Performance Analysis of Kiln for Locally Manufactured Clay Bricks

Selamawit Amaha, Hari Prasada Rao Pydi

Abstract :

Earthenware, a type of brick most widely available in Ethiopia, which is useful for the construction of houses, is being produced at Boye (Jimma) using energy inefficient traditional kiln which results in cracked and warped bricks. The quality of the brick produced is not so good due to heat it receives as a result of poor combustion that takes place inside the kiln thus in turn leads to deforestation of the local area. Three experiments are carried out during the project work. The absorption capacity test results 31.085% but, from the standard consideration; the absorption capacity of a good brick is not more than 15% of its dry mass. This suggested that, it is not suitable for building purpose. If it is, it should be used at the inner wall otherwise it absorbs moistures in to the room. The compressive strength of the brick result shows that, firing is used to increase a compressive strength of only 1.196 M Pa. And according to standards, the brick in the above is out of range (A, B, C, & D), [Ref. The Ethiopian Quality Control Agency]. The reason for this is not only the firing process but all the manufacturing process from the start. From the last experiment the moisture content of the soil is around 33.1%. From this the moisture content of the soil is very high so it needs large amount of heat to dry as well as to fire the brick. The energy audit of traditional kiln indicates that tremendous amount energy is absorbed by the structure and the floor together which accounted for 32.9% and the energy released by the flue gas is 45.56%. The total energy absorbed by the brick is the smallest fraction due to heat loss through the kiln and during manufacturing process like molding problem.

Index Terms: Kiln; moisture content, compressive strength, absorption capacity.

1. INTRODUCTION

Kilns are basically containers for heat. In the most primitive forms, this could be nothing more than a trench or pit dug into the earth. Today, there are many different types of kilns. Here is an introduction to some of the most common types of brick kiln.

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In 1857, in Germany a continuous brick kiln was invented by F. E. Hoffmann. The first kiln had a circular, arched tunnel surrounding the chimney. This reduced the fuel consumption by more than 50% compared to the periodic kilns. Thirty years later, a British engineer, W. Bull, designed an arch less version of the Hoffmann kiln, which is now called a Bull's trench kiln. It is widely used in Pakistan, India, Bangladesh and Myanmar, but is little known elsewhere. Its greatest advantage is its low cost of construction and comparatively low energy consumption [1], [2].

The Vertical Shaft Brick Kiln (VSBK) is classed as a continuous updraft kiln, which combines the simplicity and low cost of updraft firing with very impressive fuel economy, plus the benefits of continuous operation. In China, where it was developed in the late 1960s, it is used by small scale seasonal brick making entrepreneurs, wherever there is an abundance of good brick making clay and a reliable supply of coal fines. Its operation is very similar to that of a vertical shaft lime kiln, with coal and bricks being loaded at the top and fired bricks combined with a small amount of ash being unloaded at the bottom [3].

Rural brick making is an ancient art in Ethiopia. Even in the present time the art exists in a modern way throughout the world. However in our country brick makers are still using the old system of brick making as well as firing techniques. They make bricks traditionally without knowledge of how to make it efficiently, thus it may fail at different stages.

The process of brick making itself is essentially a simple one. Clay is mixed with sand, water and any required additives, and the mixture is well-grounded. It is then pressed into steel molds, or extruded through a die and then cut up into required sizes. The molded bricks are then fired in a kiln at high temperatures. Bricks damaged in the manufacturing process are recycled and reused.

In this present research work, the attempt is to identify brick makers' technical problems in 'Boye'. So the notes below try to tell the main problems, the reasons for them, and possible solutions. The final product, the fired brick will be considered and trace faults back to their cause including the laboratory work. In reality small-scale brick makers often face many problems.

Nevertheless, it is worth knowing where problems originate and how they might be solved, particularly for brick works suffering heavy losses or unable to meet the standards and their market demands. Before going to the laboratory test an attempt is made to look at the field test.

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Fig. 1 Brick production in Jimma

2. MATERIAL AND METHODS

The objective of carrying out the laboratory work is because the final output of the brick production depends on the moisture content, drying process, the soil type, and so on...

Laboratory tests to be carried out include [4]:

1.1 Water content determination

The moisture content of soil (also referred to as water content) is an indication of the amount of water present in soil. By definition, moisture content is the ratio of the mass of water to the mass of solids in the sample expressed as a percentage. In equation form,

$W=\frac{M_W}{M_S}\times 100$, where: W=moisture content of soil, in %, M_W =mass of water in soil sample, M_S =mass of solids in soil sample

1.2 Absorption capacity of the brick

Absorption of brick is the capacity to absorb water to saturation. The rate of absorption or suction of brick has an important effect on the adhesion of brick and mortar because if brick absorbs water too soon and it will be poor and will not be used for construction purpose. Water absorption in the brick can be expressed as

$\%\ absorption=\frac{(W_2-W_1)}{W_1}$, Where, W_1=weight of oven dry brick.

W_2=weight of the saturated surface dry brick, after 24hrs of submersion in cold water.

1.3 Compression test of bricks

No	Parameter	Purpose	Instrument
1	Surface temperature(To)	To calculate radiation and convective losses	Infrared thermometer
2	Flue gas composition	To calculate air ratio and combustion efficiency	Exhaust analyzer KM9014

Brick is most widely used for a construction of structural andr non-structural walls. It is a small building unit, solid or cored not in excess of 25%. Brick commonly produced as a rectangular block composed of inorganic, non metallic substance of mineral origin and hardened by heat or chemical action.

Table.1 Minimum compressive strength allowed for brick (ESC.D4.001)

Class	Average of five brick(m pa)	Individual brick (m pa)
A	20	17.5
B	15	12.5
C	10	7.5
D	7.5	5.0

2.4. Data Collection and Analysis

For undertaking the research work in Boye brick manufacturers, data has been collected from different sources like, interviews, direct observation and reading measurement[5],[6],[7],[8].

Table 2 Instruments used for Measurement.

2.5. Energy performance of brick kilns

A clear definition of the energy requirement is difficult in the kiln energy analysis. The amount of energy required for a particular firing operation includes the sensible energy required to raise the temperature of the kiln from room temperature to the maximum firing temperature, as well as the latent energy needed for the removal of moisture, volatiles and the various phase transformations occurring during firing.

In the present work, therefore, only the sensible fraction of energy absorbed by the brick and the energy needed to remove moisture are accounted for. An attempt is made to determine where all the energy generated due to combustion of the fuel goes during firing. Although this analysis would produce an underestimate of kiln efficiency values, it would throw light on the factors contributing to the increase in fuel consumption and the means that could be attempted to mitigate these factors.

In the present analysis, only the period of firing has been considered, and the quantity of energy absorbed in the various solid parts of the kiln, and other hot parts of the kiln to the ambient and the energy lost through flue gases and ash have been estimated for this period.

Ideally, an energy audit should be carried out by measurement of all the components of energy flow in a system. Since the kilns investigated here are natural draught systems, measurement of air and flue gas flow rates was

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difficult: this would have been much easier in forced flow systems where airflow could directly be measured at the blower inlet or outlet. Also, it was not feasible to insert thermocouples at all the points where temperature measurements would be desirable.

The only quantity that was measured was temperature at various points, viz., at the bottom of the payload volume in contact with the fireclay grate, at the top of the payload where the flue gases escape to the ambient and the brick wall temperatures inside the firebox and on the outer periphery of the wall, at intervals of 15 minutes. The energy terms can be grouped under four major headings [9], [10].

(a) Energy released by combustion of the fuel;

Energy of wood= $\dot{m}_{wood} \times cv_{wood}$,

Where, ρ = the average density of the eucalyptus tree

V= the average volume the wood used by the brick makers

(b) Energy absorbed by the brick;

- Sensible heat absorbed by brick

$Q = m \times cp \times \Delta T$

re, m=the total mass of the brick

specific heat

ΔT≡ change in temperature

Q= heat absorbed by brick

- Sensible and latent heat absorbed by moisture in the brick

$$C = Q/(m \times \Delta T) + L \times m$$

Where, L= latent heat

C= heat capacity

(c) Energy absorbed by the kiln, including the floor below the kiln, the walls of the kiln, the grate, plastering materials,

- Heat absorbed by the walls of the kiln

$$Qw = 2\, kw\, (Tw - Ti)\, Aw\, [t/ (\pi\, \alpha)]^{1/2}$$

Where, k_w = the thermal conductivity,

α= thermal diffusivity,

T_w= the temperature of the inner surface of the wall

t =time interval, and

Ti = the initial temperature

- Heat absorbed by the kiln floor

$$Q_f = 2\, k_s\, (T_f - T_i)\, Aw \left[\frac{t}{\pi \times \alpha)}\right]^{1/2}$$

Where, k_w = the thermal conductivity of the wall material,

T_f= the flame temperature,

t =time interval, and

Ti = the initial temperature of the wall before the heating began

(d) Energy lost directly to the surroundings through flue gases and ash, and convection from the outer surface of kiln walls.

- **heat carried away by the flue gases**

$$Q_{fg} = m_{fg} \times Cp_{fg} \times \Delta T$$

Where, Q_{fg}=heat carried away by the flue gas

m_{fg}=mass of the flue gas

Cp_{fg}= specific heat of the flue gas

- Heat lost from the outer surface of kiln walls

A. Radiation Heat loss from kiln system surface

$Q_{rad} = \sigma \times \epsilon \times A_{kiln}\, (Ts^4 - Tsky^4)$, Akiln= $n \times l \times w - n_s \times l_s \times w_s$

Where, σ = 5.67×10-8, Stepfenboltzman constant

Є = 0.78, (for oxidized surface)

Ts = Average surface temperature

T_{sky}= sky temperature

n_s=number of stack

w_s=width of stack

l_s =length of stack

B. Convection Heat Losses

$$Q_{conv} = h_g \times A \times (T_s - T_o),\ h = \frac{\overline{N}_u k}{L},\ N_u k =$$

$$\text{average Nusslet , Nu} = \left[0.825 + \frac{0.387 \times R_{a1}^{\frac{1}{6}}}{\left[1 + \left(\frac{0.492}{p_r}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right]^2$$

$$R_{a1} = \frac{gB\Delta TL^3}{v\alpha},\ B = \frac{1}{T},$$

$$Q_{conv} = h_g \times A \times (T_s - T_o),\ T_f = \frac{(Ts + T\infty)}{2}$$

Where, - Qconv= heat due to convection

k= conduction heat transfer coefficient

Nu =applies to all fluids for both laminar and turbulent flows.

L = the characteristic length with respect to the direction of gravity,

Ral = the Rayleigh Number with respect to this length.

Nu K= average Nusslet

Ts=surface temperature of the kiln

To=atmospheric temperature

Tf=average temperature

- *Heat lost from the upper surface of the kiln*

A. Radiation Heat loss from kiln system surface

$$Q_{rad} = \sigma \times \epsilon \times A_{kiln}\, (Ts^4 - Tsky^4)$$

B. Convection Heat Losses

1) $Q_{conv} = h \times A_{kiln} \times \Delta T$

- Heat loss due to moisture in fuel

$$Q_{mf} = M \times \dot{m}_f\, [h_{fw} + Cp\, (T_l - T_{am})],\quad Q = L \times m$$

Where:-M=moisture in a fuel

$\dot{m}_f$=mass flow rate of fuel

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h_{fw}=enthalpy of water

Cp=specific heat capacity

L= latent heat

M= mass of the fuel

- *Heat loss due to moisture content in air*

$Q_{ma}=AAS\times Y_A\times \dot{m}_f [Cp\,(T_{fl}-T_{am})]$

- *Unaccounted loss*

A. Heat loss due to unnecessary space b/n the socked brick

B. Energy loss due to over fired brick near the stack

Fig.2 how the brick loss after firing process has been completed

- **Specific fuel consumption**

Calculating the specific energy consumption required for firing of one kilogram of fired brick, the performance and energy consumption of the brick kilns within the cluster can be accurately determined by

$$SEC=\frac{E_{in}}{m}=\frac{132{,}355.5}{20{,}000*2.1}=3.15MJ/Kg$$

2.RESULTS and DISCUSSIONS

2.1 Water content determination

From the experiment the moisture content of the soil is 33.1%. This shows the moisture content of the soil is very high so it needs large amount of heat to dry as well as to fire the brick. It is advisable to use other drying method or else they can use appropriate water content.

2.2 Absorption capacity of the brick

The experiment of absorption capacity of the brick is 31.085% but, from the standard consideration; it says that "A good brick shouldn't absorb more than 15% of its dry mass [17]. If bricks are too absorbent they suck moisture out of mortar and weaken the bond during construction." This suggested that, it is not suitable for building purpose. If it is used, it can be putted at the inner wall otherwise it absorbs moistures in to the room. In addition to this during construction it absorbs the cement moisture instead of attaching it.

The absorption test also shows that the result is two times that of the standard. So that the brick in Boye is "porous" (Porous brick reduce the heat transfer rate).In order to reduce this problem, the brick makers in Boye must use a simple extruder mechanism that compress the mud during molding process and prevents air from entering in to the bricks.

2.3 Compression test for brick

From the result of compression test, firing is used only to increase a compressive strength of 1.196 M Pa. And according to standards, the brick is out of range (A, B, C, & D). The reason for this is not only the firing process but all the manufacturing process from the start. So in order to manufacture a brick with better strength, they have to keep in looking at all process from the start and follow the standard.

4.4. Energy lost results

The firing of the kiln started at 48 hrs on the day of observation. Smoking operation took 6hrs to raise the temperature to 150°C, after which slow firing phase started. Temperatures rose up to about 300°C in this phase, and Rapid firing raise the temperature to 660°C, and the kiln was allowed to cool on its own by natural convection after 48hrs are completed. It is difficult to distinguish the slow and rapid firing phase. Not only this, the internal wall temperature of the kiln and the outside surface temperature of the kiln taken as the same for the entire analysis. This is because when you look at the traditional kiln, the average insulation thickness of the wall is around 2.5cm that means as time goes it has a little effect on the temperature variation. Therefore the result of the total heat loss from the kiln structure is revised in table.3

Table.3 Component of Energy Flow

Component of Energy Flow		Percentage
Combustion of fuel	132,355.5MJ	**100**
Heat outputs		
heat loss from exit gases	60,400.4MJ	**45.56**
Energy stored in the brick	42,046.394MJ	**31.77**
Radiation from kiln surface	2351.306MJ	**1.78**
Heat absorbed by the wall plaster	14,853.59MJ	**11.22**
Convection from kiln surface	751.4MJ	**0.568**
Heat loss at the top of the kiln	452.51MJ	**0.34**

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Heat loss at the kiln floor	4176.57MJ	**3.16**
Heat loss due to moisture in fuel	2275.19MJ	**1.72**
Heat loss due to moisture in air	1.162MJ	**0.08**
Unaccounted Heat	5046.98MJ	**3.81**
Total		**100%**

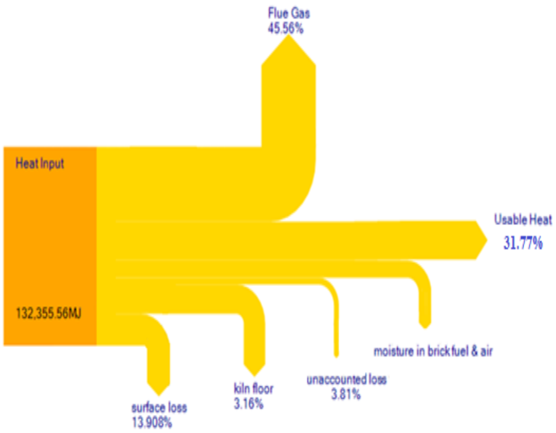

Fig.4 sunkey diagram of energy flow in the traditional kiln

3.CONCLUSIONS:

The major problem of the brick maker in Boye is, the traditional brick kiln does not have a kiln or firing house and this lead to heat loss. They use 28m^3 woods to fire 20,000 brick. In addition to this from the 20,000 bricks they get less than 50% of it. To reduce the above problems a new design of kiln is necessary. The distribution of energy during firing in the kilns has clearly shows that the smallest fraction of the heat energy is absorbed by the brick and the flue gas loss takes the higher energy because of the traditional brick manufacturers don't have a firing house or kiln. The other heat losses are accounted for surface losses of tiny insulation thickness and moisture in the brick and fuel. Hence, the following need to be considered for improving the energy utilization of the kiln.

a. The thermal mass of the structure needs to be increased. This is possible by increasing the thickness of the walls of the kiln
b. The kiln needs isolation from the floor and firing should be done on grates rather than on the floor.
c. Kiln to avoid the above losses.
d. Chimney for the flue gas exit.
e. Ensuring a less open flame and better control on air inlet areas, a better control on excess air and flame temperatures could be achieved, which would ensure better combustion and heat release from the fuel.

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