Design and Construction of a Portable Wooden Box Electric Dehydrator (PWBED) and Comparative Performance Assessment to an Electric Laboratory Oven

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Abstract

The drying performance of a Portable Wooden Box Electric Dehydrator (PWBED) constructed from ¼ inch plywood, heated by nine incandescent 100 watt bulbs and the warm air circulated by a CPU fan at the base, was assessed to determine if the PWBED could be an alternative to a conventional electric laboratory oven. The PWBED and oven took seven hours and nine hours respectively to dry tomatoes slices from the same lot and both indicated 95.9% moisture in the samples. There were no significant difference ($p \leq 0.05$) *in rates of moisture loss, and in drying efficiencies of the PWBED and oven. Electrical energy input to the PWBED cost 48.0% that of the oven. The PWBED is easy and cheap to construct, portable, easy to maintain and relatively cheaper to use compared to the oven. The PWBED could serve as an alternative or support to the laboratory oven, especially for teaching purposes.*

1. Introduction

Laboratory equipments are essential for interactive teaching of science at all levels of education. The absence of these teaching aids makes the teaching and learning of science to be abstract. One way of solving the problem is through improvisation. Improvisation is the act of creating something or using something in the absence of the ideal tool. Science teachers often try to teach students about scientific principles through the use of lab experiments, though they do not always have access to the resources needed to optimally perform experiments. Innovative teachers can use cheaper products to simulate experiments. Teachers can also help students learn improvisation as an important life skill. Teachers can work with students to come up with ways to improvise, forcing students to think critically about the scientific concepts underlying the devices. Improvisation requires that teachers use resources available in the surrounding area. Despite having knowledge of the scientific principles, many teachers do not realize that they have plenty of resources available for lab experiments. Once the teachers begin to understand the principles behind improvisation, they can begin improvising their own tools. Also, a lot of teachers lack confidence in their abilities to design their own experiments (Pearson, 2013).

Zambia has established the National Science Centre to produce locally made laboratory equipment for interactive science teaching. Under this arrangement, schools across Zambia can purchase laboratory supplies and apparatus. Local materials and labour are used, so expertise and capital are developed within the country, and the products are affordable (Malata and Landreman, n.d.). A study by Owolabi and Oginni (2012) on the improvisation of science equipment in Nigerian schools showed that the performance of sciences students in senior secondary schools which used improvised equipments was significantly better than those in senior secondary schools who did not have any equipment and did not improvise. According to UNESCO (n.d.) it is possible to build low cost equipment for science and technology education. These include simple test tube racks, tripod stands, simple gas generators, simple elementary balance, artificial lungs, etc. A UNDP (1982) project in Philippines established a centre for the design, production and distribution of school science equipment to improve science education. In the first phase of the project no less than 278 prototype items of general laboratory equipment, one complete science kits containing 172 items for elementary science and four separate complete science kits for high schools - General Science (93 items), Biology (25 items), Chemistry (5 items), and Physics (5 items) were produced. In the second phase there was transfer of technology to the private sector for the large-scale commercial production of science items and kits. The main firm concerned has a production capacity of about 2,000 kits a month. Over 12,000 of the country's 30,000 odd public elementary schools have already received kits. A substantial part of the country's needs for low cost and home-produced school science equipment has been met, the required technology has been successfully transferred to the private sector, and adequate production capacity to meet remaining and future needs has been generated.

In general school laboratories in Ghana are equipped with equipment imported from abroad. There are difficulties in procuring these equipments. Apart from being imported they are expensive. They seldom come with replaceable parts. Furthermore, when the need arises to replace a part the part has to be imported from abroad. Schools, research institutions and hospital laboratories are littered with equipments which cannot be used because the parts required to repair them cannot be obtained.

A survey by Yeboah (2012) of biology practical work in selected Senior High Schools in the Eastern Region of Ghana showed that teachers lacked among others equipment and chemicals, and laboratories for practical work resulting in the poor performance of biology students. The lack of equipments and resources for science education does not make the study of science attractive to students. In one SHS in the Central Region of Ghana the school lacked adequate resources and equipment to aid the study of science. Out of 865 students only 94 were studying science (GNA, 2004).

In the absence of original equipments, the teaching of science can be enhanced through the use of improvised equipments obtained by designing and constructing them from scratch, or through the modification or conversion of other equipment into the required one. For example, it is possible to construct a homemade incubator for incubating eggs of domestic birds from Styrofoam ice chest to hold about 40-45 eggs (Clemson Extension, 1996), or a more durable incubator can be constructed of plywood and glass to accommodate up to 100 large eggs (MSUES, 2010). Both incubators are heated by a heating cable. The heating cable can be replaced with two or three ordinary light bulbs (MSUES, 2010). Plans and designs by Price and Kirk (1943) and slightly modified by Meier (n.d.) can be used to build a Portable Electric Food Dehydrator. The dehydrator is constructed from plywood and is supplied with heat from standard incandescent household light bulbs. The heat is circulated in the heating chamber by either a 20.32 cm or 15.24cm diameter air-duct fan.

In this study the plans and designs of Price and Kirk (1943) which had been slightly modified by Meier (n.d.) were adapted to construct a portable wooden box electric dehydrator (PWBED) and the performance of the PWBED compared to that of a standard electric laboratory oven to determine if the PWBED could serve as an alternative to the laboratory oven.

2. Methodology

2.1. Design of PWBED

The following were considered in the design: Temperature, Circulation, Size, Controls, Location, Motor protection, and Mounting (Durham Geo-Enterprises, 2013).

The plans and designs used are those of Price and Kirk (1943) which were slightly modified by Meier (n.d.) for building a Portable Electric Food Dehydrator. Again, the modified plans of Meier (n.d.) have been modified by the author (Ameko et al, 2012) with regard to wiring and the choice of materials.

2.2. Materials

Table 1 Costs of main materials

Materials	Qty	(GH¢)
1/4" Plywood(4x8) feet	1	26.00
Heavy duty aluminium foil	1	7.00
Bulbs (100 watt)	10	10.00
Surface-mount socket	10	12.00
¾ nominal wood	9	16.20
CPU fan	1	10.00
Male Plug	1	2.50
Male plug (13-Amp)	1	3.50
2 Hinges		2.00
Door knob	1	1.50
LED	2	1.00
PVC Vinyl (3 yards)		9.00
Wire mesh (4 yards)		14.00
L-brackets	40	40.00
Thermostat (0 - 300^{o}c)	1	15.00
Double switch	1	4.00
Resistor (150k)	2	0.20
Porcelain (ceramic) socket.	9	22.50
Single switch	1	2.50
Total		**198.90**

Table 2 Joining materials

Materials/tools	Qty	(GH¢)
Carpenters Glue	1	3.50
Screws	2 packs	8.00
1 ½ inch nail	1 pound	1.20
Total		**12.70**

Table 3 Pieces of wood cut from one 4 feet x 8 feet ¼ inch plywood

Part of PWBED	Size
Top	10" x 24"
Left side	24" x 24"
Right side	24" x 24"

Back side	17” x 24”
Bottom	17” x 23”
Front	10 ¾” x 17”
Door	13 ¼” x 17”
Fan bulkhead	10 ¾” x 17”
Heatshield	14” x 16 ¾”

2.3. Drawings

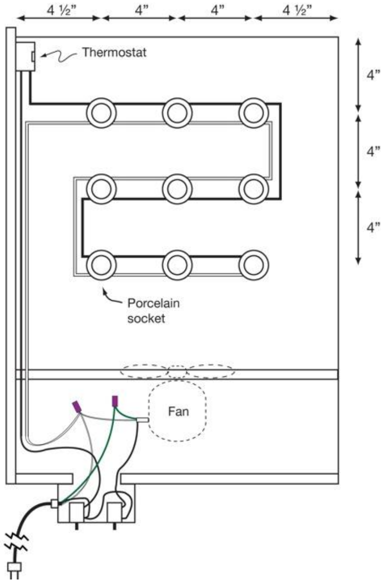


Figure 1. Layout of sockets and wiring plan

Figure 2. Fan positioned between the front panel and bulkhead

Figure 3. Air vent hole, switch and thermostat in the front panel

Figure 4. Heatshield in position over the heating chamber

Figure 5. Wire mesh screen (1mm) laid over the finished tray frames

Figure 6. Tray place holders fixed to the walls of the dehydrator

Figure 7. Door fixed to the front panel with hinges

2.4. Workshop processes

The 4 feet x 8 feet plywood was cut into various sizes for the various parts of the PWBED (Table 1). The base was placed on a flat surface. The porcelain sockets were laid out on the base and fastened to the base of the box with screws. The wires were fastened to the porcelain sockets. The left side and front side panel were screwed to the base. The thermostat, switch and indicator lights were mounted on the front panel. The wires from the sockets were connected to the thermostat. A 4½ inch hole was cut in the bulkhead. The bulkhead was fixed 5 to 5½ inches from the front panel (figure 4) and fastened in position by two screws through the left side panel. The fan was first positioned between the bulkhead and front panel and was then fixed to the bulkhead so that the fan blades faced the direction of the porcelain sockets (figure 4). The 1½ inch diameter air vent hole in the front panel was centered directly in front of the fan motor, about 1- inch away from the fan motor (figure 5). This allowed the relatively cool room temperature air to pass over the motor and cool it. The right side panel, back panel and top panel were fixed in place using wood glue and wood screws. The heat shield was wrapped in heavy aluminium foil (figure 6). This provided a reflective surface to protect the plywood heat shield. It also provided a smooth surface for easier removal of juices that may drip from the drying trays. The heat shield was slid into position over the heating chamber containing the light sockets (figure 7). Drying trays were built using 1" x 1" pieces of wood cut to the required lengths. L-brackets were used to re-enforce the corners of the trays. Wire mesh screen (1 mm) was laid over the finished tray frames (Figures 10). Place holders were fixed to the walls of the right and left panels to hold the trays (Figures 11). A 1½ inch diameter air vent was cut in the middle at the top of the door panel. The door panel was then fixed with hinges to the front panel (Figures 12). Nine 100 watt incandescent bulbs were fixed in the sockets to provide heat for drying.

The completed dehydrator had inner dimension of 17.5 x 23.5 x 13.75 inches, and five stackable removable wire mesh trays for drying. The PWBED is a vertical airflow dehydrator. Air enters the base of the dehydrator through the 1½ inch diameter air vent in the front panel and is warmed by radiating heat from the nine lighted 100 watts incandescent bulbs at the base. The CPU fan at the base circulates the warm air which then rises through the trays and exits through the 1½ inch diameter air vent at the top of the door.

2.5. Comparative performance assessment of the PWBED to that of a standard laboratory oven

The oven used for the comparative tests was a standard laboratory electric oven (Genlab Model G63-CF, 2KW, 240V AC). It is a horizontal flow with forced convection. It has been used for over ten years now in the Chemistry Laboratory of Accra Polytechnic and has undergone a series of maintenances over its lifespan.

2.5.1. Percent moisture content and percent moisture loss. The initial weight (Massinit) of slices of tomatoes was determined. The tomato slices were placed in the PWBED at 105oC and at hourly intervals the current weight (Masscurr) of the drying sample was determined. Drying continue until a constant weight was obtained. The same was done with the oven using separate samples of tomato slices. The percent moisture content and percent moisture loss were determined from the formulae:

Percent moisture content (% mc)
= [($Mass_{init}$ - $Mass_{curr}$)/ $Mass_{init}$] x 100% (1)
Percent moisture loss = (100% - % mc) (2)

2.5.1. Total moisture content (g).
The total moisture content (g) of the tomato slices was determined by multiplying the percent moisture content of the tomato slices at constant drying weight by the initial weight of the tomato slices. The same was done with the oven dried samples.

2.5.2. Residual moisture content of food at specific drying times. The mass of residual moisture of the slices at specific drying times was determined by multiplying the percent moisture content of the tomato slices at the specific times by the initial weight of the tomato slices. The same was done with the oven dried samples.

2.5.3. Mass of moisture (g) removed from food at specific drying times The mass of water removed from the slices at specific drying times was determined by multiplying the percent moisture loss of the tomato slices at the specific times by the initial weight of the tomato slices. The same was done with the oven dried samples.

2.5.4. Energy (J) absorbed by moisture in food during drying This was calculated from the mass of residual moisture by the formula:

E (J) = mcΔT (3)
E - Energy absorbed by water in food (J)
m - Mass of residual moisture in food (g)
c – Specific heat capacity of water (J/g)
ΔT = T Fin – T Init (4)
Where: T_{Fin} – 105^{o}C and T_{Init} – 25^{o}C

2.5.5. Energy (J) used in evaporating moisture from food during drying This was calculated from the mass of moisture removed by the formula:

E (J) = mcΔT
m - Mass of moisture removed from food (g)
Where: T_{Fin} – 105^{o}C and T_{Init} – 25^{o}C

2.5.6. Efficiency of drying equipment This was calculated at hourly intervals by the formula:

$$\text{Efficiency} = \frac{\text{Energy used in evaporating moisture from food during drying}}{\text{Energy absorbed by moisture in food during drying}} \qquad (5)$$

2.5.7. Energy Input Rate It is the maximum rate at which an appliance draws energy. It can be expressed in joules or kilojoules.

Energy (J) =Power (W) x time (sec) (6)

2.5.8. Production Capacity This is the amount of material that can be dried in an oven in a given time period and is directly related to the tray capacity.

2.5.9. Cost of drying The cost of drying was calculated from the formula:

Cost=watts x hrs used x cost per 1000kwh (7)
Cost of electricity = 17 pesewas/KWh for consumers in the residential category of between 51-300 units (GNA, 2010).
100 pesewas = 1.00 GH¢
1.00 GH¢ = 0.5076 USD

Results and Discussion

Table 4 Percent moisture loss and residual moisture content of tomato slices during drying in a portable wooden box electric dehydrator and a conventional electric laboratory oven

Drying time (hrs)	% Moisture loss		% Residual moisture content	
	PWBED	Oven	PWBED	Oven
0	0.0	0.0	100.0	100.0
1	59.0	55.0	41.0	45.0
2	82.0	79.0	18.0	21.0
3	91.7	92.9	8.3	7.1
4	94.5	94.3	5.5	5.7
5	95.4	95.2	4.6	4.8
6	95.9	95.5	4.1	4.5
7	95.9	95.8	4.1	4.2
8	95.9	95.9	4.1	4.1
9	95.9	95.9	4.1	4.1
Mean	**95.9**		**4.1**	

% moisture content (% mc) = 95%
Initial mass of slices = 250g
Total mc (g) = 250g x 95.9% = 239.8g

Table 5. Amount of energy absorbed, used in evaporating moisture, and efficiency of drying in a portable wooden box electric dehydrator

Drying time (Hrs)	Mass of moisture in food (g)	Mass of moisture evaporated (g)	Energy (J) absorbed by moisture in food	Energy (J) used for evaporating moisture in food	Efficiency of drying
0	239.8	0.0	80,287.5	0.0	0.0
1	98.3	141.5	32,917.9	47,369.6	1.4
2	43.2	55.1	14,451.7	18,466.1	1.3
3	19.9	23.3	6,663.9	7,787.9	1.2
4	13.2	6.7	4,415.8	2,248.0	0.5
5	11.0	2.2	3,693.2	722.6	0.2
6	9.8	1.2	3,291.8	401.4	0.1
7	9.8	0.0	3,291.8	0.0	0.0
8	9.8	0.0	3,291.8	0.0	0.0
9	9.8	0.0	3,291.8	0.0	0.0

Table 6. Amount of energy absorbed, used in evaporating moisture, and efficiency of drying in a conventional electric laboratory oven

Drying time (Hrs)	Mass of moisture in food (g)	Mass of moisture evaporated (g)	Energy (J) absorbed by moisture in food	Energy (J) used for evaporating moisture in food	Efficiency of drying
0	239.8	0.0	80,287.5	0.0	0.0
1	107.9	131.9	36,129.4	44,158.1	1.2
2	50.3	57.5	16,860.4	19,269.0	1.1
3	17.0	33.3	5,700.4	11,160.0	2.0
4	13.7	3.4	4,576.4	1,124.0	0.2
5	11.5	2.2	3,853.8	722.6	0.2
6	10.8	0.7	3,612.9	240.9	0.1
7	10.1	0.7	3,372.1	240.9	0.1
8	9.8	0.2	3,291.8	80.3	0.0
9	9.8	0.0	3,291.8	0.0	0.0

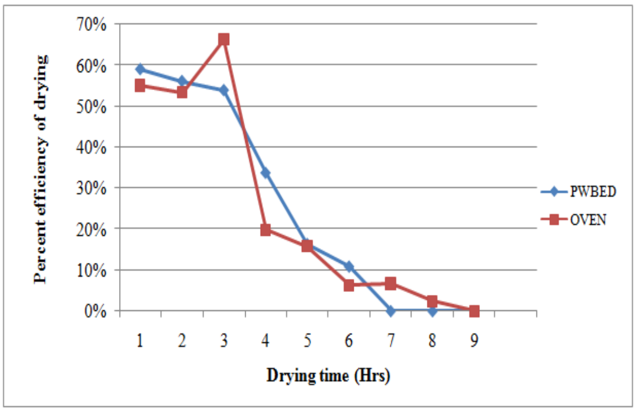


Figure 8. Efficiency of drying in a portable wooden box electric dehydrator and a conventional electric laboratory oven

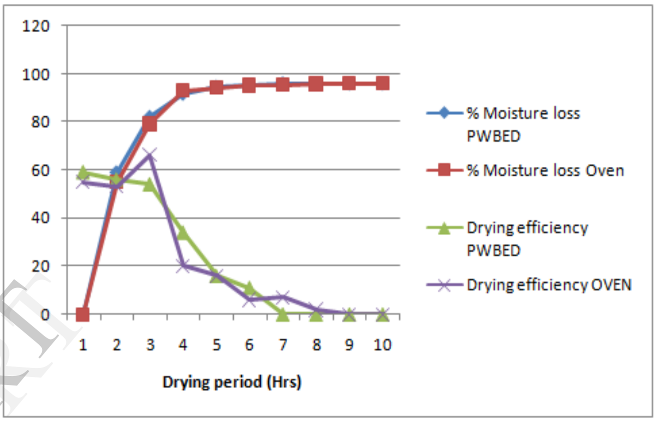


Figure 9. Amount of moisture loss and efficiency of drying in a portable wooden box electric dehydrator and a conventional electric laboratory oven

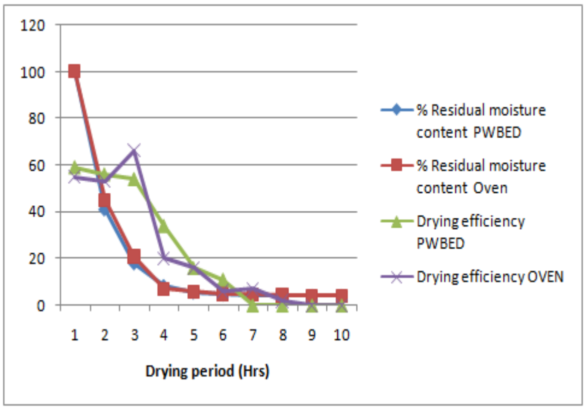
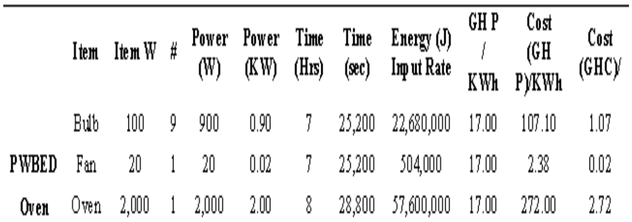


Figure 10. Amount of residual moisture and efficiency of drying in a portable wooden box electric dehydrator and a conventional electric laboratory oven

Table 7 Cost of energy input in a portable wooden box electric dehydrator and a conventional electric laboratory oven



	Item	Item W	#	Power (W)	Power (KW)	Time (Hrs)	Time (sec)	Energy (J) Input Rate	GH P / KWh	Cost (GH P)/KWh	Cost (GHC)/
	Bulb	100	9	900	0.90	7	25,200	22,680,000	17.00	107.10	1.07
PWBED	Fan	20	1	20	0.02	7	25,200	504,000	17.00	2.38	0.02
Oven	Oven	2,000	1	2,000	2.00	8	28,800	57,600,000	17.00	272.00	2.72

Energy input rate (J) = Power (W) x Time (sec)
Electricity tariff = 17 pesewas /KWh (GNA, 2010)
Cost (GH P) = KW x hrs used x tariff (GHP/ KWh)

From Table 7:
Cost of drying with PWBED for 7 hours
= GHC 1.07 + 0.02 = GH¢ 1.09 = USD 0.55
Cost of drying with oven for 8 hours
= GH¢ 2.27 = USD 1.15
Therefore, cost of PWBED drying relative to electric oven drying
= (GH¢ 1.09 / GH¢ 2.27) = 48.0%

The standard laboratory oven is a high temperature electric oven with maximum temperature of 500°C. This temperature allows it to be used both as a furnace and an oven and therefore suitable for a variety of applications. The interior chamber is made from high grade, rust proof stainless steel. The oven is fitted with high density thermal insulation to minimise heat loss throughout. It has a single front opening, side hinged door and feature an air cooled front fascia (Genlab, n.d.). Its dimensions are 54cm x 36cm x 36cm (L x B x H) which is 69,984 cm3, with three trays with a total drying area of 5,076 cm2. The PWBED has internal diameter of 44.5 cm x 59.7 cm x 34.9 cm which gives 92,664 cm3 of heating space and carries five drying trays with a total drying area of 8460 cm2.

Results from both the PWBED and oven indicated that the tomato slices contained 95.9% moisture (Table 4). It took the PWBED seven hours and the oven nine hours to obtain this result. However, statistically there is no significant difference ($p \leq 0.05$) in the rate of moisture loss from the PWBED and oven.

There were very strong negative correlations of (-0.96) and (-0.89) between the lengths of drying period and the efficiencies of drying for the PWBED and oven respectively. The efficiency of drying decreased with increasing drying period. There were positive correlations of (0.73) and (0.76) between the amounts of moisture in the tomato slices and the efficiencies of drying for the PWBED and oven respectively. There are two types of water in food and these are free or bulk water, and bound water. Free water can easily be extracted from food by the application of pressure to the food. Bound water cannot be easily removed from food and even upon dehydration, food contains bound water. During the initial three hours of drying free water was easily removed from the tomato slices (Figure 9) and the efficiency of drying was high at 54% – 59% for the PWBED and 55% – 66% for the oven (Tables 5 and 6). As the residual moisture content decreased the drying efficiency also decreased (Figure 10). The drying efficiencies at different lengths of drying periods differed significantly ($p>0.05$), but not significantly ($p \leq 0.05$) between the PWBED and oven. It took seven hours and eight hours for the PWBED and oven respectively to dry the tomato slices. The input of electrical energy to the PWBED and oven cost GH¢ 1.09 and GH¢ 2.27 respectively. This made the cost of electrical energy to the PWBED to be 48.0% of the cost of electrical energy to the oven.

Laboratories of any discipline are extremely energy intensive, with processes and experimental instruments running around the clock. Essential equipments like laboratory ovens frequently run for lengthy periods and use large amounts of electricity and are a major contributor to overall energy use. Reducing the amount of energy used by an oven can provide significant cost savings over time within the laboratory (Lab Manager Magazine, 2011). The PWBED could be used as an alternative to the laboratory oven and it would help in cost savings in laboratory operations. The cost of materials used to construct the PWBED was GH¢ 211.06 = 107.13 USD.

Conclusion

The PWBED is easy and cheap to construct, relatively cheaper to use compared to the laboratory oven used for comparison, and portable and easy to maintain. It could be used as an alternative or support to the laboratory oven, especially for teaching purposes.

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