Development of emission recovery multipurpose household backyard kiln for charcoal production

S. ONGORA[1], M. J. G. MAJALIWA[2] and S. M. BAGABO[3]
[1]Department of Mechanical and Production Engineering, Kyambogo University, P.O. Box 1, Kyambogo,Uganda
[2]Department of Environmental Management; College of Agriculture and Environmental Sciences, Makerere University, P.O. Box 7062, Kampala, Uganda
[3]Busoga University, P.O. Box 154, Iganga, Uganda
Corresponding author: ongorasolo@gmail.com

ABSTRACT

An Emission Recovery Multipurpose Backyard Charcoal making kiln was designed and constructed at Kyambogo University in Uganda. The design has modifications made on the Traditional Earth kiln commonly used in Uganda and included four compartments namely a) the water circulating system for water heating and temperature regulation, b) the drier for reducing the moisture content of the Sun-dry wood, c) the condenser and the filter to remove the smoke volatiles, aerosols and tar, and d) the kiln chamber for charcoal making. The emission recovery kiln was tested for efficiency, energy distributions and liquid smoke yield. The experiment was conducted three times using eucalyptus tree wood biomass stacked in lots of 25, 30 and 35 kg in the carbonization chamber. The parameters measured and recorded at an hourly interval of time for the entire experiment runs were: temperature variations in the kiln carbonization, drier, chimney chambers and 100 L circulating water, and the corresponding charcoal weights and volumes of liquid smoke yields. Results showed that the efficiency of the emission recovery kiln reduced gradually with the wood biomass load. Also, the relative charcoal yield, energy distributions in various kiln parts, the experiment run time, water temperature, liquid smoke yield, carbonization, drier and chimney chamber temperature variations increased with the load. The kiln was operated at household backyard with an average temperature range of 300 - 500 °C, and total efficiency range of 25.5 - 28.5 %. The emission recovery charcoal making kiln therefore, is appropriate for use as a research tool for production of charcoal with reduced air pollution.

Key words: Charcoal kiln, energy saving technology, emission reduction, Uganda

RÉSUMÉ

Un four polyvalent multifonctionnel à charbon à usage domestique a été conçu à l'Université Kyambogo en Ouganda. Le four conçu a des modifications apportées au fourneau traditionnel couramment utilisé en Ouganda et comprenait quatre compartiments, à savoir a) le système de circulation de l'eau pour le chauffage de l'eau et la régulation de la température, b) le séchoir pour réduire la teneur en humidité, c) Le condenseur et le filtre éliminant les substances volatiles de fumée, les aérosols et le goudron, et d) la chambre du four pour la fabrication du charbon. L'efficacité, la distribution d'énergie et le rendement en fumée liquide du four ont été testés. L'expérience a été menée trois fois en utilisant les bois d'eucalyptus empilés dans des lots de 25, 30 et 35 kg dans la chambre de carbonisation. Les paramètres mesurés en un intervalle de temps horaire ont été les suivants: variations de température dans la carbonisation du four, le sécheur, les chambres à la cheminée et 100 L d'eau de circulation, et les poids et volumes de fumée de charbon correspondants produits. Les résultats ont montré que l'efficacité du four diminue progressivement avec la charge de biomasse du bois. En outre, le rendement relatif du charbon, la distribution de l'énergie dans le four, le temps d'exécution de l'expérience, la température de l'eau, le rendement de fumée liquide, la carbonisation, les variations de température de la chambre de séchage et de la cheminée ont augmenté avec la charge. Le four a été opérationnel dans l'arrière-cour avec une plage de température moyenne de 300 à 500 °C, et une efficacité totale de 25,5 à 28,5%. Par conséquent, le four est approprié pour être utilisé comme un outil de recherche pour la production de charbon avec une réduction de la pollution atmosphérique.

Mots clés: Four à charbon de bois, technologie d'économie d'énergie, réduction des émissions, Ouganda

Received: 20 April, 2016
Accepted 11 February, 2017
Published: 30 June 2017

INTRODUCTION

Half of the world's population uses biomass fuels for cooking which contributes to about 12 % of today's world primary energy supplies (Demirbas and Arin, 2002). Up to now, over two thirds of the total biomass consumption worldwide comes from developing countries and some of which is utilised unsustainably (Omer, 2014). During the transformation process, wastage of biomass such as abandonment of charcoal fines, small branches and bark are often observed (Rolando, 1991). All these contribute to a rapid depletion of the biomass resource base in most of these countries as most of the households depend on charcoal for cooking.

In Uganda, over 90 % of national energy need is dependent on biomass with total annual consumption of 18 million tonnes of firewood and an estimated 500,000 tonnes of charcoal. Other sectors where wood is consumed include; construction industries, medical and crafts (Kayanja and Byarugaba, 2001). Continuous high demand for forest products, therefore, places Uganda at high risk of increasing economic, social and environmental disasters as a result of forest depletion at many locations. Therefore, the traditional charcoal production process commonly in use in African continent and particularly in this case Uganda, requires close monitoring and attention (Nahayo *et al.,* 2013). The traditional kiln being used is constructed on site and also contributes to soil degradation through reduction of soil micro-organisms, soil nutrients from the effect of waste heat (Certini, 2005) and it presents a low efficiency of <10 % (Knöpfle, 2004). High efficiency kiln (26 - 30 %) such as the Casamance kiln (Nelly *et al.,* 2006) recovers liquid tar; however, it is also constructed on site (Nturanabo *et al.,* 2010) and presents similar challenges as the traditional kilns.

Charcoal is the primary cooking and heating fuel for the rapidly increasing urban populations in sub-Saharan Africa including Uganda and it is an attractive fuel for urban households because it offers far greater energy per-unit volume than unprocessed fuel wood and can be stored without fear of insect problems (Knöpfle, 2004). The per-capita charcoal consumption varies form one region to another and can reach up to 4 and 120 kg/year for rural and urban areas, respectively (Nturanabo and Tumuhimbise, 2010). Charcoal also has excellent cooking properties such as being easily extinguished and reheated and burning uniformly for a long time (Kammen and Lew, 2005). Biomass is considered renewable source of energy because trees can be planted, cut down and re-grown or re-planted again; trees transform the sun energy during growth period and store it in chemical form which is released during pyrolysis processes.

According to Omer (2014) the very quantity taken in from the atmosphere is released back during charcoal production and biomass utilisation process. Therefore, there is need to develop and promote more ecologically sensitive charcoal production technologies to reduce on the emissions, improve the efficiency and preserve the soil biota. This study characterised an emission recovery multipurpose household backyard kiln developed at Kyambogo University. The application of this kiln therefore, was conceived to encourage cultivation of fast growing plantation trees near the household backyard so that it can discourage transportation of indigenous tree charcoal products from remote rural areas and in this way, the slowly growing and endangered indigenous trees would be conserved.

MATERIALS AND METHODS

Description of the emission recovery multipurpose backyard kiln. Figure 1 below shows the kiln developed at Kyambogo University (Ongora, 2015). The kiln has four compartments a) the water circulating system for water heating and temperature regulation, b) the drier for reducing the moisture content of the Sun-dry wood, c) the condenser and the filter to remove the smoke volatiles, aerosols and tar, and d) the kiln chamber for charcoal making.

Carbonization chamber unit. Different types of kilns may have different shapes and sizes of carbonization chamber and in this case, the chamber is designed with cage partition where charcoal remains hanging as the bottom most partition receives air intake from the adjacent adjustable inlet door to sustain combustion. The cage partitions, therefore, prevent continuous feed of biomass towards the bottom which is the most active partition. During charcoal making process, the chamber is closed and temperature measuring sensor inserted inside the chamber through the pyrometer sensor plug pot at the side of the kiln chamber for monitoring of pyrolysis progress.

The drier unit. Heat energy that would be dissipated to the surrounding from part of the chimney wall is designed to be recovered and instantly utilized for drying wet wood loaded inside the drier. The drier is positioned against the flame direction on top of the carbonization chamber and symmetrically surrounds part of the chimney to recover some of the waste heat through accommodation of sun-dry wood biomass in its chamber for moisture content reduction. Some energy is retained by the drier chamber wall and excess conducted through to the surrounding environment. The drier is insulated with fiber glass with a provision of plugging the pyrometer sensor at the side for temperature measurement and a breather on top for moisture escape. The drier is partitioned from the carbonization chamber using a three millimeter plate inside which there is sand insulation. The drier chamber has its capacity approximately the same as that of the carbonization chamber with a provision of the door for charging the biomass after which it is closed.

Water insulation system unit. The water is circulated as insulating material to reduce heat loss from the kiln carbonization chamber wall and yet allowing access to the retained heat for utilization. The heat from the kiln carbonization chamber is insulated from the surrounding using concrete within which galvanized water pipe of half inch diameter is casted for waste heat recovery through heating circulating water. The water circulating system consists of the overhead plastic tank that contains cold water which flows down the galvanized pipe water jacket by gravity. The circulating water picks some heat and subsequently boils up creating enough steam pressure to open the pressure relief valve downstream the outlet tap for steam to flow back to the plastic tank. The warm water inside the plastic tank, therefore, is used as part of the energy recovery medium.

The chimney and filter tank unit. The volatiles and aerosols from the smoke are recovered as a measure of reducing the effect of emission to the environment, with a possibility of obtaining value addition products from the smoke. The chimney being part of the condensing wall is provided with a choke and pressure regulating valve to control the pressure and temperature and eventual shut down of the kiln when required. The filter tank is an enlarged part of the chimney and is made with plate baffles inside to reduce the speed of the aerosols that facilitate settlement of heavier molecules and particles on water surface and subsequently get dissolved or settle at the bottom of the tank. The filter tank provide part of the condensation surface for the smoke volatiles, it is also fitted with the drain valve (to empty the the recovered liquid emission compounds from the filter tank and water from the insulation jacket), overflow valve (to allow out flow of excess water from the filled overhead 100 L tank and the inspection cover (provision to gain access inside the filter tank.

The kiln units' assembly. The kiln design, therefore, incorporated the four major units described above and assembled to work concurrently as represented in the drawing in Figure 1. The engineering drawing was made based on the Solidwork program which was used as a guide during fabrication, particularly in metal cutting, bending and joining. Solidwork program was chosen as it is a tool used by Mechanical Engineers in design works because of its versatile application tools including inspection, comparison and edition of engineering drawings. Solidwork also is user friendly and interactive and therefore, offers guidance and suggestion for the next drawing step. Solidwork program provides three dimensional view of the drawing component that offers more detailed and clarity in imaginative perspective. Solidwork program can be used for modeling and simulation of machines and parts and therefore, conclusive view on the viability of the functional machine part (Zuyderduyn, 2015).

Kiln Materials and fittings. The dimensions of the kiln units' components were taken through material measurements, cuttings, bending and joining to sizes and shapes using corresponding available tools and machineries in the Mechanical Workshop at Kyambogo University. The materials and fittings were chosen based on the availability in the local market and consideration to their physical properties and listed as explained in the lumber drier owner's manual by Ebac (2005) industrial products limited shown in Table 1(a) and (b).

Determination of efficiency of the kiln. Experiments were conducted to determine the kiln efficiency using dry eucalyptus wood load (removed from the drier) of 25, 30 and 35 kg charged into the kiln carbonization chamber. Wood from eucalyptus tree was chosen for this kiln charge experiments as it is reported to be extensively grown in Uganda and also as one of the best tropical tree-species for bio-energy production (Kilimo, 2011). Each experiment was conducted three times and the corresponding residence times within which the experiments lasted were also recorded. During the experiment runs, temperature variations in the kiln sections and water sink media were correspondingly recorded at hourly time interval as functions of energy

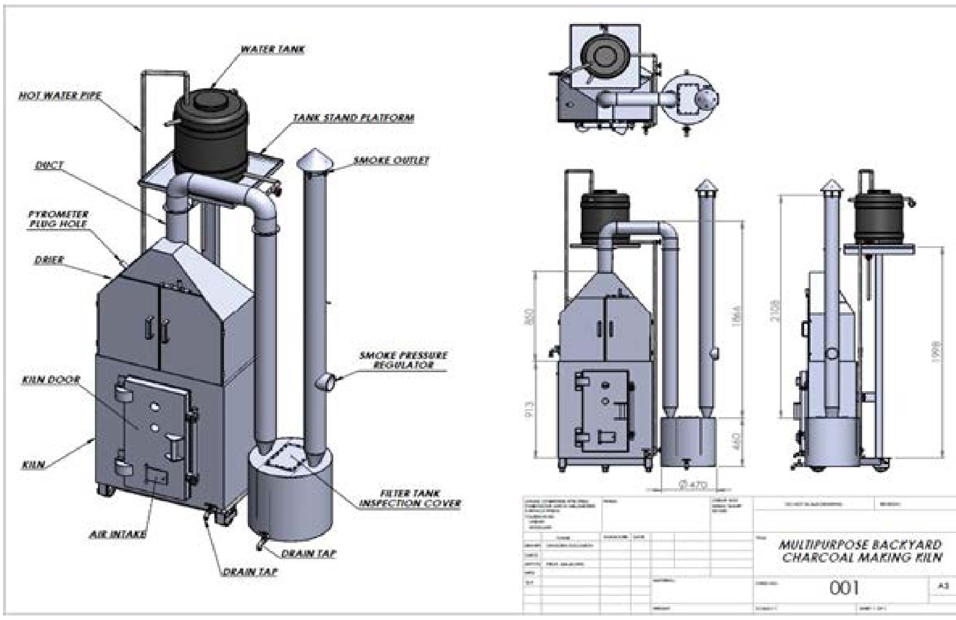

Figure 1. Multipurpose backyard charcoal making kiln drawing

Table 1(a). Kiln construction materials

No	Item	No of pieces	Description of materials	Dimension (mm)			
				Length	Width	Height	Thickness
1	Metallic casing for carbonization chamber	2	Mild steel sheet	2440	1220		3.0
2	Outer metallic casing for drier	1	Mild steel sheet	2440	1220		1.5
3	Inner metallic casing for drier	1	Galvanized steel sheet	2440	1220		1.0
4	Flue gas pipe	1	Mild steel sheet	2440	1220		1.5
5	Smoke filtering tank	1	Mild steel sheet	1220	1220		1.5
6	Water pipe	3	Galvanized steel	6098	12.7		1.5
7	Metallic frame	1	Steel hollow pipe rectangular section	6098	80	60	4.0
8	Cage bar	3	Mild steel square bar	6098	12	12	

Table 1(b). Kiln fittings

Kiln components	Fittings	Material	No. of pieces	Dimensions
Carbonization chamber	Water drain valve	Brass	1	Φ1/2” (Half inch diameter)
	Water inlet valve	Brass	1	Φ1/2”
	Water outlet valve	Brass	1	Φ1/2”
Water circulation system	Flow check valve	Brass	1	Φ1/2”
	Water tank	Plastic	1	100 litters
	Ball valve	Plastic	1	Φ1/2”
	Tank drain valve	Brass	1	Φ1/2”
	Over flow control valve	Brass	1	Φ1/2”
	Water inlet valve	Brass	1	Φ1/2”
	water out let valves	Brass	1	Φ1/2”
Filtering tank	Over flow valve	Brass	1	Φ1/2”
	Drain valve	Brass	1	Φ1/2”
Drier	Breather	Steel pipe	1	Φ1/4”

distributions. The average values of corresponding temperatures were used to compute efficiency for each biomass load and other energy distributions. The parameters which relate as functions to efficiency and energy distributions in various kiln units, and therefore, necessary for their corresponding computations were obtained from the drawing design, literature, available kiln material dimensions and measurements basing on kiln operation, input and output performance. These parameters were, therefore, predetermined at design stage, determined during the kiln operation process and from the output products after kiln operations.

Estimation of heat energy distributions in the kiln. The distribution of wood energy across the different components of the kiln was estimated as a sum of the energy used to heat up the circulating water, to remove the moisture from the sun-dry wood; energy retained by the carbonization and drier chamber walls; energy loss to the surrounding through the chimney and drier chamber walls; and, other energy losses such as to warm the cold air inflow and to char the biomass. The energy used to heat the circulating water was estimated as heat energy in the 100 L circulating water during the entire experiment run and computed based on the values of corresponding temperatures (Ayo, 2009). The energy used to remove the moisture from sun-dry wood in the drier was estimated through determination of the change in moisture content in the sun-dry wood biomass after drying further in the kiln drier chamber and expressed as a percentage of the ratio of wood weight loss to dry wood weight (Reeb and Milota, 1999). The energy loss to the surrounding through the flue gas was computed based on the "Siegert Formula" (Ulrich, 2004) and using the difference between the average chimney temperature and its initial average value. The energy conducted and radiated through the kiln body to the surrounding was estimated as the heat energy loss from the walls of the carbonization chamber and the drier chamber to the surrounding (Elustondo and Oliveira, 2009). The energy retained by the kiln body was estimated as a function of the temperature differences across the walls of the kiln, the mass of concrete and the surface area of drier chamber (Elustondo and Oliveira, 2009). Other energy losses consisted of those parts consumed during pyrolysis process that resulted into formation of ash, charcoal, tar, aerosols and liquid solution, warming the cold air flowing inside the chambers and that for compensation of errors in measurements. This energy was estimated on the basis of the energy content of dry wood charged into the carbonization chamber minus the total corresponding energy distributions in various kiln sections, water media and charcoal.

Temperature measurements in the kiln parts. The temperature readings inside all the chambers were recorded at an interval of one hour using three sets of thermocouple wires through the corresponding heat sensors connected at the joined ends. Each heat sensor was inserted inside the pot to a hot carbonization, drier and chimney chambers. The small electric current flow was induced in the dissimilar thermocouple wires and signaled to the corresponding temperature scale readings connected at the other ends. The external kiln body temperatures were taken using portable infra-red heat sensor pyrometer. Temperature as a function of time (T (t)) of the different components of the kiln subjected to regression analysis and the data were fitted to a quadratic function. The maximum temperature, the time to reach the maximum temperature and the coefficient of determination were obtained. The maximum temperatures were obtained by equating the first derivative of the T (t) to zero.

Data analysis. Temperature data from the different components of the kiln, charcoal yield and efficiency were analysed in GenStat Discovery version. A quadratic function was fit on the temperature data; while a linear regression was used to determine the trend in charcoal yield and efficiency with kiln charge. Analysis of variance was used to separate the maximum temperatures for the different components of the kiln and charcoal efficiency.

RESULTS AND DISCUSSIONS

The constructed Emission recovery (Multipurpose Backyard) Charcoal making kiln photograph and its operation. The finished kiln units were joined to positions with the carbonization chamber at the bottom of the drier in consideration of the natural flame direction. The duct from the carbonization chamber was joined through the drier and bent to the smoke filter on the ground. The carbonization chamber was partitioned with ½ inch square mild steel material cages and fitted with a door for accessing the chamber. The kiln outer body (Plate 1) was painted for protection from atmospheric corrosion and for aesthetic value with heat resistant aluminum paint of pyrofix type.

Plate 1. The kiln photograph

Basically, the operation of the constructed kiln involved majorly nine steps as follows:-i) loading the drier chamber; ii) loading the carbonization chamber; iii) filling the smoke filter and the water tanks with tap water; iv) connecting the pyrometer and setting fire on the biomass; v) sealing the kiln carbonization chamber door gaps with clay soil; vi) collection of liquid smoke overflow and hot water; vii) collection of charcoal; viii) weighing the charcoal for storage and; xi) draining off the liquid solution from the filter tank and cleaning the carbonization chamber. The constructed kiln was mounted on the platform to prevent heat discharge to the ground as this was reported harmful to the lives of micro-organisms present and destructive to the soil nutrients and properties (Certini, 2005).

Performance efficiency of the kiln. It took a range of 3 - 6 hours for the experiment to run through the nine steps when the carbonization chamber was loaded with 25, 30 and 35 kg of biomass, respectively (Figure 2).

The kiln operation temperature variations. Temperature was recorded as a function of heat energy across the different components of the kiln and this is depicted in Figure 3: (a), (b) and (c) for 25, 30 and 35 kg of wood, respectively. Generally temperature varied as quadratic function of time for the carbonization chamber, drier chamber, drier body, chimney and water. Temperature tended to be highest in the carbonization chamber, followed by the chimney, water and the lowest was recorded on the drier body. The maximum temperature reached by the components of the kiln varied from one component to another and depended proportionately on the amount of wood to be processed. The maximum temperatures in °C under carbonization chamber, chimney, water, drier chamber and kiln body for 35, 30 and 25 kg wood lot, were recorded as 442.75, 195.7, 87.3, 81.6, 70; 398.6, 205.4, 79.4, 78.6, 81.6 and 361.3, 166.4, 82.3, 73.8, 83.6, respectively. It is worthwhile to note that this temperature was reached theoretically after 2 - 3 hours from the start of the experiment. The drier, chimney and the kiln body temperatures remained relatively low for the three masses of wood. The carbonization temperature was controlled through circulating water by operating the water flow control valve and the smoke choke valve. This facilitated smoke condensation and dissolution of volatile compounds in water. It also helped in shutting down the kiln whenever need arose. In addition, the temperatures in all the kiln parts followed the same trend and depended on the carbonization chamber temperature.

The carbonization temperature was kept relatively low (<500 °C) throughout all the experiment runs to give chance for more volatile compounds to condense and dissolve in tap water (Demirbas and Arin, 2002; Ramakrishnan and Moeller, 2002). The variations in corresponding average temperature ranges was attributed to different sizes of biomass pieces contributing to the total weight in the carbonization chamber, the weather conditions, experiment run time and biomass arrangement in the kiln chamber (Kammen and Lew, 2005). High chimney temperature was also attributed to air intake resulting to high combustion rate in the carbonization chamber and subsequently resulting to shorter experiment run time. The maximum operating temperature attained inside the constructed kiln carbonization chamber was therefore, 442.75 °C.

Efficiency of the kiln. The efficiency of the kiln basing on charcoal yield tended to decrease linearly with the increase in initial mass as shown below in Figure 4 ($y = -0.260x + 24.00$, $R^2 = 0.907$, $p<0.05$). The decrease in efficiency with the increase in biomass charge was associated with the increase in weight of biomass charged in the lower partition of the chamber as it was the most active portion of the kiln due to adjacent air intake gate. In addition, for higher weight of biomass kiln charge, the lower

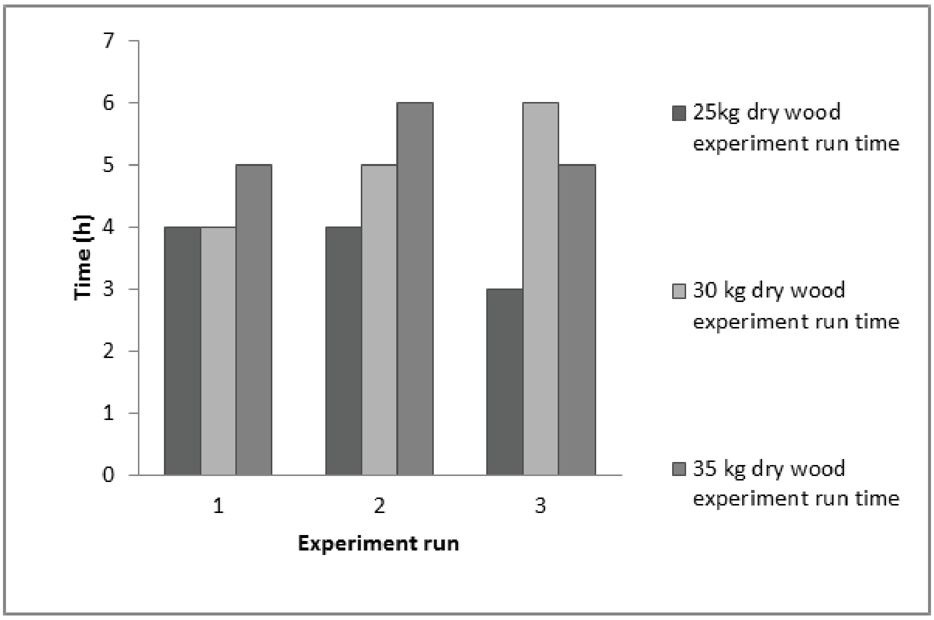

Figure 2. Kiln residence time for corresponding woodlot

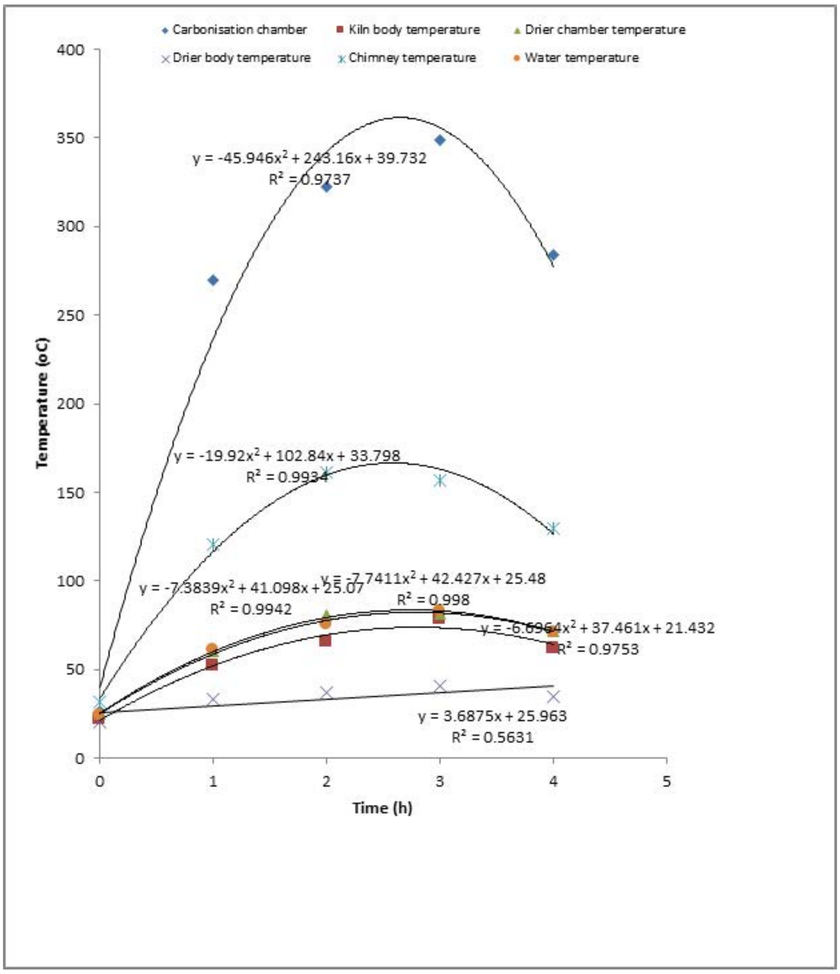

Figure 3 (a). Temperature distribution in different sections of the kiln for 25 kg of wood

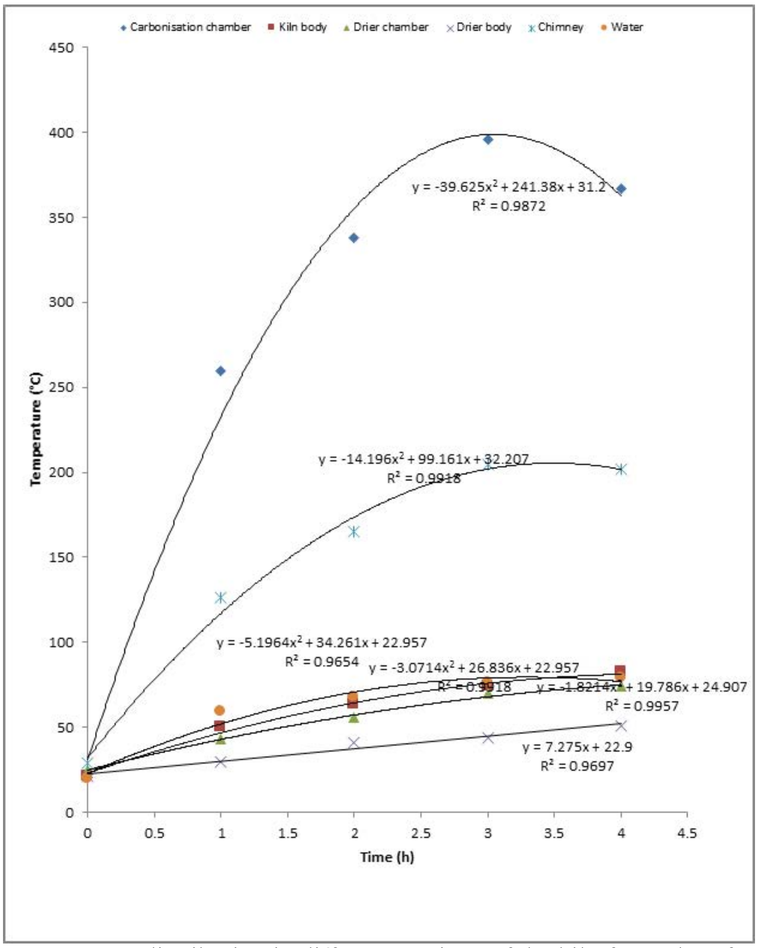

Figure 3 (b). Temperature distribution in different sections of the kiln for 30 kg of wood

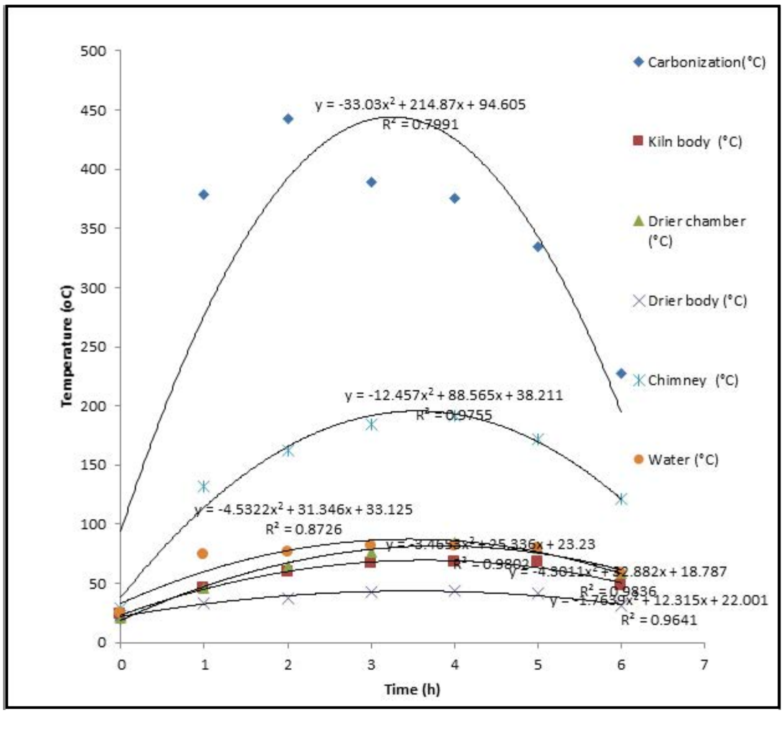

Figure 3 (c). Temperature distribution in different sections of the kiln for 35 kg of wood chamber was proportionately filled to capacity and during carbonization process, directly proportionate increase in residence time for various kiln experiment runs were also recorded. This contributed to more charcoal decomposition resulting to wastage.

The average efficiency, based on charcoal yield, decreased significantly with the charge ($p<0.05$). It ranged between 13.3 - 17.74 % for 25 kg; 11.82 - 16.26 % for 30 kg and 11.4 -14.5 % for 35 kg. During the Kiln operations, 11 % of heat energy was recovered from each of the corresponding biomass lot and therefore, increased the efficiency to a total of 25.6 - 28.5 % as shown in Figure: 4 below. The total efficiency of the kiln basing on charcoal yield plus energy recovered tended to decrease linearly with the increase in initial mass ($y = 0.260x + 35.00$, R2 = 0.906, $P<0.05$).

The efficiency and charcoal yield had opposite trends with increasing kiln charge. The efficiency linearly decreased, while charcoal yield increased with the kiln charge (Figure 4). This was linked to the differences in temperature at different charges which allowed complete burning of more biomass for the 25 kg kiln charge. It is also worthwhile noting that the constructed kiln allowed to save the energy which was supposed to be used to heat water using charcoal stove, hence increasing on its efficiency range (25.5 - 28.5 %). The amount of energy saved in this process depends on the efficiency of cooking stove to be used (Agyei *et al.,* 2014); but can be also affected by the demand of hot water (Gadir, 2009).

Eucalyptus charcoal yield. The corresponding charcoal yield for the different initial masses of wood is represented in Figure 5 below. The charcoal yield tended to increase significantly with the increase in initial mass of wood ($y = 0.081x + 2.375$, R2 = 0.862, $p<0.05$). The average charcoal weights obtained were 4.3, 5 and 5.125 kg for biomass kiln charge of 25, 30 and 35 kg respectively and as shown in the Figure 5.

Energy distribution in different parts of the kiln. The energy distribution in the various parts of the kiln components were computed as a function of corresponding temperatures and represented as in Figure 6 below. In addition, considering energy losses for heating cold air inflow and energy escaped through kiln openings, other energy losses registered the highest values of 289.2, 332.2 and 394.8 MJ for initial masses of 25, 30 and 35 kg, respectively. The various energy distributions were recorded as direct proportions to the corresponding kiln charge into the carbonization chamber.

According to Kumar and Gupta (1992), the biomass lot of 25, 30 and 35 kg would generate 711, 609 and 508 MJ of heat energy after complete burning, respectively. Part of this energy was used to make charcoal. All the other component of wood energy, except other energy losses, did not exceed 10% of the wood energy. Other energy losses represented 56% of the wood energy.

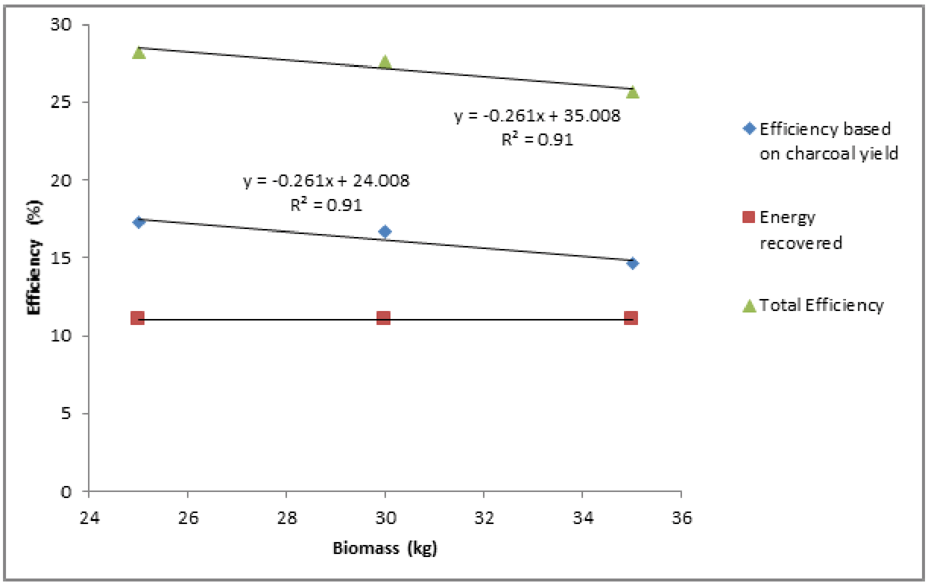

Figure 4. Change in total efficiency induced by the kiln charge (initial mass of wood)

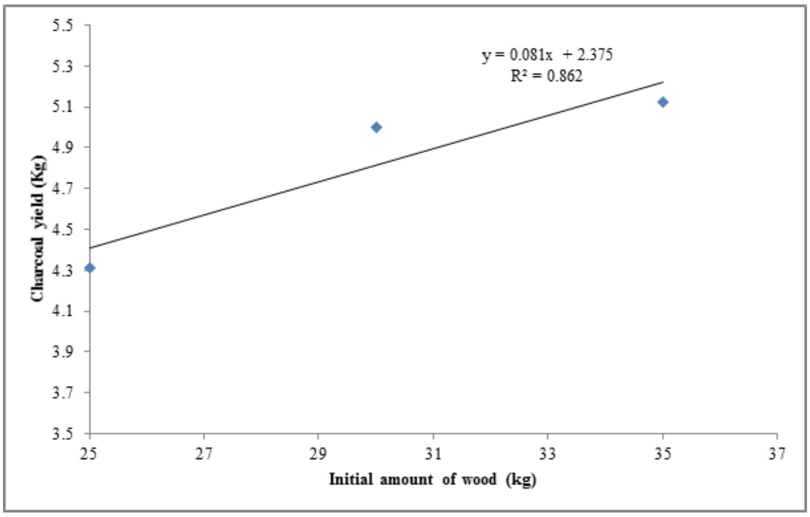

Figure 5. Trend in charcoal yield induced by the change in the kiln charge

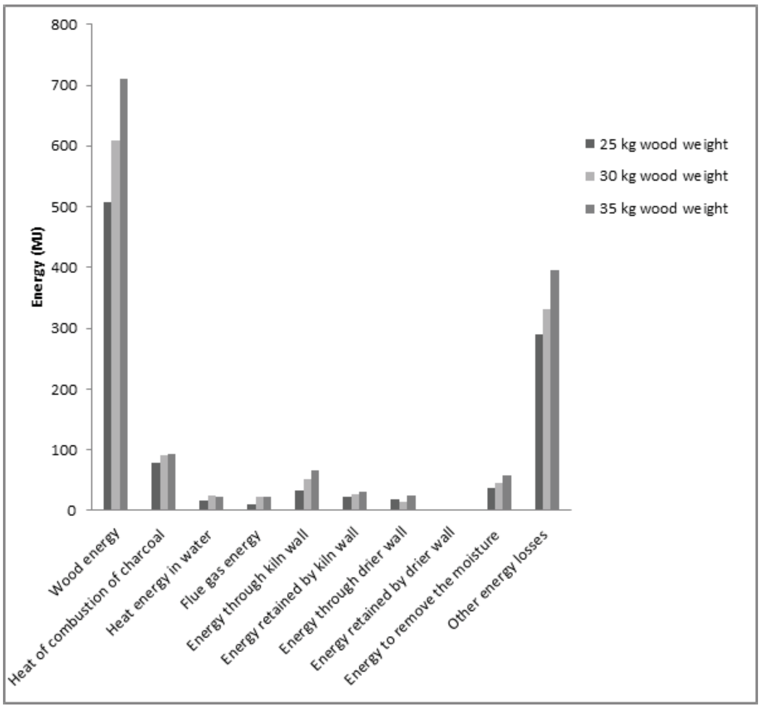

Figure 6. Energy distribution in the different components of the Kiln

CONCLUSIONS AND RECOMMENDATIONS

The multipurpose backyard charcoal making kiln has two major operational benefits, namely, reduction in smoke emissions and recovery of heat energy. This is attributed to its design that integrated the smoke condensation/filtering unit which helped reduction in smoke emissions; and, carbonization chamber and water circulation/drier chamber units which facilitates heat energy recovery. Additionally, the kiln is mounted on a platform to prevent waste heat direct contact with the ground soil. The multipurpose backyard charcoal making kiln was operated within time range of 3 - 6 hours with an efficiency range of 14.5 - 17.5 % basing on charcoal yield plus energy recovered of 11 % thus increasing the kiln efficiency to a range of 25.5 - 28.5 %. However, this kiln efficiency can be optimized using adequate materials for the different compartments. It was recommended that the insulation be improved as considerable quantity of heat energy is lost through the kiln and drier walls. There is also need to test the effect of cage partition inside the carbonization chamber and hot water demand on the on the efficiency of the kiln. The construction of bigger size multipurpose kiln will reduce cost incurred to satisfy institutional (schools, hospitals, prisons and markets) energy demand and reduce associated emission into the atmosphere.

ACKNOWLEDGEMENT

The authors acknowledge Dr. Bitek Titus Watmon (Head of Department, Mechanical and Production Engineering, Kyambogo University), and Mr. Senkosi Kenneth (Makerere University) for pre-reviewing this paper.

STATEMENT OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

REFERENCES

Agyei, A., Tawiah, P. and Nyarko, F. 2014. Efficient charcoal stoves: Enhancing their benefits to a developing country using an improved design approach. *International Journal of Engineering Trends and Technology* (IJETT) 15(2):94. ISSN: 2231 – 5381.

Arnim, F. and Marlida, Y. 2012. The effect of liquid smoke utilization as preservative for meatballs quality. *Pakistan Journal of Nutrition* 11(11):1078-1080, ISSN 1680-5194.

Ayo, S.A. 2009. Design construction and testing of an improved woodstove. *AU Journal of Technology.* 13(1): 12-18.

Certini, G. 2005. Effects of fire on properties of forest soils: a review. *Oecologia* 143 (1):1 - 10.

Demirbas, A. and Arin, G. 2002. An overview of biomass pyrolysis. *Energy Sources* 24 (5): 471 - 482.

EBAC. 2013. Lumber drier owner's manual kiln construction guide troubleshooting guide LD 800. EBAC Industrial Products Inc 700 thimble shoals boulevard, suite 109, Newport news, Virginia. 23606-2575, USA.

Elustondo, D. M. and Oliveira, L. 2009a. A method for optimizing lumber sorting before kiln-drying. *Forest Products Journal* 59 (9): 45 - 50.

Elustondo, D. M. and Oliveira, L. 2009b. Model to assess energy consumption in industrial lumber kilns. Maderas. *Ciencia y tecnología* 11(1): 33 - 46.

Gadir, B. E. S. A. 2009. Effect of Kiln type and billet size on Acacia seyalvarseyal charcoal quality. University of Khartoum.

Kammen, D. M. and Lew, D. J. 2005. Review of technologies for the production and use of charcoal: Renewable and appropriate energy laboratory Rep ort. Berkeley: University of California.

Kayanja, F. and Byarugaba, D. 2001. Disappearing forests of Uganda: The way forward. *Current Science* 81(8): 936 - 947.

Kilimo, T. 2011 Eucalyptus hybrid clone in East Africa; meeting the demand for wood through Clonal Forest Technology. Occassional Paper No. 1.

Knöpfle, M. 2004. A study on charcoal supply in Kampala. Uganda: Ministry of Energy and Mineral Development (MEMD) Energy Advisory Project (EAP).

Kumar, M. and Gupta, R. C. 1992. Influence of carbonization conditions on the gasification of acacia and eucalyptus wood chars by carbon dioxide. *Fuel* 73 (12): 1922 - 1925.

Nahayo, A., Ekise, I. and Mukarugwiza, A. 2013. Comparative study on charcoal yield produced by traditional and improved Kilns: A case study of Nyaruguru and Nyamagabe Districts in Southern Province of Rwanda. *Energy and Environment Research* 3 (1): 40.

Nelly, O., Githiomi, J., Chikamai, B. and Nyongot, C. 2006. Charcoal production using improved Earth, Portable metal, Drum Cacamance kiln. Kenya Forest Products Research Center – Karura.

Nturanabo, F., Byamugisha, G. R. and Preti, G. C. 2010. Perforamce appraisal of the casamence Kiln as a replacement to the traditional charcoal Kilns in Uganda. Second Internal Conference on Advances in Engeering and Technology. pp. 530 - 536.

Omer, A.M. 2014. Renewable Energy Technology, Sustainable Development and Environment. Energy Research Institute (ERI), Nottingham, UK.

Ramakrishnan, S. and Moeller, P. 2002. Liquid smoke: product of hardwood pyrolysis. *Abst. Papers Ame. Chem. Soc* 47: 366 - 367.

Reeb, J. E., Milota, M. R. and Association, W. D. K. 1999. Moisture content by the oven-dry method for industrial testing. Oregon State University Corvallis.

Rolando, V. R. 1991. 19th-century charcoal production in Vermont. IA. *The Journal of the Society for Industrial Archeology* 17 (2): 15 -36.

Ulrich, J. 2004. Practical guide for Emissions and Process Measurements. Flue Gas Analysis in Industry.

Underwood, G. L. 1992. High browning liquid smoke composition and method of making a high browning liquid smoke composition: Google Patents.

Zuyderduyn, J. W. 2015. Learn Solidworks.com. Solidworks tips, tricks and tutorials.