testing of the completely randomized design with two factors namely the models of the stove and the food items. The analysis of variance (ANOVA) was used to test the difference among the treatments at 5% level of significance.

The single factor ANOVA was used for the temperature rise test and the thermal efficiency and the means' separation helped to compare the performance of the tested models and to group them.

2.3.4. Reduction of annual fire wood

It is the annual fire wood saved by using improved stove over local stove which is given by the difference between annual fire wood consumption of local stove in the respective annual consumption in fire wood of each improved stove.

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

Let,

Daily fire wood consumption: DFWC

Mass of wood before combustion: MWBC

Mass of fire wood after combustion: MFWAC

Annual fire wood consumption: AFWC

Annual fire wood saved: AFWS,

Annual fire wood consumed by local stove: AFWCLS

Annual fire wood consumed by each improved stove: AFWCIS

Fire wood saving percent: FWS

$$DFWC = MWBC \text{ in } kg - MFWAC \text{ in } kg \quad (5)$$

$$AFWS = AFWCLS - AFWCIS \quad (6)$$

AFWC = DFWC x 360. (7)

Fire wood saving percent: FWS

$$FWS(\%) = \frac{AFWS}{AFWCLS} \times 100 \quad (8)$$

3. Results and discussions

Cooking test involved cooking of dry beans, rice, potatoes and tea; these food stuffs are the principal food items of Rwanda. The foods cooked during test have been chosen because they do not need intermittent checking during cooking and they are eaten every day by most of all Rwandans.

The quantity of food cooked is sufficient for three member house holds per day which contains 500 gm of beans, 1 kg of potatoes, 500 gm of rice and 1.5 litres of tea. The same amount of food is prepared on local stove as well as on 5 models of improved stoves. Temperatures were recorded for every 10 minutes. The weight of firewood used is also recorded.

As shown by the Fig 2, all the stoves pick up high temperatures between 20 to 30 minutes of starting the rice cooking. Temperature profiles of different stoves are shown in table 2.

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

Table 2: Time and Temperature rise in Rice cooking

Time in minute	Temperature rise (°C) in different stoves for rice cooking					
	Local	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
00 -10	80	83	84	83	84	88
10 – 20	90	92	94	92	94	96
20 – 30	92	95	96	95	96	
30 – 40	92					

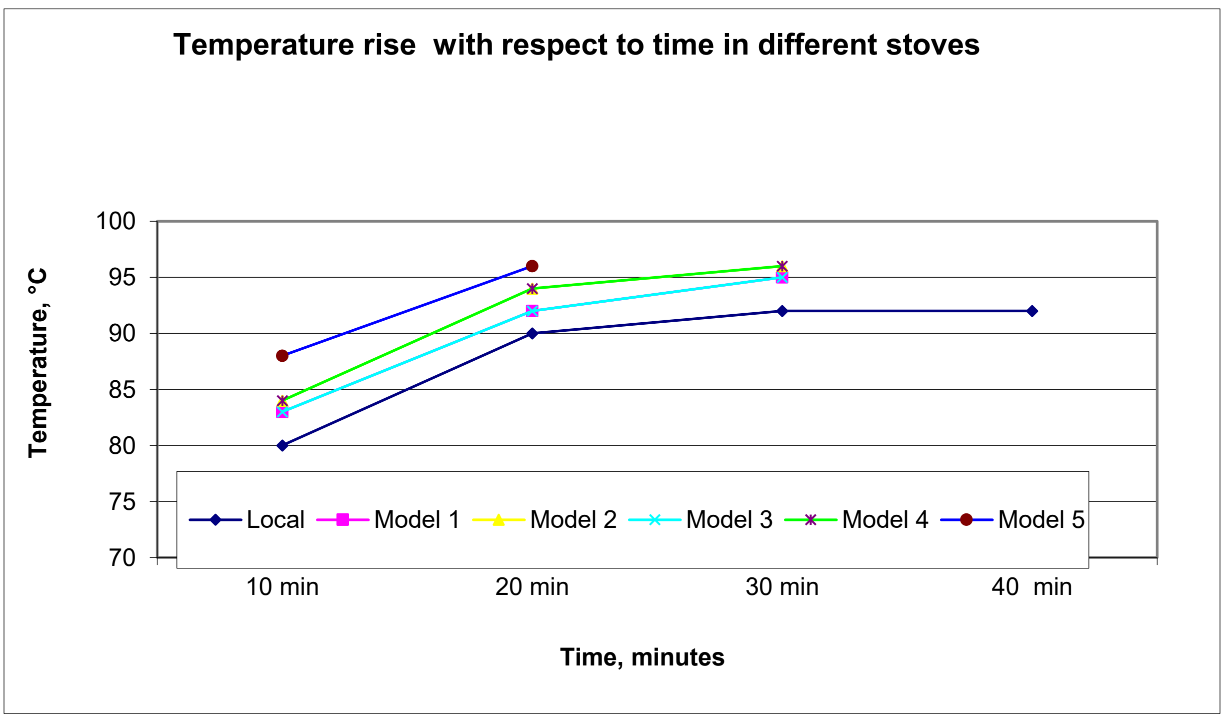

Fig 2: Temperature rise with respect to time in different stoves in rice cooking

In case of the time taken for cooking potatoes, Model 5 stove achieves fastest complete cooking only in 20 minutes as shown in fig 3. More cooking time is taken for 3 stones open fire cooking stove because of more heat energy losses, whereas for the improved stoves, especially Model 5 stove, the cooking time is lower. The reason is that the heat energy inside the body of the stoves is kept preserved for long time which results in very little energy losses.

In table 4, results indicate clearly that the Model 5 stove achieves complete cooking of beans faster than the remaining stoves, while Three-stone open fire cooking stove takes more cooking time. It means that by adopting Model 5 stoves over the local one, there is a time saving of 80 minutes which could be utilized in the other development activities. The temperature rise is initially very sharp and then it follows a curve linear path (Fig.4). The heat is produced slowly for local stove, which results in longer cooking time where the heat production is sharp for improved stoves with exception for Model 5 stove which achieves complete cooking of beans in the shortest period of time (100 minutes) compared to the remaining Models.

The time taken for preparation of tea in different types of stove is shown in table 5. The Fig. 5 shows clearly the difference in tea preparation time between different stoves. Referring to this, it is revealed that by using Model 5 stove, the complete tea preparation time is achieved faster than other stoves.

Table 3: Time and Temperature rise in Potato cooking

Time in minute	Temperature rise (°C) in Potato cooking in different stoves					
	Local	Model 1	Model 2	Model 3	Model 4	Model 5
00-10	80	83	84	80	84	88
10-20	90	95	96	90	96	96
20-30	95	95	96	95	96	
30-40	95			95		
40-45	95					

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

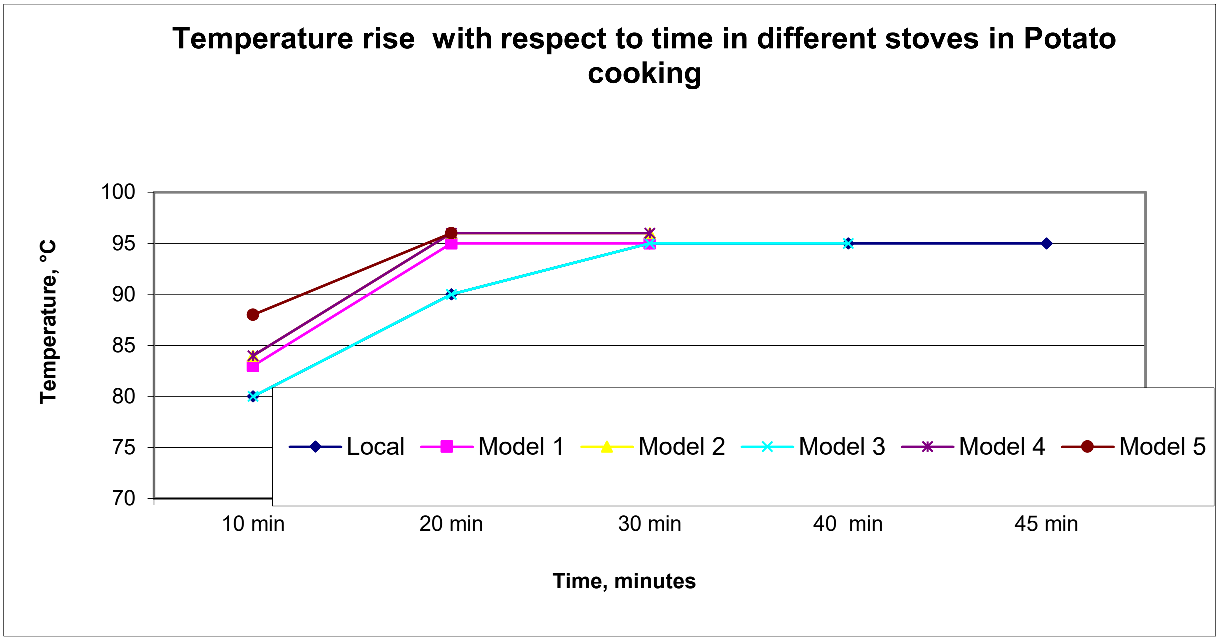

Fig 3: Temperature rise with respect to time in different stoves in Potato cooking

Table 4: Time and Temperature rise in Beans cooking

Time in minute	Temperature rise (°C) in different stoves for beans cooking					
	Local	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
00-10	50	79	80	76	80	80
10-20	59	80	89	78	82	89
20-30	64	88	90	87	90	92
30-40	72	88	90	88	92	94
40-50	76	89	91	89	93	94
50-60	80	90	91	90	94	95
60-70	83	91	92	91	95	96
70-80	83.5	92	92	91	95	96
80-90	86	92	93	92	95	96
90-100	90.5	94	94	94	95	96
100-110	90.5	95	95	94	95	-
110-120	90	95	95	94	95	-
120-130	94	-	-	94	-	-
130-140	94	-	-	-	-	-

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

140-150	94	-	-	-	-	-
150-160	94	-	-	-	-	-
160-170	94	-	-	-	-	-
170-180	95	-	-	-	-	-

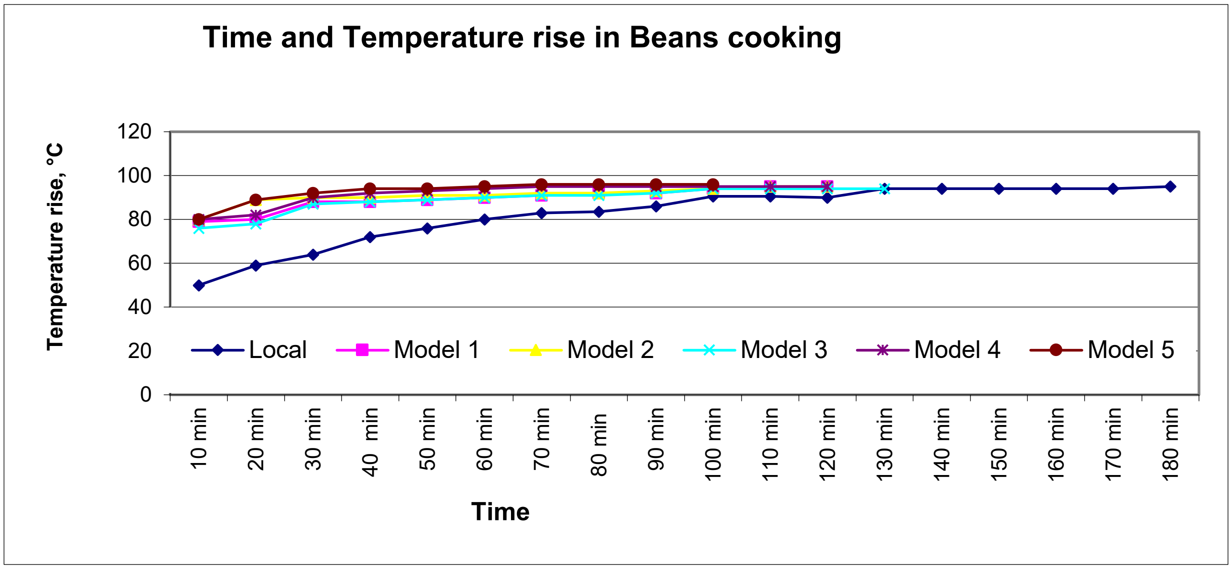

Fig 4: Temperature rise in cooking beans in different stoves.

Table 5: Cooking time of tea for different stoves.

S.N°	Stove type	Time in minutes
1	Three stone open fire cooking	15.0
2	Model 1	11.0
3	Model 2	09.0
4	Model 3	13.0
5	Model 4	11.0
6	Model 5	09.0

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

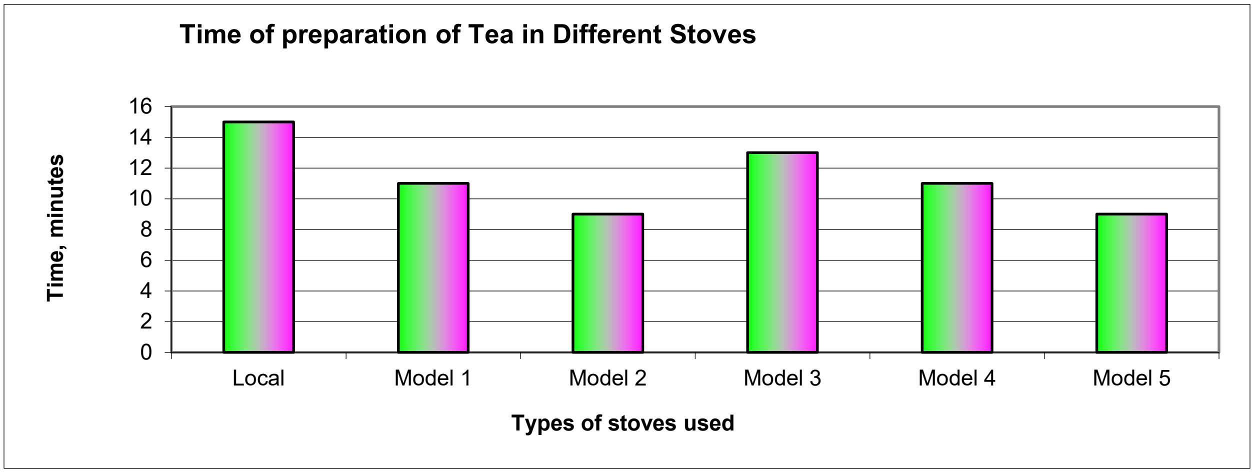

Fig 5: Time of preparation of Tea in Different Stoves

Comparative study of different food stuffs in different stoves

The cooking time of different food stuffs carried out in different stoves is shown in Table 6. It is found that Model 5 stove cooks so fast than other stoves for all food stuffs cooked during experiment. The local stove achieves complete cooking of tested food in the highest period of time.

It is found that the shortest time taken for preparing the entire food of a family at a time is achieved by Model 5, followed by Model 2 and 4. The statistical analysis showed that in all cooked items the time spent vary between the models with the significant difference. The ANOVA at 5% level show that the stove are different (P-value =0.024) with model 5 stove outstandingly using less time (Group 1) models 1,2,3,4, moderate time saving and the control being the worst performer.

Time saved in using improved stove over local stove

The cooking test is carried out for a complete menu of food required for a Rwandan family of 3 members per day. It included rice, beans, potatoes and tea. The total time required for each stove is given in Table 7.

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

Table 6: The cooking time of different food stuffs in different stoves.

Stove type	Time (in minute)				
	Rice	Potatoes	Beans	Tea	Total
Three stone open fire cooking	40	45	180	15	280
Model 1 stove	30	30	120	11	120
Model 2 stove	30	30	120	10	120
Model 3 stove	30	40	130	13	130
Model 4 stove	30	30	120	11	120
Model 5 stove	20	20	100	9	100

Table 7: Comparison of time saving % of smokeless stoves over local stove

Stove type	**Total cooking time, min**	Time saved in cooking over local stove (Minutes)	**Saving Time %**
Local stove	280	No saving of time	No saving of time
Model 1 stove	120	160	57.1 (Rank 2)
Model 2 stove	120	160	57.1 (Rank 2)
Model 3 stove	130	150	54.0 (Rank 3)
Model 4 stove	120	160	57.1 (Rank 2)
Model 5 stove	100	180	64.3 (Rank 1)

Table 7 indicates clearly that the percentage time savings varies from stove to stove. Models 1, 2 and 4 stoves having 2 pot holes and Models 3 and 5 are having 3 pot holes, hence, these additional facilities permit to cook more than one food items simultaneously. This is the range of the findings by Victor M. *et al,* 2008 with the test conducted on the Patsari stove in rural Mexican household. The improved stove offers clear benefits with respect to traditional stoves, with an average reduction in energy consumption of 67% in households exclusively using fuel wood.

Stove efficiency

During the experiment, four experiments have been done successively by boiling 3 liters of water and the mean efficiency of four

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

values obtained in 4 experiments has been taken as average thermal efficiency of each stove.

During each experiment the three liters of water were boiled and a fixed quantity of 1kg of fire wood has been burnt. The initial temperature of water before boiling was always 20°C.

Using equation (4), efficiency for different stoves has been calculated and summarized in table 8

From fig 6, it is revealed that with boiling test method of determination of thermal efficiency, Model 5 improved stove has highest efficiency of 27.6 % of all 5 improved stoves studied in comparison with local stove. Hence, considering thermal efficiency, it is better to adopt Model 5 improved stove. The one way ANOVA on the stoves efficiency shows that there is a significant difference among the tested models of stove at 5% level (P-value = 5×10^{-22}). The mean separation giving rise to three groups which are models 1, 4 and 5 being the most efficient stove, Model 2 and 3 come in the second group and local stove is the less efficient stove.

The efficiency is the ratio of energy in the pot to the energy in the fuel. The best stove in using the energy is the model 5 stove. While the local stove is the poorest stove. The Aspects of the three-stone-fire that make it inferior to most other methods that are not related to safety are that it wastes a lot of fuel and it generally cannot cook for a lot of people. The fuel is wasted due to incomplete combustion of open flames. Most of the energy is lost to the surroundings (Matthew Goon *et al, 2012)*.

The high efficient stoves over other stoves indicating a higher thermal value and hence heated up the water/food faster due to the passage of conventional airflow within the loosely packed materials in the combustion chamber as stated by (Bello R. S *et al*., 2014).

Annual fire wood saving of improved stove over local stove

Using formulas (5), (6) and (7) and the data recorded in cooking different foods they obtained results are tabulated and presented in table 10 and figure 7.

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

Table 8: Thermal efficiency of different stoves

S.N	Stove type	Efficiency (%)
1	Local stove	8.46
2	Model 1 stove	23.22
3	Model 2 stove	17.15
4	Model 3 stove	18.16
5	Model 4 stove	24.3
6	Model 5 stove	27.61

Table 9: Thermal efficiency of different stoves

S.N°	Stove type	Efficiency (%)
1	Local stove	8.46
2	Model 1 stove	23.22
3	Model 2 stove	17.15
4	Model 3 stove	18.16
5	Model 4 stove	24.3
6	Model 5 stove	27.61

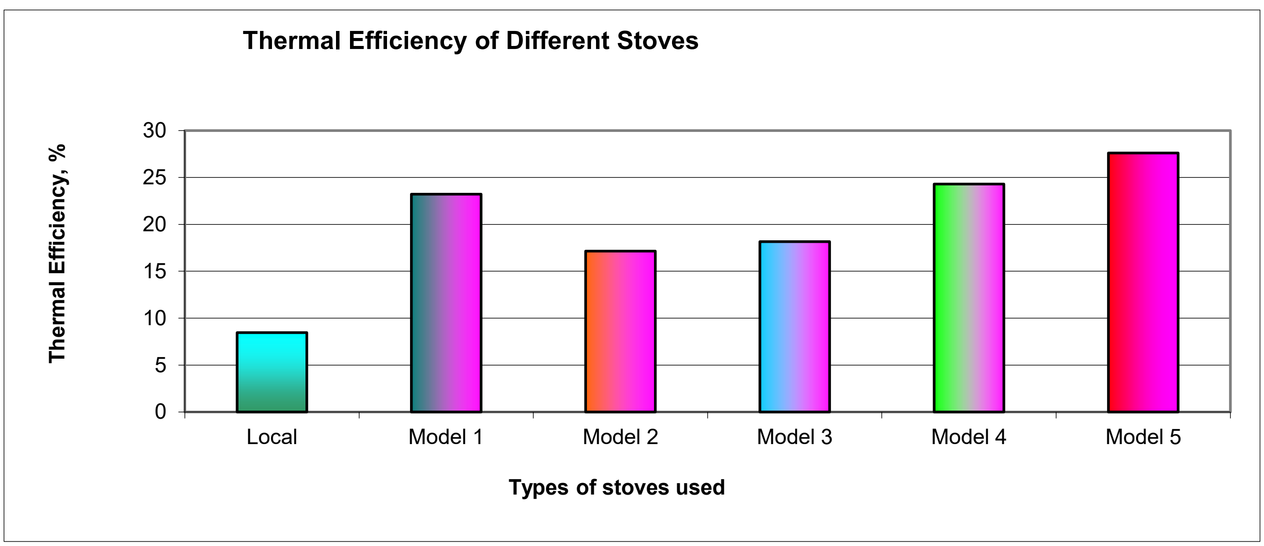

Fig 6: Thermal efficiency of different stoves.

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

Table 10: Percentage of Fire wood saving of smokeless stove over local stove.

S.N°	Stove type	Consumption /day (kg)	Consumption /year /kg	Fire wood saved/year (kg)	Saving %
1	Local	12.0	4320	0	0
2	Model 1	3.8	1368	2952	68.3
3	Model 2	5.8	2088	2232	51.6
4	Model 3	4.0	1440	2880	66.6
5	Model 4	3.5	1260	3060	70.8
6	Model 5	3.0	1080	3240	75.0

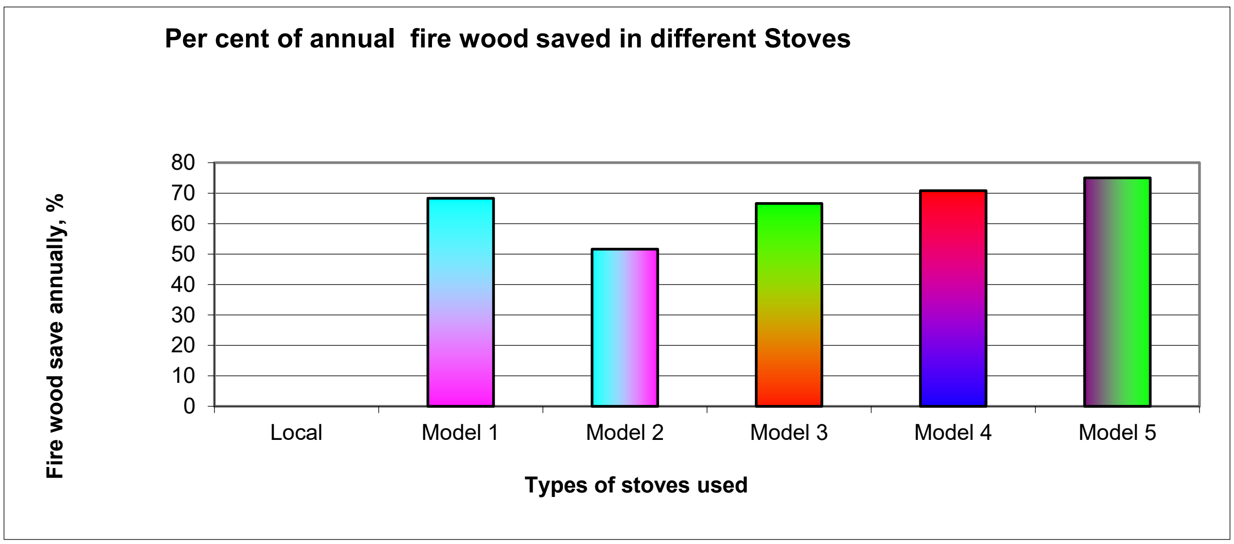

Fig 7: Per cent of fire wood saved by each stove annually.

The model 5 has the highest firewood saving 75% over local stove while the other models provide the saving of 50% to 70%. These findings are congruent with the results by (Abera A., 2016) showing that, Gonziye stove had performed by saving 41.4gm.wood/kg dough than traditional open fire furnace. In this study CCT(Controlled Cooking Test) result indicate that fuel wood saving of 60% were found and it is in line with Elisabeth *et.al,* (2014) finding that fuel wood savings of 48.8% but with 11%

deviation. These make it the outstanding model in all aspect among tested models.

It may be recommended to users after considering the thermal efficiency, the cooking time, the firewood saving over the traditional as advised by Jessica Grandersona *et al* (2009) to make an appropriate choice among stove and in light of the complex interaction between fuel parameters and stove design, reliable stove comparisons should be made on the basis of fuel-stove combinations even with efficiency tests.

Conclusions

The data analyzed and discussed about fuel efficiency of improved smokeless firewood stoves for rural household in Rwanda emanate the following points as conclusions of the study.

1. The cooking time of 20 minutes for 500 gm of rice is the lowest recorded only in Model 5 improved stove. The temperature of food product is found to be 90 to 95 °C.

2. The cooking time of 20 minutes for 1 Kg of potatoes with 2 liters of water is the lowest recorded only in Model 5 improved firewood stove. 3. The cooking time of 100 minutes for 500 gm of dry beans with 2.5 liters of water is the lowest recorded only in Model 5 improved stove.

4. The time taken for preparing 1.5 liters of tea is found to be only 9 minutes in Model 5 and Model 2 improved stoves. However, it is recommended to popularize the Model 5 stove because it gives better results in all other testing of food items.

5. The total cooking time of one day menu for a three members Rwandan family (500 gm of rice, 500 gm of beans, 1 Kg of potato, and 1.5 liters of tea in different stoves tested, the results shows that Model 5 improved stove gives the least time of 100 minutes for complete cooking / day

6. The best performing stoves based on time saving in cooking are Model 5, 4 and 1. It means that by substituting, local stove by Model 5 improved stove would reduce the time taken in cooking by 64.3%. This saved time can be utilized in other household activities.

7. It is estimated that by substituting the locally used stove by the improved stove models, the annual fire wood saving percentages are found to be75 %, 68 %, 71 %, 67 % and 52 % for Model 5, Model 4, Model 1, Model 3 and Model 2 respectively.

8. The study revealed that the Model 5 stove has highest efficiency of 27.61 % of all 5 stoves tested along with the local stove.

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com

The limitation of this study is that it was entailed to the northern part of Rwanda and local considerations. These might be different in some location where the temperature, the altitude, the wind speed are different. This implies that the decision making in other conditions will actually consider the same parameters with respect to the value derived specifically. It is believed that with time these models may be modified for the sake of more efficient devices.

Acknowledgements

The authors express their appreciation, gratitude and heartiness thanks to Prof. Dr. Sankaranarayanan Muthiah for his encouragement and support during this research and elaboration of this paper.

References

Abera Assefa Biratu (2016) . *The Implication of Wood-Burning Stove Efficiency for Environment, Health and CO2 emissions in the Jogo-gudedo Watershed*, Ethiopia *Academic Research Journal of Agricultural Science and Research* Vol. 4(4), pp. 154-163, July 2016

Boy E, Bruce N, Smith KR, Hernandez R. (2000). *Fuel efficiency of an improved wood-burning stove in rural Guatemala: implications for health, environment, and development. Energy for Sustainable Development* 2000;4(2):23–31.

Cook stoves in the Guatemalan Highlands biomass and bioenergy 33 (2009) 306 – 315

Elisabeth D, Ben D, Martin H, Louis V, and Robert M. (2014). *Fuel wood Savings and Carbon Emission Reductions by the Use of Improved Cooking Stoves in an Afromontane Forest, Ethiopia*. *Land* 2014, *3*, 1137-1157; doi: 103390/land3031137

Geneva, Switzerland, MININFRA (2009). *Energy policy in Rwanda*, Kigali, Rwanda.

International Letters of Natural Sciences 13(2) (2014) 89-99 ISSN 2300-9675

Jessica Grandersona, Jaspal S. Sandhub, Domitila Vasquezc, Expedita Ramirezc, Kirk R. Smith (2009), *Fuel use and design analysis of improved wood burning*

Laan, T., Beaton, C., &Presta, B. (2010).*Strategies for Reforming Fossil-Fuel Subsidies: Practical lessons from Ghana, France and Senegal*. International Institute for Sustainable Development.

Matthew Goon, Brian Grabowski , Nicholas Knight, Michael Jenkins Justin Mathews,(2012) *A Major Qualifying Project Submitted to the faculty of the WORCESTER POLYTECHNIC INSTITUTE In partial fulfillment of the requirements for the Renewable Energy Burning Cookstove and Surface Environment* June 4, 2012

Musanze district (2006). *Annual report. District development plan*. Musanze. 267 p.

NISR (2008a). *Demographic statistics*. National Institute of Statistics of Rwanda, Kigali, Rwanda.

Okorio A., Kaudia, Luakuba (2003). *Agroforestry handbook for the Montana zone of Uganda.* RELMA, Nairobi, Kenya, 83p.

R. S. Bello1, M. A. Onilude (2014). *Characterization of Conventional Cooking Stoves in South Eastern Nigeria*

Steve, S. (2014). *Multiple-household Fuel Use. A balanced choice between firewood, charcoal and LPG*. Published by GIZ

VITA, (1985). *Testing the efficiency of wood-burning cookstoves: international standards.* Arlington, VA: Volunteers in Technical Assistance; 1985.

World Bank. (2015).*The State of the Global Clean and Improved Cooking Sector*, 1–179

http://eajournal.unilak.ac.rw/ EAJST (Online Version) ISSN: 2227-1902 Email: eajst_editor@unilak.ac.rw / eajscience@gmail.com