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EXPERIMENTAL STUDY OF RURAL BRICK BURNING IN IRINGA AND MBEYA REGIONS

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ABSTRACT

In this paper results are presented of a study conducted between June and December 1997, on nine brick firing kilns in Iringa and Mbeya. The locations for the study were Mahenje and Ilomba in Mbeya Region and Igumbilo in Iringa region. Three kilns were investigated in each location. For each kiln the process was followed from the laying of the bricks into a kiln to the opening of the kiln for removal of the bricks in preparation for the selling. Different weights and temperatures were taken at different times.

Firing wet bricks results in consumption of 33.63 % of the total energy input to the kiln being used for drying the bricks. This amount can be saved through prolonged sun drying. In addition, large bricks, i.e. those at Ilomba, were observed to be difficult to cure uniformly. Temperature distribution was observed to be a major problem in all the kilns resulting in poor vitrification and oxidation of organic matter. This is probably a contributing factor towards reduction of the compressive strength of the burnt bricks which was observed to be between 2.17 and 4.51 MPa.

An average of 36.19% of the input wood energy is used to raise the temperature of the bricks while 31.3% is used to evaporate the moisture contained in the bricks. A further 5.6% is utilised to evaporate the moisture contained in the wood used for fuel which was observed to be between 34 and 46 % by weight. The remainder 26.9% is considered to constitute other loses including losses through convection. Calculation of wood consumption per unit mass of brick indicated high thermal efficiency if the quality of bricks produced is not taken into account and was very low when only quality bricks are counted.

INTRODUCTION

Burnt bricks are used in a number of regions in Tanzania. They are widely used for the construction of residential and co-operative village houses like offices, schools, dispensaries, churches, mosques and shops. Bricks are made from clay and dried in the atmosphere for several days. Sometimes the drying is done under cover to prevent cracking and warping as a result of drying rates which are too high. Later the bricks are fired in a simple kiln constructed by laying the bricks in such a way that they form a pile with tunnels at the bottom where wood is burned. Firing is necessary to increase the strength of the bricks and also to reduce their water absorption ability. Jastrzebski [1] outlines the following sequence of events for the curing process: At a temperature of 110 to 260 ^{0}C hygroscopic moisture is removed from the brick. For temperatures between 400 and 650 ^{0}C clay minerals breakdown releasing chemically combined water. At this point the clay loses its ability to form a plastic dough thus it can no longer be moulded.

The presence of organic matter in the brick reduces its strength hence these are removed through oxidation at a temperature of 800 to 900 ^{0}C. During this process an oxidising atmosphere (air/oxygen) has to be maintained inside the kiln. Vitrification occurs at temperatures between 900 and 1000 ^{0}C. This is a process of gradual formation of a liquid which fills up the pore spaces. On cooling the liquid solidifies to a glassy mass cementing the inert particles which increases considerably the strength of the brick. Vitrification is associated with shrinkage and its extent increases with temperature to 1400 ^{0}C where full vitrification is achieved. The extent of vitrification controls the properties of the brick such as strength, durability and water absorption.

OBJECTIVES

The study was conducted with several objectives the main one being to identify energy saving potential in the industry. Brick burning uses a lot of wood and this is obtained from existing forest with significant contribution to deforestation. A second objective was to identify possible improvements especially to the firing process which can be instituted to effect better quality of the burnt bricks.

EXPERIMENTS

Three areas were identified for the experimental study. These were Mahenje and Ilomba in Mbeya region and Igumbilo in Iringa region. This selection was purposely done to take into account the different sizes of bricks used in the regions. The dimensions of the bricks for each area were 80x170x280 mm, 105x180x320 mm and 65x100x220 mm for Mahenje, Ilomba and Igumbilo respectively. Measurements were done in three kilns for each location.

The number of bricks laid in a kiln was established by summation of the number of bricks on each layer. The later was established as the product of the number of bricks along the length of the layer and that along the width.

Before commencing firing a pile of wood considered to be more than sufficient for the firing was weighed and the kiln operators restricted to using wood from this pile only. At the end of the firing process the remaining wood was then weighed and the difference between the two weights was considered the amount of wood used for the process. In addition five samples weighing between 40 and 60 g each were randomly taken from the pile of wood and weighed. These samples were later dried in an oven for 24 hours at a temperature of 105 ^{0}C after which they were weighed again. A drying temperature of 105 ^{0}C was selected so as to be higher than the saturation temperature corresponding to the maximum possible vapour pressure under atmospheric conditions which is 100 ^{0}C. Under such an arrangement all the water in the wood is likely to be evaporated. The duration for drying was established by observing the weight of the samples till no more change in weight through drying was observed. The amount of moisture initially in the sample was then considered to be the difference between the initial and final weight.

For each kiln, before and after firing, a randomly picked sample of ten bricks was isolated for measurements of size and weight. The dimension of each brick (width, length and thickness) and weight were taken and an average evaluated.

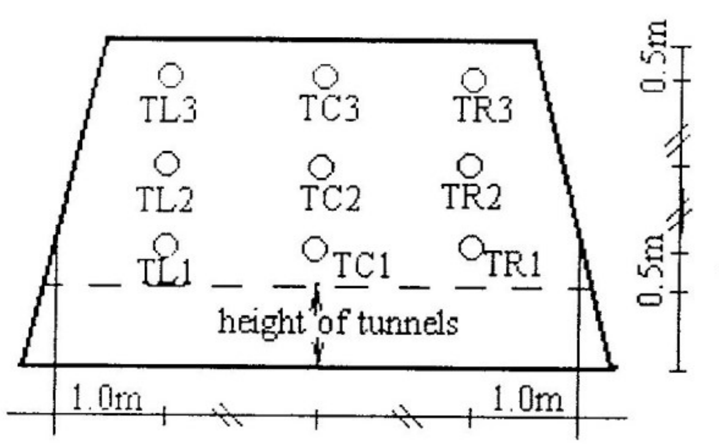

Fig. 1 Location of temperature probes

These were used as representative of all the bricks for that particular kiln.

Temperatures were measured at nine locations along the length of the kiln as shown on fig. 1. At each location, measurement were taken at a depth of 1.5 and 0.5 m into the kiln. The former represented the temperature at the centre while the later was considered to represent the surface temperature. A thermocouple probe type K coupled to a digital readout was used for the measurements. Temperature readings were taken at a time interval of two hours except late at night when longer intervals were used for safety of the operators.

In addition to the above measurements, the linear dimensions of each kiln were recorded because they do have an influence on performance.

RESULTS

The average measured sizes of the bricks before firing were 83x168x292 mm, 104x184x327 mm and 63x100x224 mm for Mahenje, Ilomba and Igumbilo respectively. Similar measurements for the burnt bricks were 76x174x284 mm, 103x175x313 mm and 63x99x221 mm.

Table 1 gives the average weight loss for a sample of five bricks sampled from each kiln.

Table 1 Loss in weight of bricks through firing

	Mahenje			Ilomba			Igumbilo		
Kiln	1	2	3	4	5	6	7	8	9
Wet	5.35	5.35	5.35	8.29	7.68	9.52	2.21	2.15	2.19
Burnt	3.87	4.10	3.71	7.04	6.64	7.63	2.08	2.05	1.92
%loss	28.0	23.0	31.0	15.0	14.0	20.0	7.0	5.0	12.0

Table 2 gives a comparison of the two ways in which the heat supplied is utilised in the kiln. The first is sensible heat, (Q_s), which is the heat required to raise the temperature of the bricks to the maximum value. The second is the heat required to evaporate the water contained in the bricks, commonly referred to as latent heat, Q_l. These are compared with the total heat input, Q_{in}, as evaluated using the calorific value of the fuel.

Sensible heat Q_s, was estimated to be the product of total mass of burnt bricks, m_b, the specific heat capacity, c, and the temperature rise from ambient, $(T_{max}-T_a)$ eq. 1.

$$Q_s = m_b c(T_{max} - T_a) \tag{1}$$

The latent heat, Q_l, was estimated to be the product of the total loss in weight of the bricks through firing and the change in enthalpy due to evaporation for steam, eq. 2.

$$Q_l = (m_w - m_b)h_{fg} \tag{2}$$

The specific heat capacity for clay bricks was considered to be 0.88 kJ/kg K [2] and the enthalpy change due to evaporation was evaluated at atmospheric pressure and an evaporation temperature of 100 ^{0}C to be 2256.7 kJ/kg [3]. Finally the energy content of the wood, Q_{in}, was considered to be the product of the total mass of wood used and the lower calorific value of wood which was 14.35 MJ/kg [4].

Table 2 Comparison of sensible and latent heat with heat input to the kiln

Kiln	Q_s [GJ]	Q_l [GJ]	Q_{in} [GJ]	$\%Q_s/Q_{in}$	$\%Q_l/Q_{in}$
1	4.62	7.88	14.64	31.6	53.8
2	3.31	4.15	12.61	26.2	32.9
3	3.63	6.51	10.88	33.4	59.8
4	11.55	9.10	30.73	37.6	29.6
5	13.62	7.79	34.06	40.0	22.9
6	24.51	8.23	66.07	37.1	12.5
7	8.43	7.81	23.39	36.0	33.4
8	54.91	9.90	148.06	37.1	6.7
9	32.27	20.77	69.03	46.7	30.1
Average				36.19	31.3

Table 3 gives average results of laboratory measurements of brick samples taken from kilns at Igumbilo and Ilomba respectively. The bricks were capped and tested for compressive strength according to BS 2028,1364:1968. Water absorption was evaluated using the dry weight of the brick and the weight after soaking for one hour.

Table 3 Laboratory Test Results for burnt (b) and clay (c) bricks

Sample	Dimensions l x w x h [cm]	Density [kg/dm^3]	Comp. Str. [Pa]	Water Absorption [%]
IGUMBILO				
Kiln 1 (b)	22.7x10.8x5.7	1.34	3.69	15.2
Kiln 1 (c)	22.8x10.4x6.3	1.57	2.11	
Kiln 2 (b)	22.3x10.2x5.3	1.72	4.51	15.0
Kiln 2 (c)	23.1x10.6x6.6	1.41	2.35	
Kiln 3 (b)	23.1x10.6x6.6	1.33	3.27	19.0
Kiln 3 (c)	23.1x10.6x6.6	1.30	1.94	
ILOMBA				
Kiln 1 (b)	32.8x18.3x10.5	1.24	2.17	27.5
Kiln 1 (c)	32.6x18.3x10.5	1.24	2.10	

Figures 2 to 10 show the temperatures measured at a depth of 1.5 m from the surface of the kiln at locations TC1, TC2 and TC3.

Table 4 gives the measured moisture content of the fuel wood used at Mahenje and Ilomba respectively. Included on the same table is the percentage of the energy content of the wood required to evaporate the water contained in it.

Table 4 Wood moisture content and percentage energy used to evaporate

	MAHENJE			ILOMBA			Average
	Kiln 1	Kiln 2	Kiln 3	Kiln 1	Kiln 2	Kiln 3	
%mc	40.65	40.1	45.9	35.8	39.6	34.2	39.38
%ec	5.74	5.66	6.48	5.05	5.59	4.83	5.56

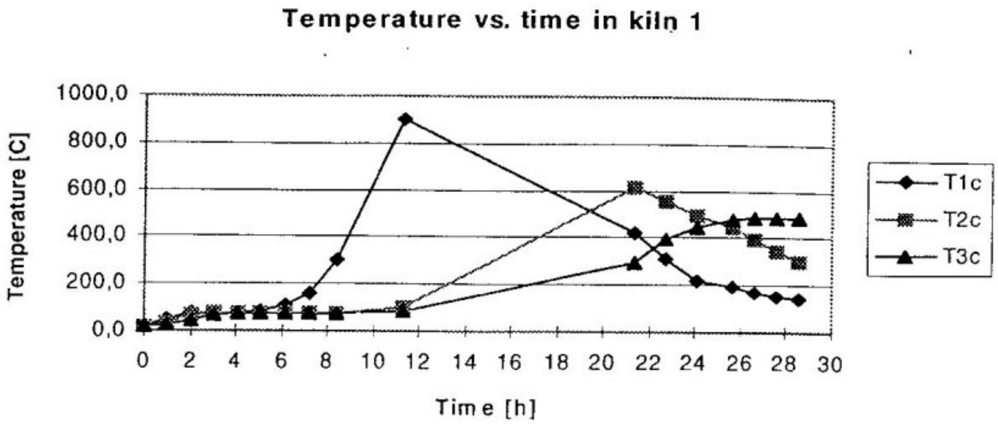

Fig. 2 Temperature for Kiln 1 (at Mahenje)

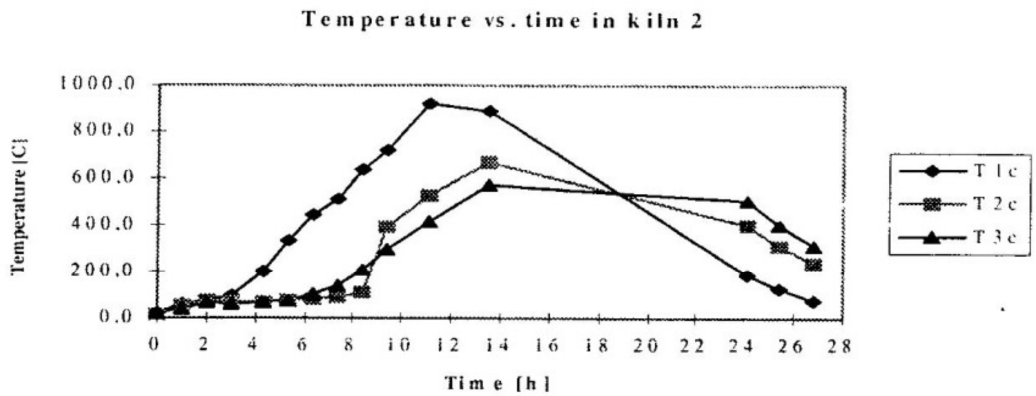

Fig. 3 Temperature for Kiln 2 (at Mahenje)

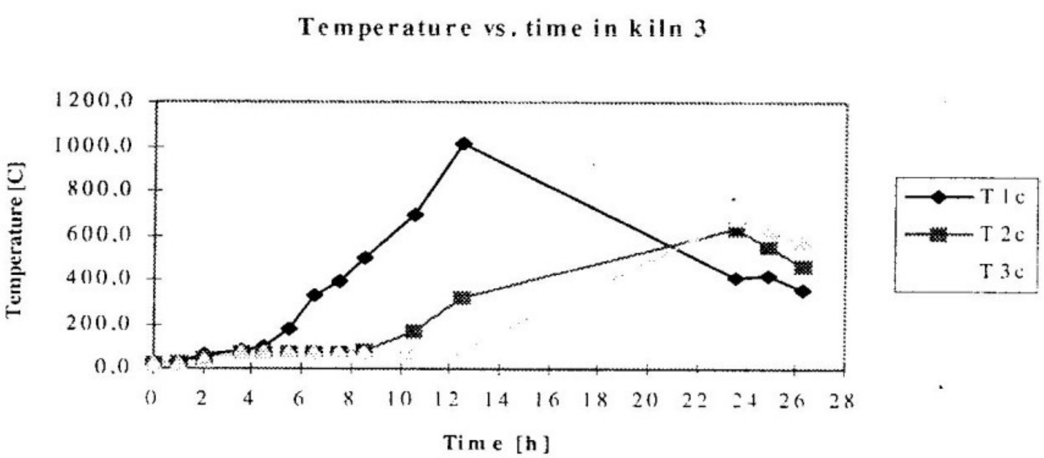

Fig. 4 Temperature for Kiln 3 (at Mahenje)

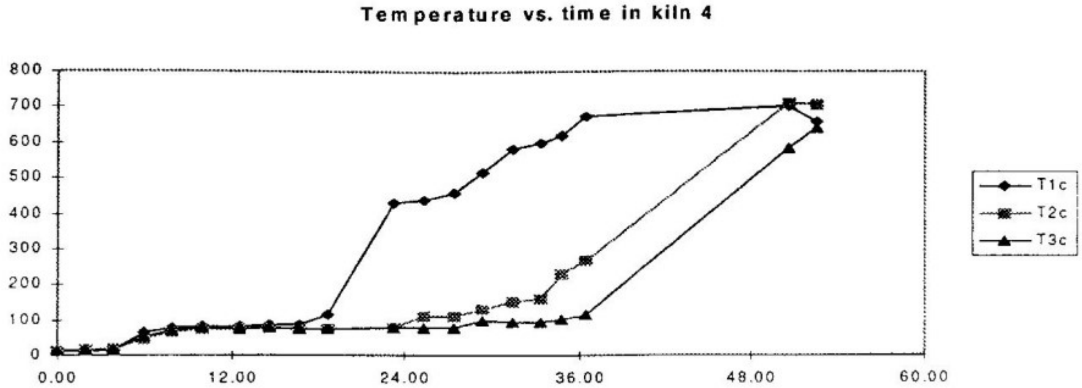

Fig. 5 Temperature for Kiln 1 (at Ilomba)

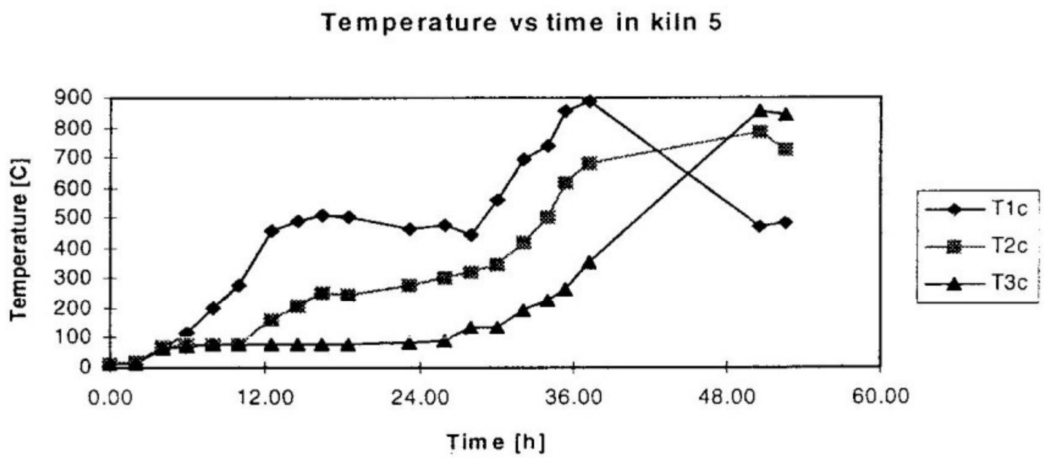

Fig. 6 Temperature for Kiln 2 (at Ilomba)

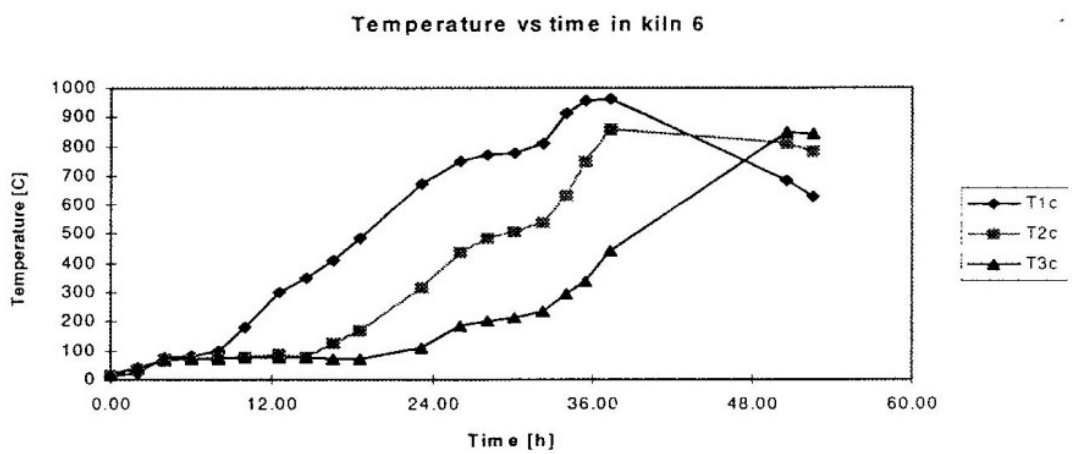

Fig. 7 Temperature for Kiln 3 (at Ilomba)

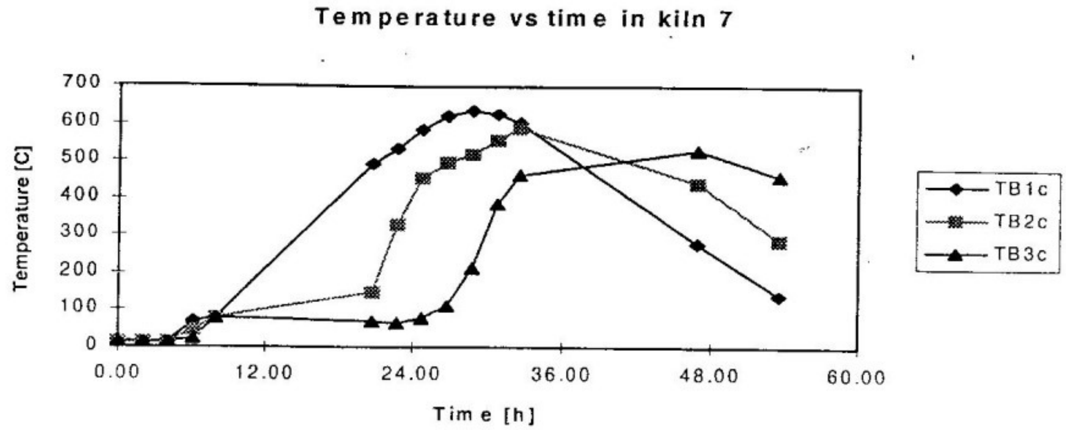

Fig. 8 Temperature for Kiln 1 (at Igumbilo)

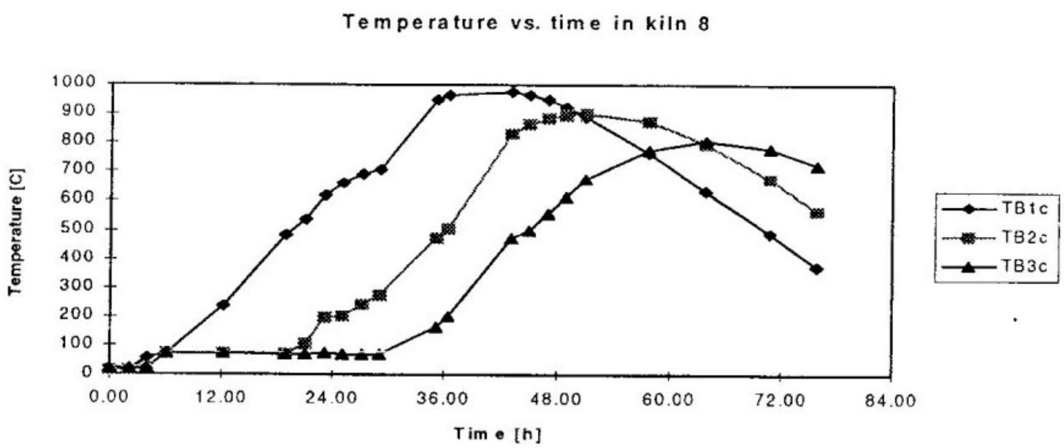

Fig. 9 Temperature for Kiln 2 (at Igumbilo)

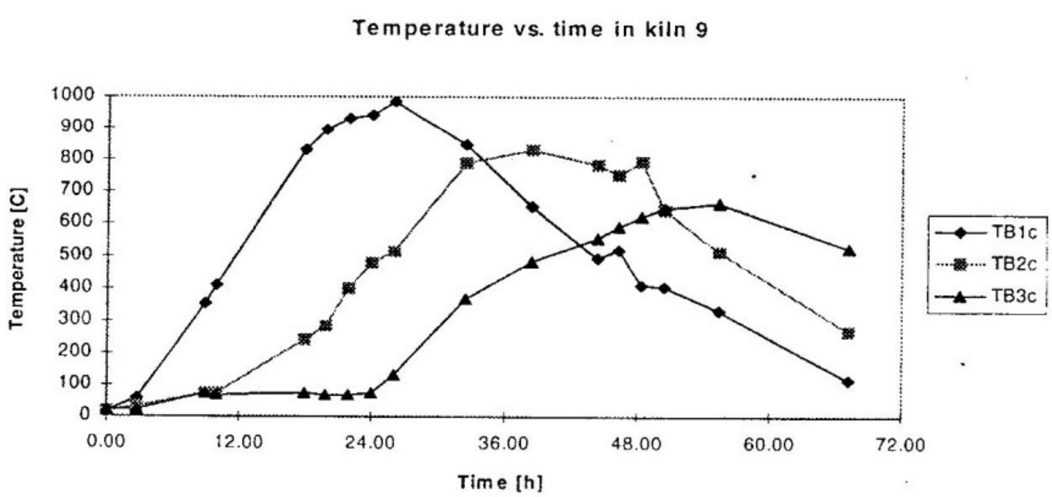

Fig. 10 Temperature for Kiln 3 (at Igumbilo)

The mass of wood used for a unit mass of brick is commonly used as an indicator of performance. Table 5 gives the wood consumption for the nine kilns investigated.

Table 5 Fuel wood consumption per unit mass of brick

Kiln	Green Bricks [kg/kg]	Burnt Bricks [kg/kg]	
		All	Good
1	0.0681	0.0941	0.1118
2	0.0821	0.1072	0.1456
3	0.0648	0.0935	0.1163
4	0.0764	0.0900	0.0943
5	0.0773	0.0894	0.1078
6	0.0815	0.1017	0.1167
7	0.0673	0.0714	0.0779
8	0.0960	0.1004	0.1088
9	0.0474	0.0541	0.0735
Ave	0.0734	0.0891	0.1059

DISCUSSION

Comparison of the dimensions of the green bricks and those of the burnt bricks indicate a certain amount of shrinkage. Bricks at Mahenje had their volume reduced by 7.8% through the process of firing. The lowest shrinkage of 2.3% was observed at Igumbilo while the highest was 9.8% observed at Ilomba. It is worth noting that the magnitude of the shrinkage increases with increase in the size of the brick. Except for the 2.3% the other two are rather high. This can be attributed to strong vitrification or may be a result of firing bricks with high moisture. The measured temperatures indicate very low level of vitrification if any hence high moisture content is likely to be the reason.

Significant loss in weight (Table 1) for the bricks can be associated with high moisture content or high organic matter which is lost through oxidation.

Deliberate efforts are made by brick makers to reduce the presence of organic matter hence observed losses in weight are mainly due to moisture content. Using this, the average moisture content of the bricks was measured as 27.3%, 16.2% and 7.4% by weight for Mahenje, Ilomba and Igumbilo respectively. It is evident that the bricks are fired with considerable moisture content.

It is also evident from table 2 that with the exception of kilns 6 and 8, the heat required to evaporate the water contained in the bricks ranges between 22 and 60 % of the total heat input with an average of 31.3%. The implication of these figures is that if other means of dying the bricks before firing can be instituted the consumption of wood fuel can be reduced by an average value of 31.3%. One possible means is the use of solar energy via sun drying. This requires reorganisation of the current practice such that bricks are moulded and sun dried for a longer periods before firing. The heat required to raise the temperature of the bricks is on the average 36.2% of the total energy input. This implies that different loses of energy, i.e. losses through convection and incomplete combustion do account for approximately 33% of the total energy input to the kilns.

From table 3, at Igumbilo the density of the burnt bricks is observed to vary from 1.33 to 1.72 kg/dm^3 while that of the clay (not burnt) bricks vary from 1.3 to 1.57 kg/dm^3. The average values for the area are 1.46 and 1.43 for burnt and clay bricks respectively. The difference between the average densities is small compared to the actual values. It is therefore valid to assume that firing results in a negligible change in density of the bricks. The bricks at Ilomba indicate the same density for both burnt and clay ones. This may be an indication of poor firing.

The compressive strength (Table 3) of the burnt bricks at Igumbilo ranges from 3.27 to 4.51 MPa with an average value of 3.82 MPa. For the clay bricks, which were tested after two months of drying, the range is 1.94 to 2.35 MPa with an average value of 2.13 MPa. Concentrating on the average values, the process of firing the bricks did increase their average compressive strength from 2.13 MPa to 4.51 MPa. Though the strength is increased two fold it is still very low. The lowest standard specifications by the American Society of Testing and Materials (ASTM, C62-75a) recommends a compressive strength of 10.3 MPa (1494 psi) for bricks intended for backup or interior masonry. Values obtained above are below 40% of the recommended strength. This calls for efforts to be directed towards improvement of the firing process.

Burnt and clay bricks from Ilomba had approximately the same value of compressive strength (Table 3). This is an indication that the firing process did not result in an increase in strength of the bricks. Over 2000 kg of wood was used for fuel in this kiln, probably to effect drying and perhaps a change in the colour of the bricks. This is an example of massive waste of fuel. It is also important to note that the bricks involved have the largest size. In addition to other contributing factors, the size is likely to have influenced the firing process. Too large a size hinders the uniform firing of the brick which in turn leads to low increase in strength. Since the builders in the area prefer these large bricks then one way of reducing the problem is to user perforated bricks. This will ensure proper firing and the inherent holes can be used to effect circulation of hot gases hence improving the temperature distribution.

The observed water absorption (Table 3) is high for areas with heavy rainfall. Fortunately the improvement on the strength of the brick does also reduce the water absorption especially when such improvement is achieved with significant amount of vitrification.

Figure 2 to 4 present the temperatures measured at Mahenje from three kilns. It is evident that the temperature close to the fire tunnels, TC1, takes a shorter time (approximately 7 hrs) to start rising towards a maximum. It is also evident from the figures that temperatures at mid-height (TC2) and at the top of the kiln (TC3), are significantly lower than those close to the fire tunnels with the exception of the period towards the end of the firing period where higher temperatures are observed. These temperatures indicate that a large number of the bricks do experience maximum temperatures which are less that 900 ^{0}C. For these bricks, fusion vitrification (900-1000 ^{0}C) which is vital for increasing the strength of the bricks is not achieved.

Further, for each kiln a large number of bricks do not attain temperatures above 800 ^{0}C. This is detrimental in that oxidation of organic matter contained in these bricks does not occur. The combined effect of having no vitrification and no oxidation of organic matter leads to a conclusion that the process of firing the bricks does not increase significantly their strength.

That temperatures sometimes higher than 1000 ^{0}C were achieved close to the fire tunnels implies that its is possible to achieve the same throughout the kiln, provided the system is properly designed. The common practice of laying the bricks is such that very small gap if any exists between the bricks. Such an arrangement prevents the flow of hot gases between the bricks thus creating a situation where heat transfer is highly dependent on conduction. This explains why it takes a long time for temperature to start rising at locations not close to the fire tunnels. In addition to this the walls of the kilns are covered completely with mud while the fire tunnels are completely closed some hours after firing. This prevents the flow of air from the atmosphere through the fire tunnels where it will assists the combustion and the hot products go up the kiln distributing the heat as they flow. This air is also required for the oxidation of contained organic matter, which improves the strength of the bricks as well as reducing water absorption. Improvement can be achieved by allowing a certain gap between the bricks and providing limited air flow throughout the kiln for the whole of the firing period.

The most common type of wood used for brick burning in both Iringa and Mbeya is eucalyptus. Occasionally other types of wood are used, euphorbia has being used in Iringa where it was mixed with eucalyptus. The logs used for the processes are usually bought from the forests close to the brick making area. In most cases a whole tree is bought and cut into smaller pieces and these are transported using lorries to the location of the kilns. Under this arrangement the wood is not dried prior to being used. The observed moisture content (mc), Table 4, is between 34.2 and 45.9% by weight. Energy required to evaporate the water (ec) is between 4.83 and 6.48% of total energy content of the wood. This energy could be put to better use if the wood is sun dried prior to burning in the kiln.

An average fuel consumption of 0.073 kg/kg for green bricks, 0.089 kg/kg for burnt brick including bad ones and 0.106 kg/kg evaluated using good burnt bricks was observed, Table 5. These values correspond to those obtained from energy efficient kilns [5]. It is important to note at this juncture that a brick was judged good by the kiln owner if by his opinion it can be sold. Invoking the earlier discussion on the influence of the firing process on the quality of the bricks only a few bricks per kiln will be considered good. In this context the energy consumption will be alarmingly high compared to the figures on table 5. For someone interested in energy utilisation without considering the quality of the product the kilns used in Iringa and Mbeya are very efficient. When both quality and energy efficiency are considered together one sees a need for improvement.

CONCLUSION

Firing wet bricks results in an average consumption of 31.3% of the total energy input into the kiln. This amount can be reduced considerably by introducing prolonged sun drying of the bricks to reduce the water content before firing.

Bricks which are small in size as the ones observed at Igumbilo respond well to the firing process. Large sizes such as those observed at Ilomba require additional techniques to improve the influence of the firing process. These may include perforation of the brick which will improve the firing and also facilitate uniform firing.

Measurements of temperatures indicate non uniform distribution with large number of bricks not attaining temperatures required for oxidation of organic matter and vitrification which are vital for increase in strength and reduction of water absorption. There is a need to ensure uniform temperature distribution throughout the kiln to reduce losses and improve quality.

The observed compressive strength of between 2.17 and 4.51 MPa is below the minimum recommended value of 10.3 MPa. Efforts are required to improve on this.

Wood consumption figures per unit mass of brick indicate high thermal efficiency of the kilns used. This is without considering the quality of the resulting bricks which misleads those whose focus is on energy use only. When the quality of the produced bricks is taken into account these kilns leave much to be desired.

Fuel wood with moisture content between 34.2 and 45.9% by weight was commonly used for firing the kilns with a loss of 4.83 to 6.48% of the total energy in drying the wood in the kiln.

REFERENCES

1. Jastrzebski Zbigniew D., *The Nature and properties of engineering materials,* John Wiley & Sons, New York, 2nd Edition, 1977 pp 338-342
2. Eckert E. R. G. and Drake, R. M., *Analysis of heat and mass transfer,* McGraw-Hill, International Student Edition, 1972, pp 783
3. Rogers G. F. C., and Mayhew Y. R., *Thermodynamic and Transport Properties of Fluids,* Basil Blackwell, Fourth Edition, 1991, pp 2
4. Rose, J. W. and Cooper, J. R., *Technical Data on Fuel, The British National Committee,* World Energy Conference, London, 1977, pp 304
5. Nyabezi W. And Maboyi B., *Development of improved energy efficient brick firing kiln in Zimbabwe,* Country Report VI, SADC Informal Industries Energy Efficiency Improvement Studies, SADC Energy Sector, 1995