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Effect of Insulating Materials on Performance of a Solar Heater

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Abstract: Insulator influences performance efficiency of the solar heater. In order to reduce the cost of solar device, it is advisable to use as local insulating material. Some agricultural wastes are abundant and causing environmental nuisance in Nigeria. This research focussed on use of some agricultural waste as insulator in box-type solar device. A box-type solar heater was developed. Dried insulating materials (maize cob, air, maize husk, coconut coir and polyurethane foam) were used to fill the space between the inner and outer boxes in such a way that there was an 80 mm thickness of insulating materials all around between the inner box and the outer box. The space housing the insulating materials was sealed with four pieces of plywood noggins. Heat retention and water abilities of the solar device were tested for period of 3 years. Peak stagnation temperatures for 1st to 3rd year were 159, 140 and 138°C, respectively. These were obtained using coconut coir (1st and 2nd year) and polyurethane foam (3rd year). During the dry season, shortest duration taken to heat 1 and 1.5 L of water was 50 and 65 min, respectively in coconut coir insulated device. Time required to boil 1 L of water in wet season ranged from 120-170 min. Comparatively the orders of performance were coconut coir, polyurethane foam, maize cob, maize husk and air. The evidence from performance evaluation indicates that agricultural by-products like maize husk, maize cob and coconut coir can perform as solar device insulator.

Key words: Solar device, insulator, agricultural waste, heating, Nigeria

INTRODUCTION

In most developing countries, part of the energy consumption goes to the domestic sector out of which a major part goes for heating (Nandwani, 1992). It has been estimated that cooking accounts for as much as 80% of all energy used in the domestic sector in Nigeria (Adegoke and Akintunde, 1999). The usual fuels used for cooking in Nigeria are electricity, charcoal, firewood, gas and kerosene. All these are best with one problem or the other. It was estimated that only about 40% of the country's population have access to electricity with its distribution in favour of the urban areas (Ige, 1999). Even at this, its epileptic supply does not encourage its use. The supply of petroleum products in the country falls below demand and has its availability favours of urban dwellers that constitute about 30% of the country's population (Umar *et al*., 2000). In addition, the escalating cost alongside with erratic supplies has also gradually drawn some urban consumers away from these petroleum products back to local wood stoves for cooking their foods.

The rural population, however who make up the majority and the urban poor have their cooking energy needs met from the use of wood fuels. Fuel-wood, accounts for over 50% of the overall domestic energy consumption in the country (Iwu, 1998). About 80% of this is consumed as firewood and mainly in the rural household. The attendant over-exploitation of the nation's wood fuel resources have resulted in severe deforestation and associated problems in many parts of the country (Asere and Aliyu, 1992). The afore-mentioned problems underscores the need to find an alternative source of energy for heating which apart from being available at low cost will also offer some advantages like constituting no health hazard, being non-degrading to the environment and conforming with the cooking habit of the people. This makes solar energy an attractive option as a domestic cooking fuel in Nigeria, especially the rural areas.

Due to her geographical location (lying between 4 and 14° North of the equator), Nigeria is blessed with a significant level of solar insolation. The country receives about 5.08×10^{12} kWh of energy per day from the sun and if solar appliances with 5% efficiency are used to cover 10% of the country's surface area then 2.54×10^{6} MWh of electrical energy from solar energy resource which is equivalent to 4.656 million barrels of oil per day will

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be realisable (Aremu, 2004). There are between 2000-3000 h of sunshine per year in Nigeria translating to between 3.5-7 kW/m^2/day of energy being received from the coastal latitude to the far North (Okonkwo and Mageswaran, 2001). Energy is essential if adequate food supplies are to be converted into adequate diets. The technology of solar heating involves the conversion of solar energy to heat energy. Solar heating systems could be box-type, concentrating type or a hybrid of the two. Box-type solar cooker makes use of both diffuse and direct radiation while the concentrating type depends on its ability to make use of direct radiation only.

Heat retention allows heat to remain inside the device; insulation acts as a heat barrier that increases the heat capacity and efficiency of the device. Most solar heater designs require good insulating material in order for it to reach interior temperatures high enough for cooking (Bowman, 1985). Good insulating materials include aluminium foil, spun fibre-glass, rock wool, cellulose, rice hulls, wool, straw and crumpled newspaper (Aalfs, 1999). Many dry, fluffy materials with high melting temperatures could be used for insulation. In order to reduce the cost of solar box heater (Funk, 2000), it is advisable to use as much local insulating material as possible (Baryeh, 1988). This research focussed on effect of some agricultural waste as insulator in box-type solar heater. These materials were reported to be abundantly available and constituting environmental nuisance in urban and peri-urban areas of Nigeria (Olorunnisola, 1999).

MATERIALS AND METHODS

Fabrication of the inner box: The inner box of the heating device was made majorly from 3 mm thick hardboard. The base of the box has a dimension of 360×360 mm. The slanting sides were attached to the base plate with the aid of wooden battens to reinforce the joints. The four slanting sides were inclined at an angle of 45° to the horizontal and have dimensions of 600×360 mm and height of 170 mm. These created a frustrum (of a pyramid). Battens attached to the outer side of the base plate were used to elevate the inner box to the level of the outer box and to create room for lagging of the base. The underside battens, four in number are 80 mm high. They were made from Afara wood (*Terminalia superba*) with cross sectional dimensions of 50×50 mm. The battens (stands) were attached to the base plate with 50 mm nails and glue. Batumin was used to line the joints of the assembly. The inner box was centrally placed in the outer box. Dried insulating materials (maize cob, air, maize husk, coconut coir and polyurethane foam) were used to fill the space between the inner and outer boxes in such a way that there is an 80 mm thickness of insulating materials all around between the inner box and the outer box. The space housing the insulating materials was sealed with four pieces of plywood noggins.

Double walled glass cover: The glass frame was made up of four battens of Afara wood (*Terminalia superba*). Each of the battens has dimensions of 760×80×50 mm. From the outer edge, the battens were bevelled at an angle of 45° to form the shape of the frame. A 12 mm deep by 3.5 mm wide and 20 mm apart grooves were cut into the four battens using crosscut circular saw. The grooves houses the 3 mm thick glasses and the 0.5 mm clearance provided accommodates the seasonal dimensional changes of the glass and wood resulting from temperature changes.

Tempered, float glasses were used as window covers because of its low iron content. The glass panes were in sizes of 610×610 mm. These were cleaned to ensure that no dust or dirt was trapped on the undersides of the glasses. The cleaned glass panes were fitted into the grooves of the frame one after the other. The surface area of the glass panes were 600×600 mm after 10×10 mm of the panes has entered the grooves. The edges of each batten were smoothening with sand paper and were joined using glue. The joints were further nailed together using 50 mm nails and reinforced with flange fasteners. The joints and all open spaces were filled with batumin to ensure on the outer box via hinges on one side while the other side was left free for opening and closing the cooker as required.

Reflector lid: The reflector lid is an additional accessory to boost the energy production in the device. Aluminium foil was used as the reflector because of its availability, low cost and effectiveness. The foil was cut into size and pasted on the lid. The lid was made from hardboard and reinforced with four battens of dimensions 760×40×40 mm which were aligned along the edge of the outer side of the lid to give it stability. The lower batten is to act as a means of coupling the lid to the cover surface batten. The edges of the battens were rounded with sand paper and the hinges fastened onto the lower batten and the cover batten with 25 mm nails. In fixing the aluminium foil onto the lid, care was taken to ensure that the glue used did not smear the reflecting surface as this can reduce the reflectance of the foil. Aluminium foil was also pasted on the inside surface of the inner box to reflect radiation incident upon it onto the absorber and cooking pot and to reduce heat loss by radiation.

The absorber plate: The absorber plate was made from two materials; the aluminium sheet and flat, black coating placed on it. Aluminium sheet of 1.4 mm gauge was cut to a dimension of 380×380 mm. The edges were dulled to prevent tearing of the aluminium foil. Flat, black paint was then applied to coat the surface. Three layers of coating was applied in order to ensure that the plate was completely hidden under the paint. The dried plate was later introduced to rest on battens at the base of the device.

Performance test: The solar heaters were designated 1-5. These numbers define the material of insulation which were maize cob, air, maize husk, coconut coir and polyurethane foam in this order, respectively. The device were evaluated in November over a period of 3 years.

Stagnation temperature test: This entailed setting up the five developed box solar device under the sun at a location that was obstruction-free and free of shadows. Thermocouple attached to digital multi-meters was placed on the absorber plate of each of the devices to monitor the temperature of the plate and the heaters were then tightly closed. The heaters were oriented to face the direction of the sun. This orientation of the devices was in such a way that the lid reflector was set normal to the rays of the sun. Thermometers were placed in the surroundings to monitor the ambient temperature around the device. A solar meter was also oriented to face the direction of the sun's rays to measure the total horizontal insolation. This experiment monitored the rise in temperature of the absorber plate under no load condition to determine the peak temperature attainable at a given solar insolation on a particular day. Readings were taken at 15 min interval and peak temperature was recorded as stagnation temperature.

Water heating test: The experimental set up was the same as described in the stagnation test, except that litres of water were loaded into each of the heaters. Water temperature inside the pots, ambient temperature and solar insolation were recorded at intervals of 10 min. The experiment continued until water reached 100°C. This was repeated three times for each volume of water in each season.

RESULTS AND DISCUSSION

Stagnation temperature: In the 1st year, stagnation temperatures were 148, 134, 145, 159 and 147°C for maize cob, air, maize husk, coconut coir and polyurethane foam insulated solar heater, respectively (Fig. 1). In addition, 124, 120, 134, 140 and 126°C were 2nd year stagnation temperatures for maize cob, air, maize husk, coconut coir and polyurethane insulated device, respectively (Fig. 2).

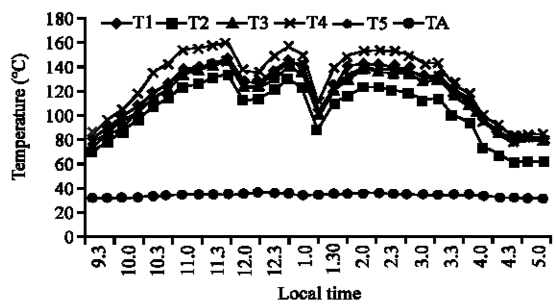

Fig. 1: Plot of temperature against time (1st year)

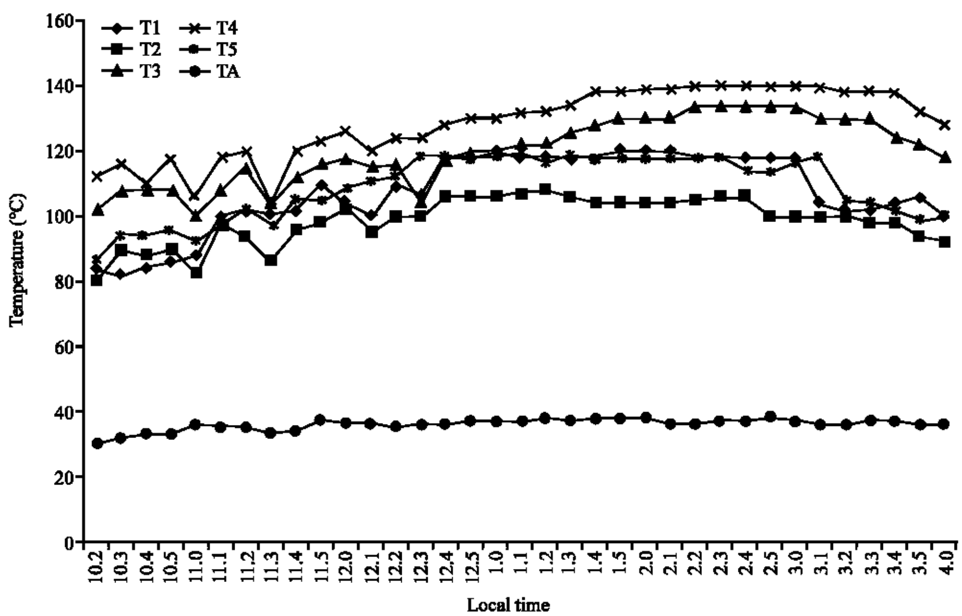

Fig. 2: Plot of temperature against time (2nd year)

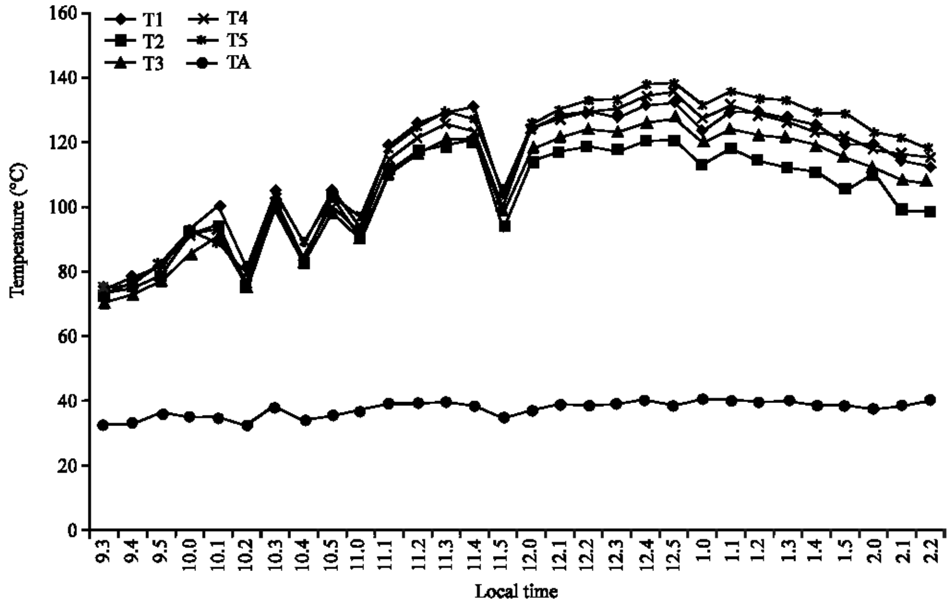

Fig. 3: Plot of temperature against time (3rd year)

At 3rd year of the test, 132, 121, 127, 135 and 138°C stagnation temperature were obtained from maize cob, air, maize husk, coconut coir and polyurethane insulated heater, respectively (Fig. 3). Least recorded stagnation temperature (120°C) was >100°C, the device can be adopted for drying crops and heating. Crops are dried at temperature below 100°C (Akinoso, 2009). The gradual reduction in stagnation temperature can be attributed to deterioration (scratches of the foil, dirt, weakness of the joints) of the heater with time. From Fig. 1 and 2, peak stagnation temperatures were recorded in heater 4 (coconut coir insulation). It is an indication that coconut coir possesses good insulating property. The 3rd year testing (Fig. 3), peak stagnation temperature occurred in heater 5 (polyurethane foam insulation). Generally, stagnation temperatures were attained between 12:00 and 2:30 p.m. local time (13.00-15.30 GMT) when the solar insolation was between 867 and 946.5 W m^{-2} (Aremu, 2004). In addition, increase in heater plate temperature (except for drops recorded during cloud covers) with time up until about 3:00 p.m. local time (16 GMT) when temperatures begin to drop gradually.

Water heating: Table 1 shows the time taken to heat 1 and 1.5 L of water from ambient 29-100°C. During the dry season, shortest duration taken to heat 1 and 1.5 L of water was 50 and 65 min, respectively in coconut coir insulated device (Table 1). However, air insulated solar heater took longest duration to boil 1 L (170 min) and 1.5 L (185 min) of water in wet season. The time taken by heater 5 (foam insulation) was close to haeter 4. Heaters 1 and 3 (maize cob and maize husk) gave nearly the same performance. The time taken for to raise 1 L of water from 29-100°C in dry season ranged between 50-115 min, this agreed with the findings that the average achievable cooking times in box-type solar cookers is between 1 and 3 h for good insulation (Kuhnke, 1991). The results recorded during wet season (120-170 min) corroborate the finding of on water heating in Winter using solar device (Garg, 1987). It was observed that the raising of water temperature from ambient 29-85°C took a shorter time compared with the time than it took the water to rise from 85°C to boiling point (100°C). This was because in temperature rises above this point heat loss from the heater increases and the time taken to reach boiling point is now a function of the insulation properties. In addition, the test revealed how quickly useful cooking temperatures can be reached. This is a combination of the heaters's ability to capture and transfer solar energy to the pot.

Table 1: Time taken to boil different volumes of water

	Duration (min)			
	Wet season		Dry season	
Heaters	1 L	1.5 L	1 L	1.5 L
1 (Maize cob insulation)	120	142	90	125
2 (Air)	170	185	115	145
3 (Maize husk insulation)	120	140	100	125
4 (Coconut coir insulation)	100	110	50	65
5 (Polyurethane foam insulation)	110	125	85	100

CONCLUSION

A design meeting the unique requirements of a typical tropical environment using indigenous insulation materials was presented. Stagnation temperature as high as 159°C was obtained from the solar heater lagged with coconut coir. This compares well with the best-designed box solar heater reported, especially in very sunny places like India. Comparatively the orders of performance were coconut coir, polyurethane foam, maize cob, maize husk and air. The evidence from performance evaluation indicates that agricultural by-products like maize husk, maize cob and coconut coir can perform as well and even better than some manufactured or imported insolating materials. The employment of these local materials can lead to a substantial reduction in the initial cost of box solar heater.

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