A Re-designed Kiln for Ashing Cocoa Pod Husk (CPH) in Cocoa Growing Areas of Ghana

P. S. Kwawukume[1], Albert Essuman[2], P. S. Kwawukume Jnr[3]

[*1, 2]Department of Industrial Art (Ceramics), KNUST-Kumasi, Ghana

[3]Department of Building Technology, KNUST-Kumasi, Ghana

[*1]parpahkaye@yahoo.com; [2]albertessuman@yahoo.com; [3]parpah1@gmail.com

***Abstract*-A redesigned downdraft kiln for ashing cocoa pod husk in cocoa growing areas of Ghana was calculated using three-layer brick wall structure derived from thermal conductivity calculations yielding outer wall temperature of 85 ^{o}C capable of withstanding cyclical heat and cold temperatures without shelter over the structure. All calculations were based on the length of the bricks and their thermal conductivities. Activities on cocoa farms led to tons of leftover cocoa pod husks (CPH) as waste after harvest seasons when nearly all useful products have been extracted and sold to marketing boards. Farmers on their own have attempted to ash the CPH by bonfires but ended up unintentional bushfires, which even destroyed their farms As an improvement in bonfires, up-draft kilns were used but did not serve the purpose entirely due to technical problems in some elements of kiln design parameters that led to low quality of ash from high percentage of unburned husks. The approach used was the prototype design of down-draft kiln with three new features, namely, an dedicated chamber to provide heating fuel in the raining season when only the drying husks are required; an empty chamber in front of the chimney duct which eventually reduces the speed of hot air on escape through the chimney by natural draft principle and maintains a steady temperature in the main combustion chamber; the suspending metal grates with high density bricks which turn into the suspension brick platform. Compared with the unburned lumpy ash from the previous kilns, the re-designed kiln with drying and incinerating chambers produced good ashes throughout the year for industrial use.**

Keywords- Cocoa Pod Husk (CPH); Kiln Design; Uniform Heat Distribution; Chimney Wall/ Height; Suspension Grate Design

I INTRODUCTION

Ghana has large volumes of cocoa pod husk (CPH) left on the farms after each harvesting season. Ayeni [1] found that the cocoa pod husk ash (CPHA) contains high plant nutrients as N, P, K, Ca, and Mg, while Adejobi et al. [2] revealed how micronutrients in CPHA are good for tomato production.

Activities on cocoa farms revealed huge tons of leftover pods as waste after harvest seasons when useful ingredients associated with Cocoa pods have been extracted and sold. Cocoa buying agencies have been encouraging farmers to ash the leftover CPH, packaged and transported to user agencies. Woode [3] explained that the ashed husk can be converted to potassium carbonate (potash) which can be used for the production of fertilizers, printing inks, soaps, detergents, potassium salts, dehydrating agents, pigments, special glasses for optical and color television tubes, medicine such as oral rehydrated salts (ORS), bicarbonates for baking powders, fire extinguishers, and also for general purposes such as food activities.

Hope [4] advanced the argument further and pointed out the economic potentials of cocoa pod husk ash in job creation for the youth as well as harnessing export market potentials of the ash. To alleviate the difficulties especially in between the harvesting seasons where the farmers become jobless and migrate to major cities for jobs, proper ashing of cocoa pod husk on a commercial scale would help create wealth in cocoa growing areas. Ashing of the husk needs a well-designed kiln without which the stated economic values of the ash would not be realized. Simpson [5] stated that the efficiency of a kiln determines the quality of ash produced.

Farmers have attempted to ash the CPH by bushfires but ended up an unintentional bonfire, which destroyed their farms. As an improvement on bonfires technique of ashing, the use of old oil drums as furnaces have become popular but the quality of ash was low since the quantity of unburned husks were large. Others resorted to the use of cement concrete slabs with blocks forming a container where the husks are burned for the ash. But these never worked well as the heat destroyed the cement concrete within a week. Experimental kilns have been designed and commissioned for proper ashing by Government to help farmers improve on their ash yield but the high level of unburned husks created low ash yields. Field investigations have been conducted on such kilns and the results showed that such existing kilns have not been able to ash properly because the up-draft nature of the design and construction severely restricts the height of the chimney which leads to smoke nuisance and non-uniform distribution of heat in the combustion chamber due to poor draft. In addition, the bricks used in such kiln designs were poorly selected with single wall arrangement that allowed the alkaline nature of the CPHA and fumes that quickly ate up the common burnt brick wall composite during repeated incinerations leaving holes through the walls as smoke penetrated the cracks and eventually engulfed the kilns and destroyed them. The purpose of this research is to re-design the kiln as both dryer and combustion kiln which can withstand slag attack from the cocoa pod husk ashing as well as provide uniform temperature in the ashing chamber by minimizing steep temperature gradients through the walls of the kiln.

II MATERIALS AND METHOD

Various heat transfer calculations were performed on a number of self-designed component brick wall arrangements. The most effective arrangement in terms of temperature gradient by both the calculated results and the observed temperature readings on the thermocouple is the composite three brick kiln wall arrangements comprising dense refractory brick inner wall backed by medium heat insulating brick and finally a common brick all forming a three unit thermal wall arrangement. Another common brick wall was attached to the three thermal wall layers to form good structural support totaling four layers as shown in Fig. 1.

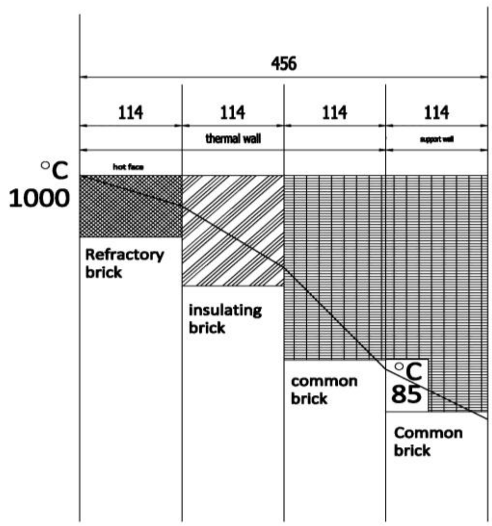

Fig. 1 A schematic representation of the kiln wall with the inner wall servicing 1000 °C and the outer servicing 85 °C

A thermocouple was inserted after the third layer to compare the calculated heat temperature to that of the actual temperature recorded by the thermocouple which averaged around 85 ℃. The actual heat at the end of the 4th layer was not measured since external factors like prevailing wind and air directions created several variables. However, the calculations ensured a more economical way for the entire wall arrangement giving the outer temperature after the third layer bricks of about 85 ℃ that helped for efficient ashing. All calculations were based on the length of the bricks and their thermal conductivities but not the total area of the bricks. A natural draft produced by the installed chimney pulled air into and through the kiln, and the installed dampers located just before the chimney are used to regulate the atmosphere and temperature within the kiln. This kiln has one main door at the front with dimensions 0.4 m × 0.4 m through which the CPH is charged.

III CALCULATION OF HEAT TRANSFER THROUGH THE WALLS IN STATIONARY MODE

Thorough planning was necessary in the choice of refractory materials and the calculation of the thicknesses of the kiln walls enabled the researchers to predict the heat transfer in the heat conduction mode of the three-layered kiln. Masters et al. [6] explained that the amount of heat lost through the furnace structure varies with the amount, thickness and properties of the furnace insulation, the size and type of furnace (batch or continuous) and its mode of operation. For heat transfer between two plane surfaces, such as heat loss through the wall of a kiln, the rate of conduction heat transfer is:

$Q_1 = \frac{kA}{d}(t_{hot} - t_{cold})$ = Total quantity of heat passing through the three-layered brick wall

$$\frac{kA}{d} = \frac{1}{\left({}^{l_1}/_{\lambda_1} + {}^{l_2}/_{\lambda_2} + {}^{l_3}/_{\lambda_3}\right)} = \frac{1}{\sum_k^n \frac{l_k}{\lambda_k}} \quad \text{where n} = 3 \text{ layered bricks in a kiln wall}$$

$Q = heat\ transfered\ in\ time\ t$

$K = thermal\ conductivity\ of\ the\ barrier$

$A = area$

$T = temperature$

$d = thickness\ of\ barrier$

$T_{hot} = 1000\ ^{\circ}$C, where T_{hot} is the maximum temperature expected at the hot face of kiln

$l_1 = l_2 = l_3 = 0.114m$ = length of the refractory bricks

$T_{cold} = 85\ ^{\circ}$C = expected boundary temperature at the end of the third layer

$\lambda_1 = 0.37\ \lambda_2 = 0.3 \quad \lambda_3 = 0.21$ = thermal conductivities of the selected refractory bricks

Substituting them into Q_1 $we\ have$

$$Q_1 = \frac{1000 - 85}{\left(\frac{0.114}{0.37} + \frac{0.114}{0.3} + \frac{0.114}{0.21}\right)}$$

$$Q_1 = \frac{915}{1.231}$$

$$Q_1 = 743.298\ kcal/m^2h$$

$(ii).\ for\ n = 1$

$$Q_1 = \frac{t_i - t_1}{{l_1}/{\lambda_1}} \longrightarrow t_1 = t_i - Q_1\left({l_1}/{\lambda_1}\right)\ where\ t_i = T_{hot}\ and\ t_1 = T_{cold}$$

$$t_1 = 1000 - 743.298\left(\frac{0.114}{0.37}\right)$$

$$t_1 = 1000 - 743.298(0.308)$$

$$t_1 = 1000 - 228.936$$

$t_1 = 771.064^{o}C$ = expected boundary temperature after the first layer

$(iii).\ for\ n = 2$

$Q_1 = \frac{t_i - t_2}{\frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2}} \longrightarrow t_2 = t_1 - Q_1\left(\frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2}\right)$ Where $T_{cold} = t_2$

$$t_2 = 1000 - 743.298\left(\frac{0.114}{0.37} + \frac{0.114}{0.3}\right)$$

$$t_2 = 1000 - 743.298(0.688)$$

$$t_2 = 1000 - 511.389$$

$t_2 = 488.611^{o}C$= expected boundary temperature after the second layer

That is n=3

$$Q_1 = \frac{t_i - t_o}{\frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2} + \frac{l_3}{\lambda_3}} \longrightarrow t_0 = t_2 - Q_1\left(\frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2} + \frac{l_3}{\lambda_3}\right)$$

$$t_0 = 1000 - 743.298\left(\frac{0.114}{0.37} + \frac{0.114}{0.3} + \frac{0.114}{0.21}\right)$$

$$t_0 = 1000 - 743.298(1.231)$$

$$t_0 = 1000 - 915$$

$t_o = 85^{o}C$= expected boundary temperature at the end of the third layer

To facilitate easy maintenance on the entire structure, the bricks were laid flat forming independent wall arrangements as shown in Fig. 2 and the arch bricks were used to form the dome. In achieving good draft and avoiding smoke nuisance, the chimney was built from the ground level up to the height of 8 m with the same thickness as the wall brick arrangement. This wall thickness prevents crack development in the chimney with continuous thermal cycling. To prevent steep temperature gradient through the wall bricks, insulation and common bricks were used as backing layers.

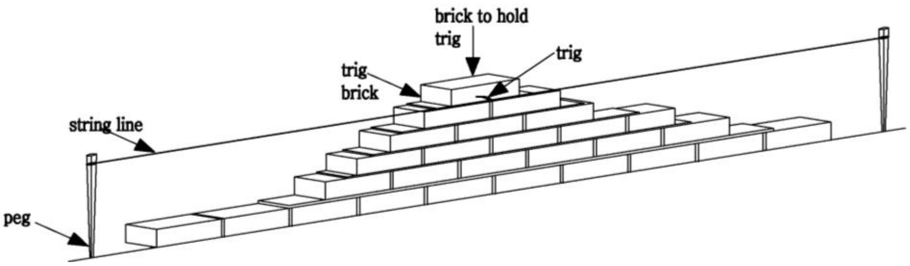

Fig. 2 Technique for laying arrangement of the brick wall construction

This re-designed kiln used three types of bricks with standard dimensions (230 mm × 114 mm × 65 mm): the refractory bricks were used for the hot face with servicing temperature of over 1200 ℃ manufactured by high alumina clays based on the methods in [7]; and then were backed by refractory insulating bricks and the outer bricks were made from common clay bricks. The outer bricks served two functions; apart from providing the final thermal layer, it also provided the rigid aesthetic structural layer. The inner three layers were laid with refractory cement whilst the outer layer was laid with ordinary Portland cement.

The re-designed kiln structure has three identified compartments; the first compartment is a dedicated chamber for the initiation of drying the fresh cocoa pod husk during the rainy season. This chamber has perforated walls where the low heat for drying is drafted over the combustion chamber by the chimney pull. The third chamber is empty and designed to hold the smoke for at least two seconds before entering the chimney. This helps in the equilibration of the heat. Hiromi et al. did similar work by adding another cavity before the smoke finally entered the chimney [8].

The grate that holds the main charge is made from high density refractory bricks to avoid contamination of the ash as presented in Fig. 3. Woodwork was constructed inside the kiln before the refractory bricks were laid over in a normal masonry brick laying technique.

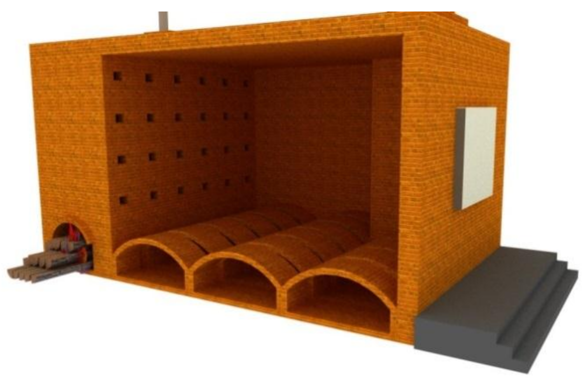

Fig. 3 Perspective view showing novelty in design of the fixed arches with refractory bricks and fire wood heat generating chamber

The wall bricks were laid in the stretcher bond with staggered vertical joints so that no two bricks can line up with standard dimensions of 230 mm × 114 mm × 65 mm (allowing 10 mm joints) to produce a wall of 456 mm thick. The structure was uniformly made up of the four layer bricks including the chimney structure conforming to the usual masonry construction techniques as graphically illustrated in Fig. 4.

Most incinerators and kilns for such purposes usually have designs with metal fixed grates to serve as the loading platform. The method used in this development work replaced the metal grates with arched bricks, which formed the brick suspending platform with gaps on which the husks were ashed to avoid contamination of the ash.

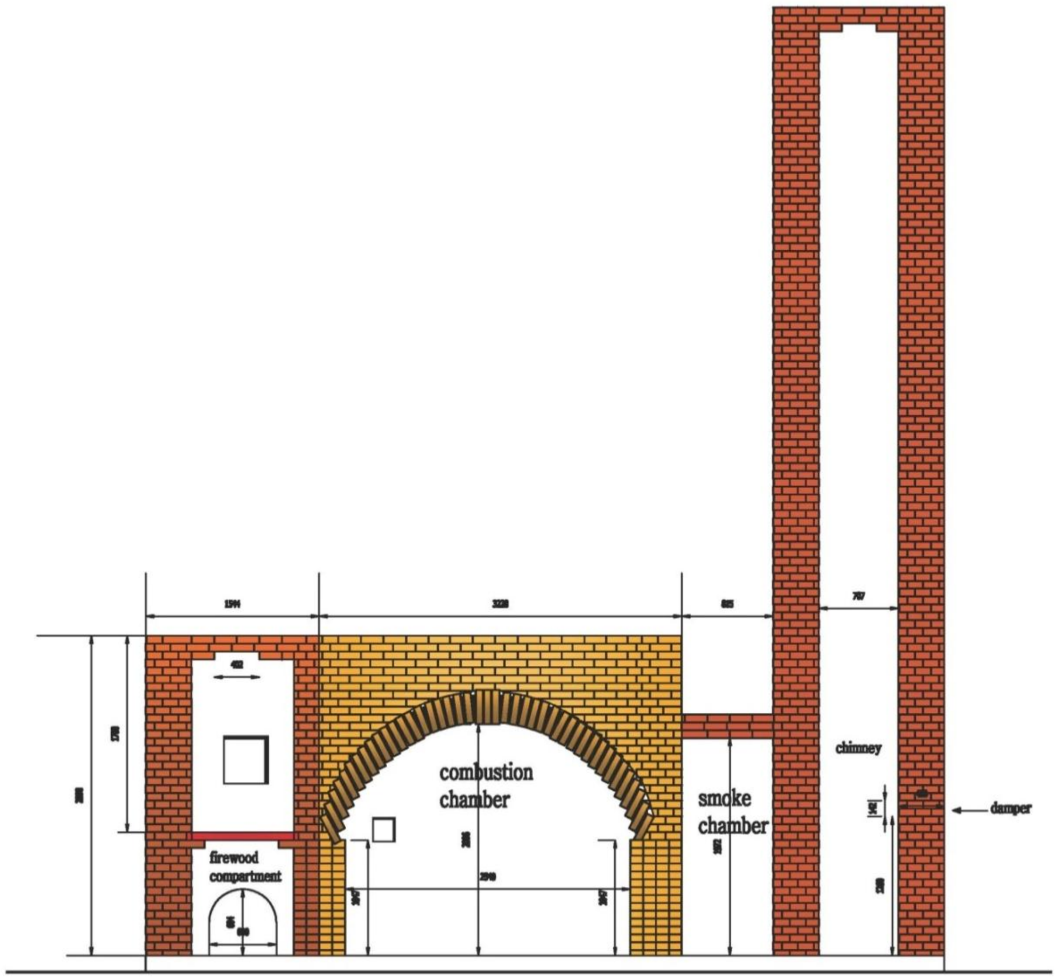

Fig. 4 Cross section of the re-designed kiln showing main combustion chamber, smoke retention chamber, and firewood stoking chamber

IV RESULTS AND DISCUSSIONS

Woode [3] recommended that the optimum temperature for ashing cocoa pod husk into useful ash should be 600 ℃. The design parameters used, especially the choice of the refractory bricks, primarily aimed at achieving uniform heat distribution in the kiln so that all combustion chambers were exposed to the uniform temperature for effective ashing. The kiln walls have the thermal wall arrangement so that enough heat was stored to avoid the steep temperature gradient in the cyclical ashing.

The re-designed kiln using three different types of bricks has considerable advantages over the existing ashing kilns only using the common bricks. The dense refractory bricks used in the first layer hot face exhibited the capacity of withstanding thermal cycling, higher resistance to alkaline slag in corrosion effects at elevated temperatures, and higher heat storage. Kwawukume [7] explained that refractory bricks with high density can withstand hash atmospheres and higher thermal cycling when used in kilns and furnaces.

Additionally, the heat capacity of the refractory brick (with high alumina content) is higher than the common bricks as reported [9]. In this re-design, the refractory bricks were used for the hot face normally exposed to temperatures around 1000 ℃; in the next layer bricks, the insulating bricks were exposed to only boundary temperature of 771 ℃. The 2nd layer boundary bricks have the boundary temperature of 488 ℃ and common bricks were used and the 3rd layer were exposed to only 850 ℃ which is very comfortable for the common bricks hence a good thermal wall. Andreatta and Pompeii agree that such wall arrangements have positive effect on the life span of the kiln [9, 10]. The brick wall layer adopted for the entire construction portrayed an independent wall arrangement that facilitated easy relining in case of replacement of the entire hot face inner wall.

The novel drying chamber incorporated in the design assisted in increasing the yield of ashing of the CPH in the rainy period when drying rate is at the lowest. It is accepted that the key to burning wet wood is to burn at very hot furnace temperature, perhaps starting fire with dry wood. The facility has a chamber where dry wood is used to start the firing to dry the wet cocoa pod hush before increasing the fire to ash the CPH in the adjoining chamber [11]. Technically, the first chamber is only for generating hot air to dry the CPH in the next chamber before firing starts in that combustion chamber using the dried CPH. This arrangement does not allow wood ash to mix up with the CPH ash as metal sieve is placed over the perforated wall that traps the flue ash.

The chimney structure was designed to accommodate thermal losses as well as corrosion by the continuous flue gases since the high density bricks interface the flue gases in the chimney column. The walls were composed of 4 layer bricks with the same heat loss capability as the main combustion structure. This chimney wall arrangement enabled good draft through the chimney since heat loss through the chimney walls are about the same as the main combustion chamber presented in Fig. 4. Additionally, since the draft in the chimney depends on the temperature difference between the average flue gas temperature and the temperature of the outside air, the insulated walls of the chimney enabled higher chimney flue gas temperatures than the temperature of the outside air, thus leading to effective drafting of the spent gases through the 8 m chimney.

To maintain uniform temperature for ashing, heat input and output are very critical and how much heat is driven off through the chimney since available heat for most combustion is only about 26% in view of the fact that 74% usually escapes through the chimney as explained by Buddy [12]. The addition of smoke chamber helped solve the temperature evenness in this kiln. The smoke chamber holds the smoke and releases the spent gas into the chimney duct much more gradually through the damper placed at the outlet of the smoke chamber thereby slowing the stream of very hot gases from escaping through the chimney. In this way, the combustion chamber gets balanced and uniform temperature for effective and constant ashing temperature. This intervention is similar to the work done by Hiromi, et al. [8].

The suspending grate holding structure was designed to use metal bars. This earlier design was found inappropriate in that with time, the metals get corroded and interfere with the chemical composition of the ash and in most time the metal suspension bars are often stolen when left unattended in the farms. The refractory bricks have properties that are virtually inert to corrosion by the residual ash. The feeding of the kiln is through the main door. Galvanised metal containers are placed under the refractory grates where the temperature is not as high as that in the combustion chamber due to the canopy shield created by the brick grate for the ash collection and manually bagged in sacks and stored away after cooling.

V CONCLUSION

The purpose of this research is to re-design an ashing kiln with a facility to dry the CPH during the rainy season in a dedicated chamber stoked with firewood or farm dried biomass. Thermal brick wall arrangement was added to the structurally common brick wall to ensure longer life span of the ashing kiln. The chimney design also guarantees safe outer temperature despite high temperatures in the inner wall cavity during continuous ashing without thermal mismatch during cold and rainy seasons. The usually accelerated rush of hot gases from the combustion chamber to the chimney was minimized by the novel incorporation of a smoke holding chamber that delayed the exit of the smoke and creates uniform temperature in the combustion chamber for effective ashing at a full heat of 600 ℃.

REFERENCES

[1] L. S. Ayeni, “Effect of combined cocoa pod ash and NPK fertilizer on soil properties, nutrient uptake, and yield of maize (Zea mays),” Journal of American Science, vol. 2010, pp. 3, 2011.

[2] K. B. Adejobi, A. O. Famaye, O. S. O. Akanbi, S. A. Adeosun, A. B. Nduka, and D. O. Adeniyi, “Potentials of cocoa pod husk ash as fertilizer and liming materials on nutrient uptake and growth performance of cocoa,” Research Journal of Agriculture and Environmental Management, vol. 2(9), pp. 243-251, 2013.

[3] M. Y. Woode and K. A. Hammond, Proceedings of the 1st School of Engineering research, Retreat Kwame Nkrumah University of science and technology, Kumasi, pp. 24-25, Sept. 2001.

[4] K. Hope, “Treasures of the Cocoa Pod,” The Ghanaian Times - Business & Finance, Kumasi, pp. 2, 2009.

[5] R. K. Simpson, J. H. Oldham and A. M. Martin, “Extraction of potash from cocoa pod husks,” Science Direct Journal (2003).

[6] J. Masters and R. J. Webb, “The Development of a Recuperative Burner for Gas-Fired Furnaces,” Proceedings of the Royal Society of London, Series A, Mathematical and Physical Sciences, vol. 393, no. 1804, pp. 19-49, 1984.

[7] P. S. Kwawukume, “Material specifications for the production of high density refractory brick with locally available high alumino-silicates,” Journal of the University of Science and Technology, Kumasi, vol. 19, nos. 1, 2&3, 1999.

[8] Hiromi, T. Roppo and K. Naoki, “Building Your Own Kiln: Three Japanese Potters give Advice and Instructions,” Japan, Kodansha International Ltd., pp. 96.

[9] D. Andreatta, “Heat loss from stoves: Thermal properties of insulated bricks overall heat losses,” 2003, [Online] Available: http://www.bioenergylists.org/stovesdoc/Andreatta/Heatloss.htm.

[10] Pompeii oven instructions eBook V 2.0, 2011. [Online] Available: http://www.fornobravo.com/pompeii_oven/pompeii_oven.html.

[11] Hammond, “The effect of ashing temperature on composition of ash from cocoa pod husk,” in proceedings of the 1st School of Engineering

Research Retreat, 2001.

[12] F. Buddy, “Heat recovery,” In R. C, Brodie (Ed), the energy efficient potter. Watson-Guptill, pp. 159, 1982.