

Performance Evaluation of Ncam-Modified Kerosene-Fired Batch Dryer



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Abstract

Performance evaluation of the NCAM modified, kerosene-fired batch dryer was made at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria, using two different crop products: paddy rice and cassava. Parameters measured were moisture content, drying rate, fuel consumption, and drying time. Test results revealed kerosene consumption rates of 0.057 l/kg, 0.064 l/kg and 0.046 l/kg during drying of paddy rice, irregularly shaped cassava chips and threadlike shaped cassava chips, respectively. It took the dryer a total of 60, 114 and 120 minutes to dry 35 kg of parboiled paddy rice, 60 kg of threadlike shaped cassava chips and 43 kg of irregularly shaped cassava chips to a final moisture content of 14 %, 12 % and 22 % wb, respectively. The NCAM-modified kerosene-fired batch dryer was economical for drying of threadlike shape cassava chips. Because of the residue observed on the dried cassava chips, there would be the need to further modify the batch dryer

in order to make it suitable for the drying of cassava chips by incorporating a heat exchanger to reduce or eliminate fumes on the chips.

Introduction

Rice is a health staple and one of the most important food crops, being consumed by about 80 percent of the world population (Yadollahinia *et al.*, 2008). Rice production occurs in all agro-ecological zones of Nigeria (Wudiri, 1990). Rice is consumed in almost all households in Nigeria. It is a meal that cuts across all tribes. The average Nigerian eats 24.8 kg of rice per year, representing 90 percent of annual calorie intake (Ogunlade *et al.*, 2010). The demand for rice is increasing at a much faster rate than domestic production in Nigeria; more than any other African country since the mid-1970s (Ogunlade *et al.*, 2010).

Cassava, on the other hand, is a root crop which is one of the most important sources of energy in the human diet in the tropics. Nigeria ranks as the highest producer of

cassava in Africa (FAO, 2000). Jeon and Halos (1992) stated that cassava accounted for 60 % of root crop consumption in Africa.

Thin-layer drying is the process of removal of water from a porous media by evaporation, in which excess drying air is passed through a thin layer of the material until the equilibrium moisture content (EMC) is reached. Moisture removal from an agricultural product depends on the drying temperature, velocity and air relative humidity, variety and maturity. Hence, various isolated and combined parameters are involved in moisture removal from a grain (Couto, 2002). The simplest situation is when the drying resistance (isothermal process) lies on the grain surface for which the decay of moisture with time follows approximately an exponential law (Yadollahinia *et al.*, 2008).

Drying processes play an important role in the preservation of agricultural products. They are defined as a process of moisture removal due to simultaneous heat and mass transfer (Ertekin and Yaldiz, 2004). The most important reasons for the

popularity of dried products are longer shelf-life, product diversity and the substantial volume reduction. This could be expanded further with improvements in product quality and process applications. Drying is essential for normal preservation of perishable foods and some crops. Drying can be enhanced by processing into more stable products. Cassava roots stored at 13 °C and 85-90 % RH can last for a maximum of 2 months and can last between 5 to 6 months when stored at 0-2 °C and 85-90 % RH (NRI, 1994).

Rough rice is generally stored at between 12.5 and 14 % moisture content (wet basis). According to the equilibrium moisture data, rice at moisture content above 14 % (wb) will be exposed to drying conditions when relative humidity is less than 64 % at 400 F or less than 75 % at 800 F. If 14 % moisture content (wb) rice is exposed to humidity above these conditions, it will gain moisture (RQW, 2003)

When heated air is used as a drying medium, the primary factor influencing the rate of drying is the drying temperature (Yunfei and Morey, 1987). A study conducted by Sun and Woods (1994), revealed that drying is independent of air veloc-

ity in the range of 0.15 to 0.81 m/s, but depended sharply on the drying temperature of the air, from 21.1 to 76.7 °C.

In cassava processing, the most common processing method is the prolonged direct sun drying of peeled root into a storable product (Mlingi, 1995). However, quick drying using mechanical dryers is advantageous in the sense that risk of the contamination and mould growth are minimized.

FAO (1987) reported that moisture content was the most important factor in preventing deterioration. Hence, use of drying to prevent deterioration is a very important process in post harvest operation. In a study by Pathak *et al.* (1991), the effect of drying temperature on thin layer drying of crops was high. Other factors that govern drying rate are moisture content, air velocity and relative humidity.

In order to improve the poor storage method of preserving food in Nigeria, the evaluation of the NCAM-modified kerosene-fired batch dryer is necessary to provide an alternative means for drying for the preservation of farm produce after harvest.

Objectives of the Study

The basic objective of this research was to carry out performance tests on the NCAM-modified kerosene-fired batch dryer. The specific objectives were to: -

1. determine the dryer suitability for

drying cassava chips and paddy rice using thin layer drying;

2. determine the rate of moisture removal from cassava chips and paddy rice; and

3. determine uniform distribution of heated air within the batch dryer system both at the plenum and above the drying tray.

The Batch Dryer

Description of the Batch Dryer

A batch dryer was modified by NCAM to make it suitable for the purpose. It consisted of an axial fan blower unit, a 4.5 kW diesel engine, belt-pulley transmission system, kerosene burner incorporated with a metering device, a plenum and drying tray. The drying tray was made of a 2 mm diameter stainless screen. The batch dryer had an overall length of 2,501 mm, width of 1,165 mm and height of 810 mm. The dryer was mainly constructed with 1.5 mm galvanized sheet and 50 mm by 50 mm angle iron. **Fig. 1** shows the pictorial view of the modified batch dryer.

Working Principle of the Batch Dryer

For the purpose of this experiment the working principle of the modified batch dryer was as follows:

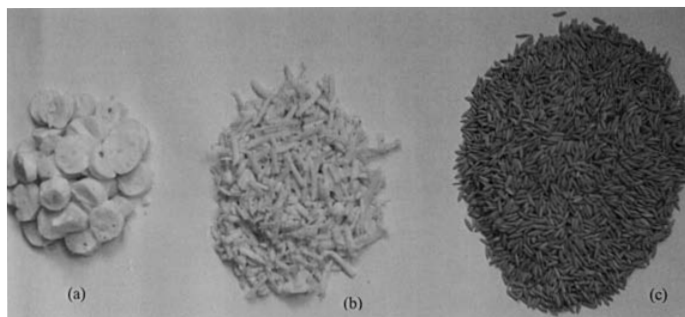
1. The burner was lit after turning on the kerosene supply knob to wet the wick in the burner;

2. The diesel engine was started to set the axial flow fan. The fan sucked the heated air across the burner, thereby transferring the

Fig. 1 The NCAM-modified kerosene-fired batch dryer



Fig.2 a) Irregularly shaped cassava chip; b) Threadlike shaped cassava chip; c) Unparboiled paddy rice



heated air to the plenum of the dryer for the drying operation to begin.

Materials and Methods

Materials: Cassava Chips

Freshly harvested cassava roots (*Manihot spp*) were obtained from the Farm Management Unit (FMU) of the National Centre for Agricultural Mechanization (NCAM). They were peeled, washed and chipped. For this experiment, two different types of cassava chips were used, namely: irregularly shaped cassava chips and threadlike shaped cassava chips. These two types of cassava chips were obtained using two different types of NCAM-developed chipping machines. One of these cassava chipping machines was designed to produce irregular shaped cassava chips with an average thickness of 0.92 cm and a length varying between 30 and 50 mm depending on the size of the cassava root. The other type of NCAM-developed cassava chipping machine produced cassava chips having threadlike shape. The different shapes of cassava chips obtained were as a result of the two different types of chipping discs incorporated into the cassava chipping machines.

During this experiment, the initial weight used for conducting the experiment for irregularly and thread-

like shaped cassava chips were 43 kg and 60 kg, respectively.

Paddy Rice

Paddy rice used for this evaluation was Faro 56 purchased from the National Cereals Research Institute, Baddegi, Nigeria. The paddy was parboiled using the NCAM farm level paddy parboiler. The average moisture content of the parboiled paddy before drying was 27 % w.b. 35 kg of parboiled paddy rice was used for the drying experiment with the NCAM batch dryer while five kg of parboiled paddy rice was used for the sun-drying method.

Fig. 2 shows the pictorial view of the three samples of agricultural materials used in their fresh state before drying.

Methods: Instrumentation of the Modified Batch Dryer for Temperature Monitoring

In order to monitor the temperature of the drying air at the point of entering the drying tray through the plenum and the temperature of the moist air immediately after drying the agricultural materials, 4 K-type thermocouples were placed above the drying trays marked T₁, T₂, T₃ and T₄ for monitoring the moist air and a K-type thermocouples was placed at each dryer plenum marked T₅ and T₆ for monitoring the drying air. Each of the thermocouples was connected to a separate ALDA model AVD890G digital multimeter

operating in the temperature mode. **Figs. 3** and **4** show the arrangement of the K-type thermocouples above and below the drying trays, respectively.

Drying Procedure

Before starting the drying experiment, the burner was fired, with the suction blower (axial flow fan) powered by a 4.5 kW diesel engine (Viking prime mover) and allowing it to run for a period of 30 minutes to stabilize the heated air in the dryer. Temperature was taken at six different points as identified above. The relative humidity and the ambient air temperature were recorded with the hygrometers and digital thermometer, respectively, while the speeds of the prime mover and blower were obtained with an analog tachometer. The measured parameters that included moist air temperature, drying air temperature and moisture content were recorded at specified time intervals. **Fig. 5** shows the pictorial view when the records were taken for the temperature reading.

The time required for all the operations was recorded using an analogue stop watch. Moisture contents were determined at intervals using an analogue quick moisture analyzer and confirmed by using the oven drying method. Weights of samples were determined using a sensitive electronic weighing balance. The fuel consumption for the kerosene

Fig. 3 Arrangement of thermocouples for sensing moist air temperature just above the agricultural materials

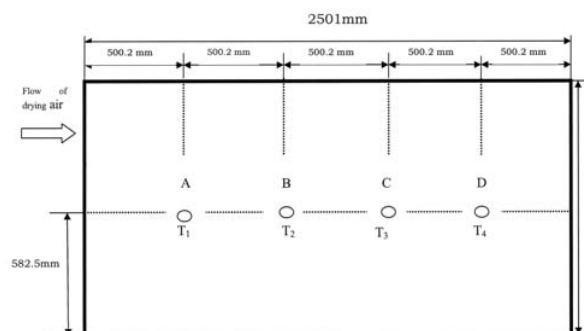


Fig. 4 Arrangement of thermocouples for sensing drying air temperature just below the agricultural materials

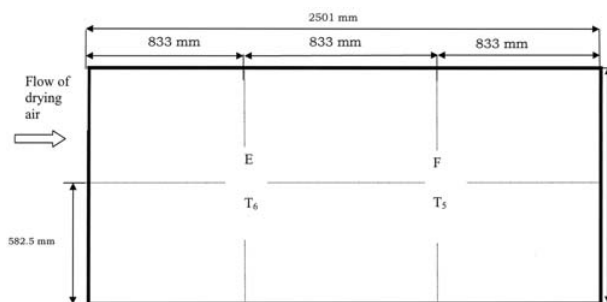


Table 1 Readings of Ambient Temperature and Relative Humidity before drying

Agricultural material dried	Measured parameters	
	Ambient Temperature (°C)	Relative Humidity (%)
Paddy rice	28	35.9
cassava chips	33	12.4

burner was measured using a graduated cylinder.

Test Parameters

Kajuna *et al.* (2001) gave the equations below for obtaining the amount of bone dry matter based on the initial moisture content of the sample:

$$MC_{db} = 100 (\% MC_{wb}) / 100 - (\% MC_{wb}) \dots \dots \dots (1)$$

$$\text{But, } MC_{db} = M_w / M_{dm} \times 100 \% (2)$$

$$M_w = MC_{db} \times M_{dm} / 100 \dots \dots \dots (3)$$

$$M_{dm} = M_s - M_w \dots \dots \dots (4)$$

where,

MC_{wb} = moisture content wet basis, %

MC_{db} = moisture content dry basis, %

M_s = mass of sample, kg

M_w = mass of water, kg

M_{dm} = mass of bone dry matter, kg

Eqn. 4 was found useful for obtaining the amount of moisture removed, moisture present in the sample, average moisture content dry basis (db) and the drying rate. All these parameters were related using the mathematical expression given below to calculate the drying rate.

$$R = Mw / To [(Mbd) / 100] \dots \dots \dots (5)$$

Table 2 Temperature distribution at six different locations of NCAM batch dryer during paddy rice drying

Time, t (Minutes)	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)	T ₄ (°C)	T ₅ (°C)	T ₆ (°C)	T _a (°C)	T _b (°C)
0	25	29	27	22	27	25	25.75	26.00
10	21	24	32	21	42	40	24.50	41.00
20	22	25	36	21	46	39	26.00	42.50
30	26	25	31	29	54	48	27.75	51.00
40	36	34	37	37	85	78	36.00	81.50
50	37	43	36	35	100	89	37.75	94.50
60	40	46	42	34	80	72	40.50	76.00
70	32	35	37	40	56	47	36.00	51.50

Legend:

T₁: temperature at point 1 on the top layer of the dryer

T₂: temperature at point 2 on the top layer of the dryer

T₃: temperature at point 3 on the top layer of the dryer

T₄: temperature at point 4 on the top layer of the dryer

T₅: temperature at point 5 under the dryer

T₆: temperature at point 6 under the dryer

T_a: average moist air temperature: (T₁ + T₂ + T₃ + T₄) / 4

T_b: average drying air temperature: (T₅ + T₆) / 2

where,

R = drying rate in gm of water per minute per 100 gm of bone dry material.

M_w = Amount of moisture removed, %

Mbd = Total bone dry weight of sample, gm

To = Time taken to dry, mins

Drying of Paddy Rice

Temperature readings taken at six different locations of the dryer for paddy rice drying using the NCAM-modified kerosene-fired batch dryer are presented in **Table 2**. The average temperature readings of the moist air and drying air were used in plotting the graph presented in **Fig. 6**. **Fig. 6** shows the graph of average temperature versus drying time for paddy rice. The temperature of the drying air increased steadily from 26 °C to a maximum of 94.5 °C within the first 50 minutes of drying. It took the drying air temperature an additional 20 minutes to move from 94.5 °C to 51.5 °C which is considered to be within the

Results and Discussion

The initial relative humidity and ambient temperature of the environment obtained during the drying process of the agricultural materials is presented in **Table 1**.

Fig. 5 Pictorial view showing how temperature readings were taken



Fig. 6 Average temperature versus drying time for paddy rice

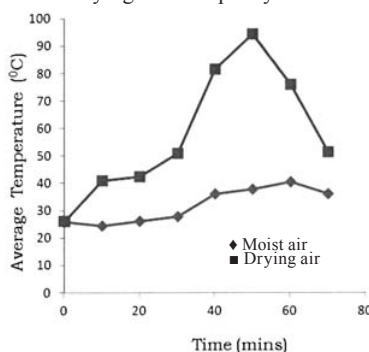


Fig. 7 Moisture content versus drying time for paddy rice

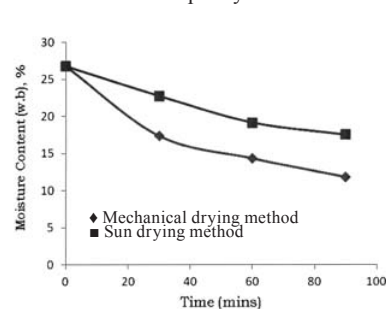


Table 3 Moisture content readings obtained during drying of paddy rice

Drying Method in Use	Moisture Content value (% w.b)			
	Initial	Time, t (minutes)		
		30	60	90
Mechanical drying using NCAM Batch dryer	26.8	17.37	14.33	11.8
Sun-drying	26.8	22.77	19.15	17.5

Table 4 Drying characteristics of the paddy in the batch dryer

Drying time, min	Moisture removed, kg	Moisture present in the sample, kg	Moisture content, % d.b	Average moisture content, % d.b	Drying rate, R, g of water/ min 100 g of bone dry materials
0	0.00	9.38	36.61		
30	3.99	5.39	21.02	28.815	0.519
60	5.09	4.29	16.73	18.875	0.331
90	6.21	3.17	12.36	14.545	0.269

Table 5 Drying characteristics of the paddy during sun drying

Drying time, min	Moisture removed, kg	Moisture present in the sample, kg	Moisture content, % d.b	Average moisture content, % d.b	Drying rate, R, g of water/ min 100 g of bone dry materials
0	0.00	1.34	36.61		
30	0.26	1.08	29.48	33.045	0.237
60	0.47	0.87	23.69	26.585	0.214
90	0.56	0.78	21.21	22.45	0.17

Table 6 Temperature distribution at six different locations of NCAM batch dryer during cassava chip drying

Time, t (minutes)	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)	T ₄ (°C)	T ₅ (°C)	T ₆ (°C)	T _a (°C)	T _b (°C)
0	26	26	25	26	26	26	25.75	26.00
10	28	36	30	39	61	69	33.25	65.00
20	27	35	29	37	50	55	32.00	52.50
30	30	33	34	43	56	63	35.00	59.50
40	40	35	39	47	55	62	40.25	58.50
50	27	29	31	37	41	45	31.00	43.00
60	52	37	43	53	66	79	46.25	72.50
70	31	40	45	49	48	59	41.25	53.50
80	33	50	60	65	70	88	52.00	79.00
90	35	52	69	74	74	95	57.50	84.50
100	34	49	64	69	59	80	54.00	69.50
110	34	46	63	70	65	84	53.25	74.50
120	33	46	62	69	33	80	52.50	56.50
130	33	44	59	69	33	76	51.25	54.50

Legend:

T₁: temperature at point 1 on the top layer of the dryer

T₂: temperature at point 2 on the top layer of the dryer

T₃: temperature at point 3 on the top layer of the dryer

T₄: temperature at point 4 on the top layer of the dryer

T₅: temperature at point 5 under the dryer

T₆: temperature at point 6 under the dryer

T_a: average moist air temperature: (T₁ + T₂ + T₃ + T₄) /4

T_b: average drying air temperature: (T₅ + T₆) /2

range of safe drying air temperature for paddy rice.

The moisture content at different time intervals for paddy rice drying with the NCAM modified batch dryer and sun-drying method are presented in **Table 3** and plotted in **Fig. 7**. The rate of moisture removal was high within the first 30 minutes of drying using the NCAM-modified batch dryer. This might be attributed to the high initial drying air temperature that drove out moisture from the surface of the grains at this initial time. The moisture removed gradually increased over a period of time. As drying continued, the paddy rice attained a safe storage/milling moisture content of 14.3 % within 60 minutes. After 90 minutes of drying using the NCAM-modified batch dryer, 6.21 kg of moisture was removed corresponding to 0.269 kg of water/minute (**Table 4**). For the sun drying method, only 0.56 kg of moisture was removed after 90 minutes of drying, which corresponded to 0.17 kg of water/minute (**Table 5**). Thus, the drying rate was faster with the NCAM-modified batch dryer compared with the sun drying for drying of paddy rice.

Drying of Cassava Chips

Readings taken at six different locations of the dryer for cassava chip drying are presented in **Table 6**. The average temperature versus drying time for the moist air and drying air are shown in **Fig. 8**.

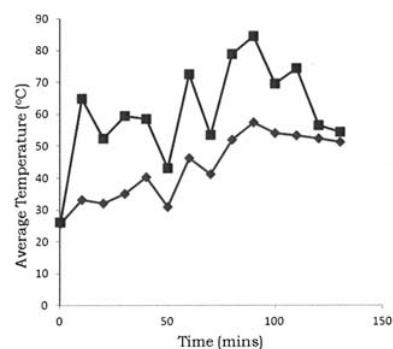
Fig. 8 Average temperature versus drying time for cassava chips

Table 7 Moisture content readings obtained during drying of threadlike shaped cassava chip

Moisture Content (% w.b)				
Initial	Time, t (minutes)			
	30	60	90	120
73.2	58.5	53.8	52.8	21.8

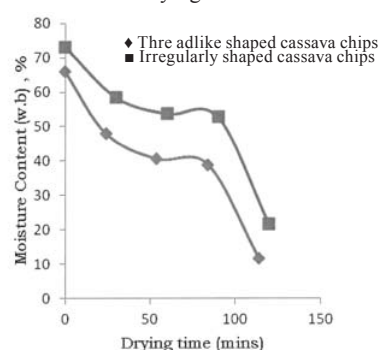
Table 8 Moisture content readings obtained during drying of irregularly shaped cassava chips

Moisture Content (% w.b)				
Initial	Time, t (minutes)			
	24	54	84	114
65.92	47.93	40.6	38.95	11.73

The temperature of the drying air increased steadily from 27 °C to a maximum of 84.5 °C within the first 90 minutes, while the moist air temperature was at a maximum of 57.5 °C within 90 minutes of drying. This might be attributed to the high moisture content nature of the cassava chip.

Results obtained for the moisture content readings taken at different time intervals for drying both threadlike and irregularly shaped cassava chip are presented in **Tables 7 and 8**, respectively, and are plotted in **Fig. 9**. The moisture content of the thread like cassava chips decreased from the initial moisture content of 66 % wb to 12 % wb within 114 minutes, while the round shaped cassava chips reduced from an initial moisture content of 73 % wb to 22 % wb within 120 minutes. This showed that the thicker cassava chips took longer to dry. Within the

Fig. 9 Moisture content versus drying time



first 60 minutes of drying, the outer layer of the chips looked drier than the inner part. Further drying of the cassava chips for 40 minutes at a lower temperature allowed for migration of moisture from the region of higher moisture concentrations (inner part) to the region of lower concentration (the outer part). Thus, it can be deduced that fast drying using higher temperature resulted in faster removal of moisture from the outer surface of the chips. However, to reduce the drying time, it was advised to start drying with high drying air temperature within the first one hour because of the fast rate at which moisture was removed.

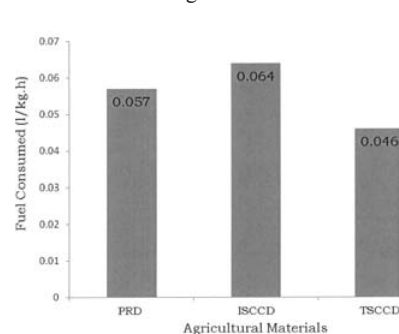
Fuel Consumption

The amount of kerosene used by the kerosene burner is presented in **Table 9**. **Fig. 10** presents a bar chart showing the amount of kerosene consumed per kilogram per unit

Table 9 Fuel consumed during drying operation

Agricultural material dried	Quantity of material dried, kg	Time taken to dry the agricultural material, mins	Amount of fuel used (l)	Fuel consumption rate, l/kg.h
Paddy rice	35	60	2.00	0.057
Irregular shaped cassava chips	43	120	5.53	0.064
Threadlike shaped cassava chips	60	114	5.23	0.046

Fig. 10 Fuel consumed per kilogram per unit time of agricultural material



time of agricultural material dried. Drying of the threadlike shaped cassava chips gave the least fuel consumption rate of 0.046 l/kg.h. This was followed by paddy rice drying which gave a fuel consumption rate of 0.057 l/kg.h, and drying of irregular shaped cassava chips with the highest fuel consumption rate of 0.064 l/kg.h. This implied that the NCAM modified batch dryer was economical in drying the threadlike cassava chips as compared to the other two agricultural materials.

PRD = Paddy Rice Drying; ISCCD = Irregular Shaped Cassava Chips Drying; TSCCD = Threadlike Shaped Cassava Chips Drying

Conclusions

Performance evaluation was made on the NCAM-modified kerosene-fired batch dryer and the following conclusions were made:

1. The NCAM-modified kerosene-fired batch dryer was most economical for the drying of threadlike shape cassava chips.
2. The maximum average drying air temperature attained within the dryer was 94.5 °C.
3. Flow of heated air within the batch dryer system, both at the plenum and above the drying tray, was not uniformly distributed.
4. The drying rate at which the

NCAM-modified kerosene-fired batch dryer dried agricultural materials was much faster when compared with the sun drying method.

5. The NCAM-modified kerosene-fired batch dryer was able to dry irregularly shaped cassava chips from an average thickness of 0.92 cm with initial moisture content of 73 % wb to a thickness of 0.62 cm with final moisture content of 22.0 % wb within 120 minutes using a total amount of 5.53 litres of kerosene.
6. The NCAM-modified kerosene-fired batch dryer was able to dry threadlike shaped cassava chips from an initial moisture content of 66 % wb to 12.0 % wb within a drying time of 114 minutes using a total amount of 5.23 litres of kerosene.
7. The NCAM-modified kerosene-fired batch dryer conveniently dried cassava chips. However, it was observed that the dried cassava chips were contaminated by soot/fumes from the burner. As a result, there was a need to incorporate a heat exchanger to eliminate fumes from the chips.
8. With the incorporation of the proposed heat exchanger into the batch dryer system, it was safe to conclude that the dryer was suitable for drying all types of agricultural materials grown in the world.

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