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DESIGN AND CONSTRUCTION OF WALK-IN HOT AIR CABINET DRYER FOR THE FOOD INDUSTRY

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Summary

The need for an efficient dryer which is within the reach of all categories of food processors has resulted in the design, construction and testing of a 140-tray "walk-in" hot air cabinet dryer. It is an improvement of a dryer made by Rolls Royce Industrial Ovens Ltd of England. The number of trays were increased by 40 per cent to give a loading area capacity of 86.8 m^2 with corresponding increases in air circulation and heat requirement by 17 per cent respectively. Temperature distribution tests conducted at five positions within the dryer recorded highest deviations of +2.8 °C from the set temperature at 60 °C during the transient period and 1.1 °C when the temperature settled after 13 min. Further tests conducted with fermented cassava dough established a drying capacity of 3.9 kg of the dried product/m^2 and an overall drying rate of 0.32 kg/H_2O/h m^2. The total cost of construction amounted to $10,000.00 which is 20 per cent the cost of the one from Rolls Royce industrial Ovens Ltd of England and hence its affordability. The dryer has since been exported and installed at Pouma, Cameroon.

Introduction

Processing of agricultural produce not only contributes to food preservation but also offers better opportunity for expanded product utilization and adds value. Dehydration is one of the most effective means of preserving agricultural produce that have limited storage properties. Dehydration provides solution to maintain quality and improve the storability of products.

In most developing countries, dehydration of agricultural produce such as cassava, pepper, yam, okro, etc. using the sun (i.e. natural drying) is a very common practice. Here the materials are spread on floors such as flat rock surfaces, soil (clay) grounds, cemented pavements, raised mesh trays, etc. to sundry. This method is time consuming and it takes for example 4-6 days to dry cassava chips (20 mm thick, loading rate 5 kg/m^2) to 14-16 per cent moisture content (Jeon & Halos, 1991). Product quality suffers because of prolonged drying which makes the product susceptible to contamination. Losses are also incurred due to repeated handling and direct consumption by animals.

The use of solar dryers as an improved means of natural drying using the sun's energy is gradually gaining popularity and replacing the direct sun drying. Solar dryers produce better quality products within a relatively shorter period. Odogola (1991) observed that the natural convection solar dryer in clear and sunny weather produced mold-free cassava chips (20×25 mm size, loading rate 20 kg/m^2) in 2.5 - 3 days to 12-13 per cent moisture content. Drying using solar dryer or direct sun drying depends mainly on the weather and, therefore, not reliable and attractive during the rainy season or in wet weathers.

Commercial dryers such as hot air cabinet dryers, spray dryers, thin film dryers, drum dryer, etc, do not have the negative tendencies mentioned above. They are more efficient, permit closer control of the drying operations, produce quality products and do not depend on the weather. However, virtually all such dryers available in Ghana are imported, expensive and beyond the reach of the small- and medium-scale food processor, thus denying the latter access to improved and effective technology and subsequent participation in achieving national objectives of:

i. reducting post-harvest losses

ii. adding value to products

iii. expanding product utilization

As its contribution towards the realization of the above objectives, the Engineering Division of the Food Research Institute (FRI) has, among its programmes, the development of effective and efficient but cheaper food-processing equipment/ machinery which are within the reach of all categories of processors. Consequently, a hot air cabinet dryer manufactured by Rolls Royce industrial Ovens Ltd of England was redesigned and constructed using locally-available materials upon request by AID CAMEROON/UNIFEM sponsored project "Usine de Transformation de Manioc" in Cameroon in 1993. The dryer has since been exported and installed at Pouma, Cameroon.

This report covers the design, construction, testing and establishment of performance data of the dryer.

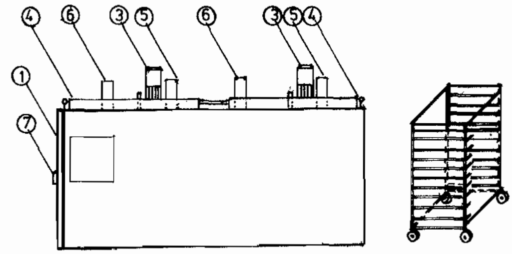

Fig.1a. Side view of dryer and trolley

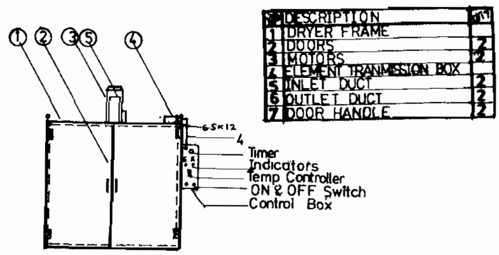

Fig.1b. Front view of dryer

Experimental

Design features

The design was based on the improvement of an industrial dryer manufactured by Rolls Royce Industrial Ovens Ltd of England. Factors considered during the design include the following:

a. average amount of moisture to be removed,
b. average time needed to remove moisture,
c. sufficient fan capacity and heat required,
d. air recirculation and speed,
e. shape of ductwork,
f. construction materials,
g. distance between trays (Perry *et al.*, 1963).

The design considered improvements in the areas of loading capacity, air circulation and power requirement. Ten trolleys each carrying 14 trays (787 mm× 787 mm ×31 mm) were constructed to increase the loading capacity from 60.8 m^2 to 86.8 m^2. Two high speed metres (3 kW, 3 hp, 2800 rpm) with fan impellers (44 blades, 25 mm wide, 125 mm long) were used to increase air circulation by 17 per cent. Power necessary to maintain air temperatures in the dryer was also increased by 17 per cent to 70 kW.

Side and front views and some components of the dryer are presented in Fig. 1. The dryer consists of a rectangular chamber of sheet metal with a 75 mm-fibre glass insulation, external dimension of 4445 mm × 2200 mm × 1850 mm and 10 trolleys each containing 14 shallow trays. Two fans driven by high-speed electric motors are installed on top of dryer at positions which ensure uniform air circulation in dryer. Ductwork with diffuser is done to direct part of the air towards the heating elements and part to the exhaust duct.

Thirty heating elements (2.5 kW each) are fixed behind a panel at the right side along the depth of the dryer and 28 of them connected to electrical

TABLE 1
Technical Information

External size	2200 mm wide
	1850 mm high
	4445 mm deep
Size of internal	
working chamber	1900 mm wide
	1545 mm high
	4350 mm deep
No. of tray	140
Size of tray, mm^2	787 × 787
Maximum operating	
temperature, deg. C	120
Power, kW	75
No. of elements	28
Type of elements	2.5 kW, 8 mm diameter,
	2440 mm long, 240V incoloy
Electrical supply:	415 volts, 3 phase, 50 Hertz
Motor power, kW	4
speed, rpm	2800
Fan size mm^2	229×127
Chamber material	mild steel
Controller	GEFREN RD - 87

the dryer and 28 of them connected to electrical power source in the element termination box (ETB) on the top of dryer, leaving two as spares. A control box installed at the right side controls the operation of the dryer and ensures constant temperature in the dryer and also has the facility to predetermine operation period. The control box consists of devices such as temperature controller with thermocouple probe, contactors with and without overload relays, timer, fuses, start and stop switches and indicator pilot lamps among others. Technical information on the dryer is presented in Table 1.

Principle of operation
The principle of operation of a typical hot air cabinet dryer is illustrated in Fig. 2. Heated air is circulated between the trays (T) by the fan impellers (B) which are driven by motors (M) and passes over the heaters (H). Some moist air is continuously vented through the exhaust ducts (E) whilst make-up fresh air enters through inlet ducts (I).

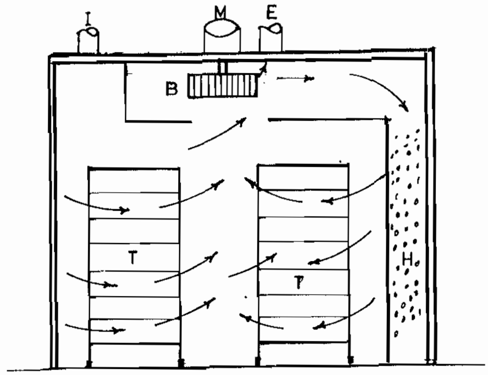

Fig. 2. Hot air cabinet dryer

Testing
Electrical connection was made to the dryer through the control box using 4 × 35 mm^2 PVC/ SWA/PVC (armoured) cable. Three tests were carried out:

1. *Dryer workability test.* A no-load test was conducted to find out if the machine responded to commands from the control box. The dryer was run from "start" to "stop" through setting of different operating temperatures and times for about 2 h on three occasions.

2. *Temperature distribution test.* Tests on temperature distribution in the dryer were conducted also without load at 60 °C to find out how uniform the heat is distributed in the dryer. Probes of five (5) type K (Chromel - Alumel) thermocouples were positioned near the four corners and at the centre at a height of 1.5 m from the floor of dryer corresponding to the height of the top most tray. The other ends of the thermocouples were connected to the rear of a recording thermometer Model KM 1242. The thermometer was programmed to record the five temperatures at 1 min intervals. Also re-

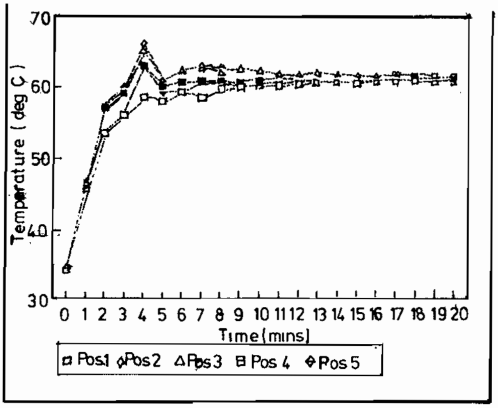

Fig. 3. Temperature distribution curves

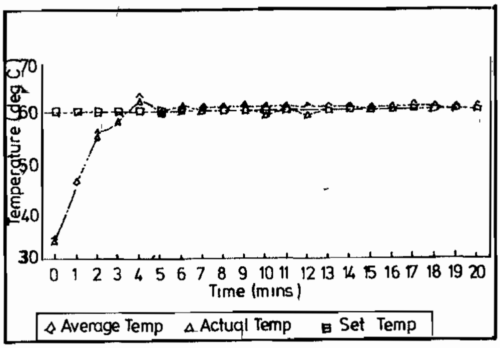

Fig. 4. Temperature curves

corded simultaneously were temperatures read from the temperature controller which represent the actual dryer temperature at any given time. The temperature was set at 60 °C and the dryer was started at the same time with the recording thermometer and stopped after the set temperature had stabilized for some time. The test was repeated on two other occasions and average values calculated.

3. *Performance data test.* Further tests were conducted using fermented cassava dough to determine performance characteristics of dryer. The fermented cassava dough was obtained from the Cassava Processing Demonstration Unit of FRI at Pokuase near Accra. Known quantity of the dough was spread on known number of trays at a loading depth of 12 mm as evenly as possible and dried at 65 °C for 15 h. Samples at zero and final times were taken for moisture determination. Final weight of the product was also recorded. The test was repeated on two other occasions and average values calculated.

Results and discussion

Test on workability of dryer

With the temperature set above the ambient and timer in an "ON" regime, the contactors brought the fan motors and the heaters to work when the "start" button on the control box was pressed. The heater contactor automatically cut off when the set temperature was attained while the fan motors continued running. The heater contactor energized again when the temperature in the dryer just fell below the set temperature. This "on" and "off" cycle of the heater contactor continued, ensuring constant temperature in the dryer as long as the dryer remained in operational mode. The dryer stopped operating i.e. the fan motors and heaters stopped working simultaneously when the "stop" button was pushed in or when the timer reached an "OFF" regime. The above tests demonstrated that the dryer operated smoothly without any problem.

Temperature distribution test

The results obtained from this test are presented in Table 2 and given graphical interpretations in Fig. 3 and Fig. 4. Fig. 3 shows temperature curves for positions A to E while Fig. 4 shows the set temperature, actual dryer temperature (from the temperature controller) and the average temperature from the five positions (from KM 1242 re-

TABLE 2
Temperature readings at five positions

Time	*Pos. 1*	*Pos. 2*	*Pos. 3*	*Pos. 4*	*Pos. 5*	*Av.temp.*	*Actual temp.*	*Set temp.*
0	34.0	34.2	34.4	34.0	34.5	34.2	34.0	60
1	45.6	46.7	46.2	45.3	44.1	45.6	46.0	60
2	56.6	57.5	57.4	53.0	53.6	55.6	55.0	60
3	58.6	59.7	58.7	55.5	56.0	57.7	58.0	60
4	62.7	65.6	64.7	58.1	62.8	62.8	62.0	60
5	59.8	60.6	60.5	57.5	58.8	59.4	60.0	60
6	60.2	62.0	61.9	58.8	59.1	60.4	61.0	60
7	60.3	62.5	62.3	58.0	60.1	60.6	60.0	60
8	60.3	62.1	61.8	59.0	60.0	60.6	60.5	60
9	60.2	62.0	62.1	59.4	59.6	60.7	60.0	60
10	60.4	61.8	61.8	59.5	59.8	60.7	59.0	60
11	60.8	61.2	61.3	59.6	60.0	60.6	60.0	60
12	60.2	61.0	61.2	59.8	60.1	60.5	59.0	60
13	61.1	61.2	61.4	60.0	60.4	60.6	60.0	60
14	60.1	61.1	61.1	60.2	.60.1	60.5	60.0	60
15	60.2	60.9	60.8	59.8	59.9	60.3	60.0	60
16	60.1	60.7	60.8	59.9	60.0	60.3	60.0	60
17	60.4	60.8	60.9	61.0	60.2	60.7	60.0	60
18	60.2	60.5	60.6	60.8	60.0	60.4	60.0	60
19	60.0	60.2	60.4	60.7	60.1	60.3	60.0	60
20	60.0	60.3	60.3	60.6	60.2	60.3	60.0	60

cording thermometer). The curves show that temperatures at various positions within the dryer rise faster in the first 3 min and slows down between 3 and 5 min before setting about the set temperature. Temperatures at the five positions show higher variations between 3 and 12 min of the transient period before converging to the set temperature (Fig. 3). Fig. 3 also shows temperatures at the five positions oscillating about the set temperature recording a maximum deviation of 2.8 °C before setting. This is because the temperature controller (GEFRAN RD-87) used in the construction of the dryer was a proportional controller which has a proportional band of 0-10 per cent. Such a controller gives an output of aperiodic character i.e. absence of a periodic response. A more precision controller with manual or autotuning PID (Proportional-Integral - Derivative) control functions and higher setting accuracy will deliver an aperiodic output and eliminate oscillations about the set temperature. Fig. 4 shows that both the actual and the average temperatures from the five positions reached the set value (60 °C) at 3.5 min but it took the former 13 min to settle at 60 °C and the latter 6 min at 60.7 °C. This difference of 0.7 °C can be attributed to the differences in performance accuracies and efficiencies of the controller and the KM 1242 thermometer.

Performance data test

Data obtained from this test are presented in Table 3. With depth of loading averaging 12 mm on 93 trays, a drying time of 15 h was needed to dry 502 kg of fermented cassava dough from an initial moisture content to 60.3 per cent (w.b.) to 11.6 per cent (w.b.) to give 226 kg of dried dough. The loading area capacity of the dryer was then

TABLE 3
Performance data

Material	*Fermented cassava dough*
Number of trays used	93
Tray spacing, mm	90
Tray size, mm	787×787×31
Depth of loading, mm	12
Initial moisture, per cent (w.b.)	60.3
Final moisture, per cent (w.b.)	11.6
Loading area capacity, m^2	86.8
Drying capacity, kg product/m^2	3.9
Drying time, h	15
Overall drying rate, kg H_2O/h m^2	0.32

determined as 86.8 m^2 with drying capacity of 3.9 kg of dried fermented cassava dough /m^2 and an overall drying rate of 0.32 kg H_2O/h m^2.

Conclusions

A 140-tray walk-in hot air cabinet dryer has been designed, constructed and tested at the Engineering Workshop of the Food Research Institute. The dryer has a loading area capacity of 86.8 m^2, drying capacity of 3.9 kg of dried fermented cassava dough per square metre and an overall drying rate of 0.32 kg of water per hour per square metre. The dryer has since been exported and installed at Pouma, Cameroon, and working satisfactorily. The total cost of construction was $10,000.00 i.e. 20 per cent the cost of the dryer from Rolls Royce Industrial Ovens Limited of England. It is recommended that a temperature controller with PID function be installed if set temperatures are to be achieved faster without any oscillations.

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References

JEON, Y. W. & HALOS, L. S. (1991) Technical performance of a root cropchipping machine. *Proc. 9th Symposium of the Inter. Society for Tropical Root Crops (ed. F. Ofori and S. K. Hahn)* Accra, Ghana, 1994.

ODOGOLA, W. R. (1991) A comparative study of solar and open sundrying of cassava chips in Uganda. In *Proc. 9th Symp. Int. Soc. Trop. Root Crops* (ed. F. Ofori and S. K. Hahn). Accra, Ghana.

PERRY, J. H. *et al.* (1963) *Chemical engineers' Handbook,* 4th ed. New York: McGraw Hill Inc.

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