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Temperature variation in a sawdust oven using different wood species

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A b s t r a c t. An investigation was carried out on the use of sawdust as fuel for firing oven. An oven was fabricated and fired with sawdust from four selected wood species (*Triplochitus scleroxylon*, *Milicia excelsis*, *Khaya sinegalensis* and *Celtis zenkeri*). The temperature of the oven was measured at four different levels. The results indicate that the temperature of the oven increases with the degree of hardness of the wood species and nearness to the heat source. The temperature was the highest for khaya sinegalensis followed by milicia excelsis, celtis zenkeri and triplochitus scleroxylon, respectively. The average temperatures recorded for the species in that order were 209.62, 173.50, 166.37 and 104.19°C. Statistical analysis of the data obtained indicates that the separate and interactive effects of all the factors (duration of heating, location and wood species) were significant at 99%.

K e y w o r d s : temperature variation, sawdust oven using, wood species

INTRODUCTION

Wood is a ready source of fuel ever known to man. Its uses in both industry and domestic purposes cannot be over emphasized. In most developing countries wood and charcoal are the predominant fuels for preparation of food as well as serving as fuel for small and medium scale industries (Zerbe, 2004; Bhattacharya *et al.*, 1999). Wood is said to be the largest renewable source of energy at present and the fourth largest source of energy *ie* rated after petroleum, coal and natural gas in that order, all of which are non-renewable energy sources. Wood was man's main source of heat until coal, oil, gas and electricity replaced it. In recent years, however, the high cost of oil and gas has again induced people to burn more wood.

The chemical composition of wood is an important parameter in determining the energy value of wood materials. Wood is a composite of three basic polymers, namely cellulose ($C_6H_{10}O_5$), lignin ($C_6H_{10}O_3$) (OCH_3) (0.19-1.7) and hemicelluloses such as xylem ($C_5H_8O_4$) (Tillman, 1978). Hard woods are deciduous trees or wide leafed trees, while soft woods are coniferous trees which are cone-bearing evergreens. Hard wood generally contains more energy than softwood on a dry weight basis due to higher lignin content plus the presence of more resins in the extraction (Brown *et al.*, 1952).

Specific heat capacity is the amount of heat energy required to raise the temperature of a unit mass of a substance by one degree centigrade. Specific heat capacity differs from one species of wood to another. Thermal conductivity is the measure of the rate at which heat is conducted through the material; conductivity increases with the wood density. Wood thermal conductivity is found to increase with higher moisture content (Panskin *et al.*, 1962).

Sawdust is the powdery wood waste produced by cutting wood with a saw. The size of the sawdust particles depends on the kind of wood from which the sawdust is obtained and also on the size of the teeth of the saw (Afuwape, 1983). Between 10 and 13% of the total content of the log is reduced to sawdust in milling operations; this depends largely on the average width of the saw kert and the thickness of the timber sawed.

Transfer of heat plays an important role in oven, furnace and dryer designs. Transfer of heat energy could be through conduction, convection or radiation. The rate of heat transfer by conduction through a substance is directly proportional to the temperature gradient, dT/dx, and to the cross-sectional area of the path (Bird *et al.*, 2002):

$$q = KA(\frac{dT}{dx}), \qquad (1)$$

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where: q – heat rate (kW), A – cross-sectional area of flow path (m^2), T – temperature (°C), x – distance through conducting medium (m), K– thermal conductivity of the material (W m^{-1}°C).

Transfer of heat by transport of heated fluid material may be through free or forced convection. The heat rate is proportional to the difference in temperature between the surface and the main bulk of fluid and to the surface area, thus:

$$q = h_c A(t_s - t_f), \tag{2}$$

where: $t_s - t_f$ – difference in temperature between bulk of fluid and surface area (^{o}C), h_c– convection heat transfer coefficient.

Radiation is the emission of energy, without need of a conducting or convecting medium, from the surfaces of opaque bodies and from within semi-transparent objects. Radiation rate depends upon the area, the nature and absolute temperature of the surface.

The relationship of those factors is defined as:

$$q = AE\sigma T^4, \tag{3}$$

where: E – emissivity, σ – Stefan-Boltzman constant, T – temperature.

If a heating element is located in a thermally insulated chamber, most of the heat generated is conserved and can be applied to a wide variety of heating processes. Such insulated chambers are called ovens or furnaces which depend on the temperature. Ovens can be classified as electric ovens, gas ovens, coke ovens, microwaves ovens, wood fired ovens, coal fired ovens and kerosene fired ovens. They are used for baking and roasting foods, drying paints and organic enamels, baking foundry cores, thermal treatment of metals and drying of agricultural materials (FSTC, 2003). This study undertakes the development of a sawdust fired oven as a way of utilising the wastes from the saw mills to generate energy for various purposes.

MATERIALS AND METHODS

The oven was designed to have essentially two components: a heat exchanger and an oven chamber.

Figures 1-3 show the components of the oven (constructed for the study) and the arrangement for temperature measurement. The heating unit consists of a heat exchanging unit and a fire compartment (Tin can stove) as shown in Fig. 2.

The heat exchanger consists of four concentric rectangular parts (Fig. 2). A little opening is made on one side of the rectangular part to allow air intake, for the burning of sawdust. The other sides of the rectangular box are closed so as to reduce loss of heat to the surroundings. This rectangular box is constructed from a mild steel sheet – both inner

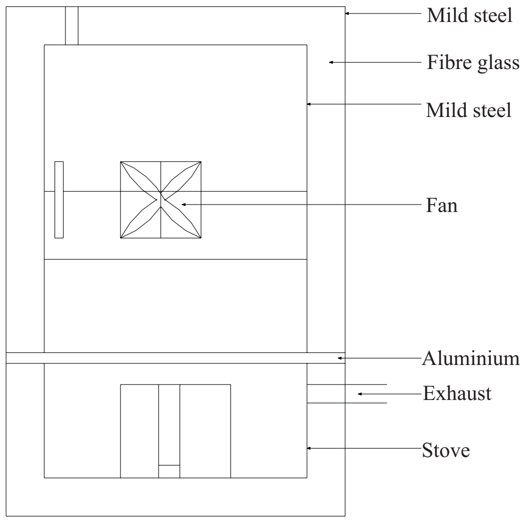

Fig. 1. Saw dust oven.

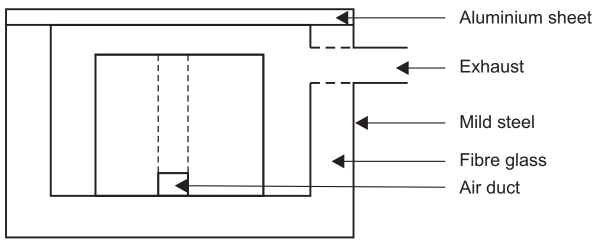

Fig. 2. A cross-section of the heat exchanger.

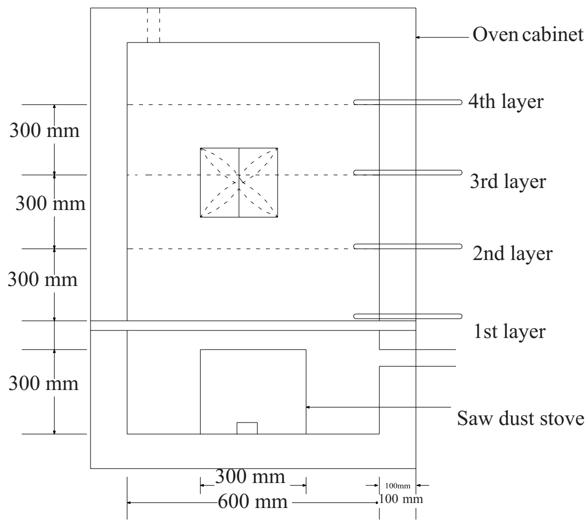

Fig. 3. Arrangement for temperature measurement in the oven.

and the outer parts, with fibre glass in between as lagging material to prevent heat loss. The upper part of the rectangular box is constructed from aluminium sheet. The base of the rectangular box is also constructed from mild steel and lagged with fibre glass. This is done to reduce heat dissipation to the surroundings.

The stove which uses sawdust as fuel is positioned inside the rectangular box. It is similar in design and construction to the Thai bucket stove (Bhattacharya *et al.*, 2002, Dixit *et al.*, 2006). It involves cutting a hole in the bottom on one side of a three gallon can. A short length of rod of about 25 mm diameter is placed horizontally in the hole so that it reaches the centre of the stove. The can is filled with sawdust, stamped down with a wooden block during filling. The rod is removed. The stove is lit through the air hole at the bottom. The performance of the oven was determined by the preheat time measurement method as specified by ASTM (1999). Preheat time is time required to raise the temperature of the cavity form room temperature to cooking temperature (about175°C). The temperature of the oven was measured at four different levels, A, B, C and D, along the height of the oven chamber, with A the closest point to the heat source. The oven temperature was measured both on heating and after removal of heat source. The temperature was monitored at intervals of 5 min for a period of 1 h. Four different types of wood, namely *Triplochiton scleroxylon* (arere *wood local names in Nigeria), *Milicia excelsis* (iroko*), *Khaya senegalensis* (mahogany*) and *Celtis zenkeri* (ita*) were used in the form of saw dust for firing the oven. Data collected were statistically analysed using SAS statistical package (SAS, 1987). Analysis of variance (Anova) was carried out; the single and interactive effect of the factors (time, wood species and location) on the oven temperature were also determined using the statistical package.

RESULTS AND DISCUSSION

Figure 4 shows the effect of type of wood and location (of temperature measurement) on the temperature of the oven. It could be observed that the temperature of the oven varies with the type of sawdust (wood) used. The temperature of the oven was observed to be the highest with sawdust from Mahogany, while those from Iroko, Ita and Arere followed in that order. This result may be explained that Mahogany and Iroko are both hardwood which retains more energy than softwood (Ita and Arere) (Brown *et al.*, 1952). Similar results were also reported by Klasnja *et al.* (2002) who observed that the calorific value of poplar and willow wood species vary. This result provides an insight into the estimation of the preheat time required for the oven when different types of sawdust are used.

The temperature of the oven was also observed to decrease with increase in the distance from the heat source. The results also agree with the findings of Ekundayo *et al.* (1998) on a tunnel oven. The temperature profiles of the tunnel oven were observed not only to vary according to the heater profile but also to be dependent on the proximity to the heating element. The temperature of the oven was observed to reduce as the distance form the heating source increased. For example, for a heating element of 503 W, the temperature reduced form 95 to about 74°C as the distance increased form 0 to 80 mm. Related findings were also reported by Abraham and Sparrow (2004) on another electrically-heated oven. The temperature profiles of the oven were observed to differ in the different sections of the oven. The result also corroborates the report of Zareifard *et al.* (2006) who indicate that the time temperature profiles vary and depend on the location of the h-monitor in a baking chamber.

However, the pattern of temperature variation due to heat removal changed as the temperature reduced in the mahogany, ita, iroko and arere, respectively (Fig. 5). The variation of the temperature with location follows a similar pattern as that of heating. Statistical analysis (SAS, 1987) shows that the mean temperatures for arere, iroko, mahogany and ita were 104.19, 173.50, 209.62 and 166.37°C, respectively.

Table 1 shows the results of the statistical analysis of the effect of the factors considered (time, location and wood) on the temperature of the oven. It could be observed that the separate and the interactive effects of the all the factors on the oven temperature were significant at 99%.

Table 1. Statistical analysis of the effect of factors in oven temperature

Source	Numbers	Anova SS	Means square	F value	Pr > F
Time	12	952729.6	79394.1	2564.0	0.0001
Location	3	76675.0	25558.3	825.4	0.0001
Wood	3	299115.2	99705.1	3220.0	0.0001
Time x Location	36	8633.7	239.8	7.8	0.0001
Time x Wood	36	73482.0	2041.2	65.9	0.0001
Location x Wood	9	7042.9	782.5	25.3	0.0001

*Wood local names in Nigeria.

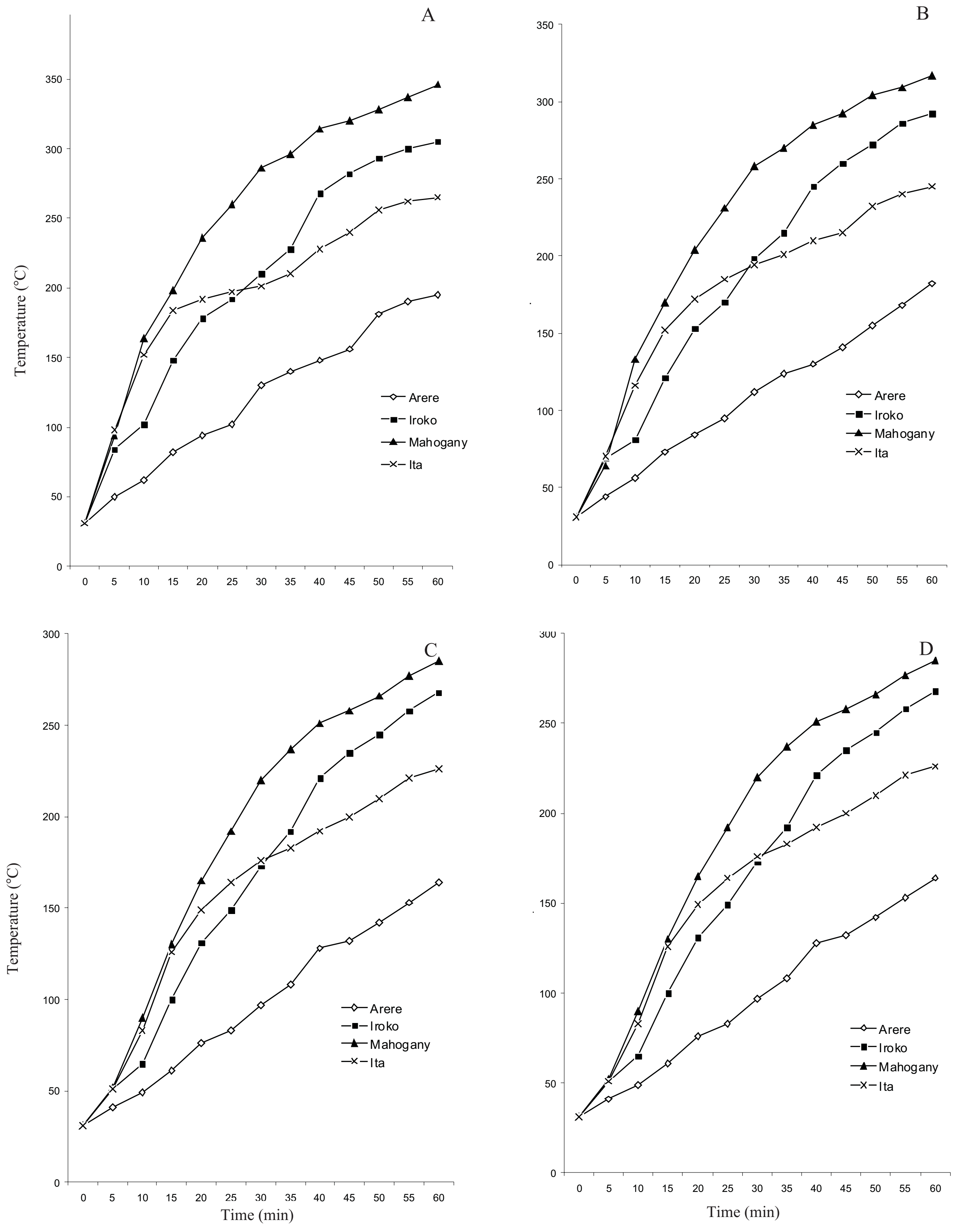

Fig. 4. Effect of wood type on oven temperature changes (heat supplied) at location: A, B, C, and D.

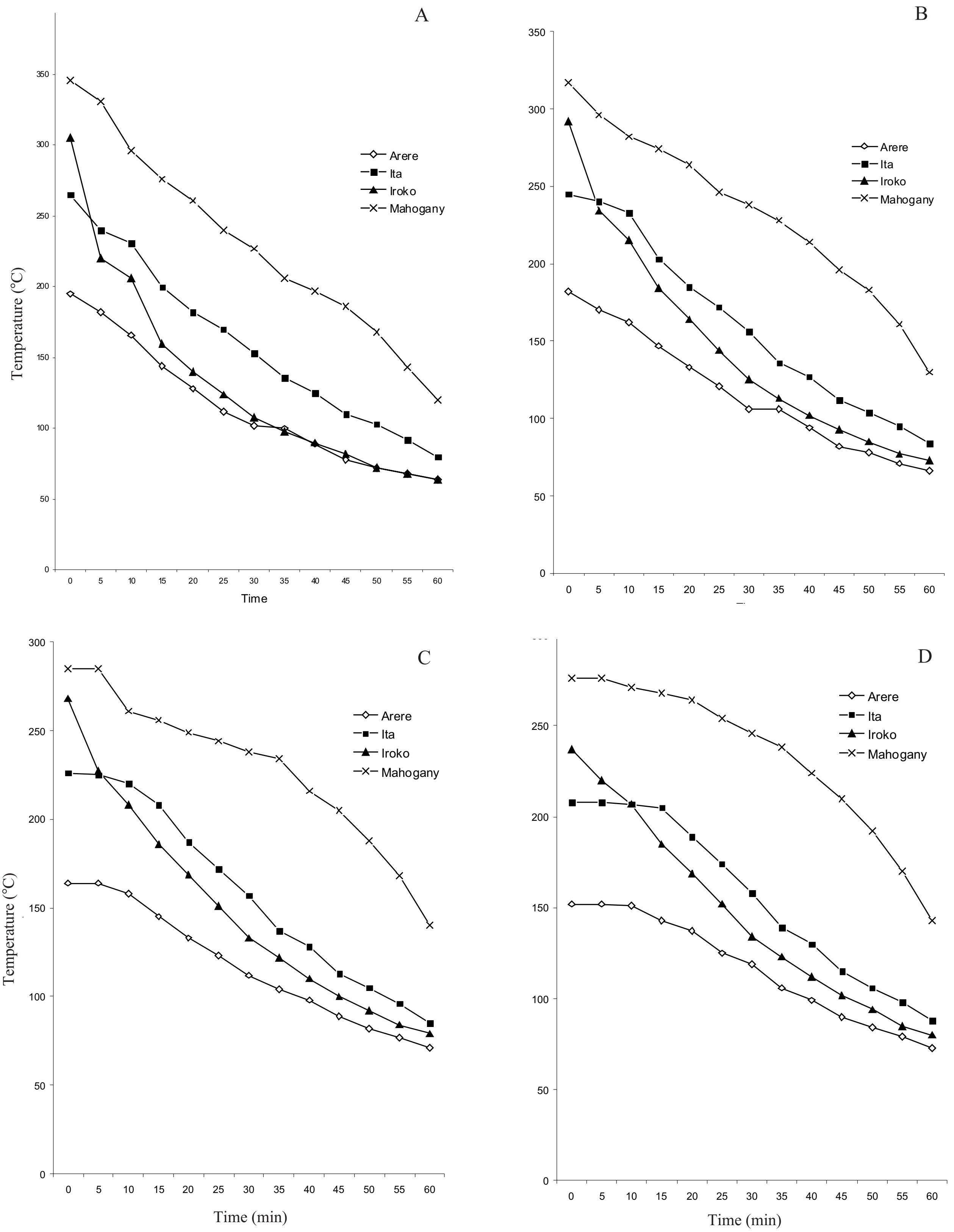

Fig. 5. Effect of wood type on oven temperature changes (heat removed) at location: A, B, C, and D.

CONCLUSIONS

1. There is an indication that high temperature can be obtained in the oven from the use of sawdust as fuel.

2. The temperature attained in the cavity had a correlation with the type of wood.

3. The data not only provide an insight into the choice of sawdust in the operation of the oven but also on the time required to attain a particular temperature within the cooking range. This will be useful in cooking as well as drying of agricultural products.

4. Going by the high temperatures recorded, it is evident that the oven will serve a useful purpose in drying and preservation of agricultural products.

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