Development and performance evaluation of a mini horizontal flash dryer

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Abstract: Cassava (Manihot esculenta) is a major staple crop in Nigeria, as cassava itself and its products are found in the daily meals of Nigerians. Currently, cassava crop is undergoing a transition from a mere subsistent crop found on the field of peasants to a commercial crop that will be grown in large quantities in plantations. A flash dryer was designed, fabricated, assembled and tested following the standard procedures. The flash dryer is a mechanized way of drying cassava mash for mass production of cassava flour, for flour mills, confectionery and pharmaceutical industries. The traditional method of producing cassava flour, results to low product quality and quantity for industrial usage because the mode of drying is dependent on climatic conditions and susceptible to contamination. The equipment was tested using already prepared cassava mash dewatered to a moisture content of 40%. Twenty five samples of this prepared cassava mash at varied temperatures of 70 ℃, 80 ℃, 90 ℃, 100 ℃ and 110 ℃ were subjected to different air velocities of 5 m/s, 10 m/s, 15 m/s, 20 m/s and 25 m/s. The equipment was fed at the rate of 60 kg/h. Air velocities of 5 m/s and 10 m/s were too low to convey the cassava mash and not all the material fed into the dryer went through. Air velocities of 20 m/s and 25 m/s were too high and do not allow enough drying time instead, the materials formed knots. Thus, these velocities and their corresponding temperatures were not appropriate for use in this dryer. At air velocity of 15 m/s all the materials went through and the combination of this velocity (15 m/s) with the air temperature of 90 ℃ the first constant moisture content of 12.4% was obtained. The same moisture content was also obtained at a temperature of 100 ℃ and 110 ℃ at air velocity of 15 m/s. The flash dryer is very effective in drying cassava mash; it can be used to dry products to safe storage moisture content level.

Keywords: flash dryer, cassava mash, cassava flour

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1 Introduction

Cassava (*Manihot esculenta*) is a root crop cultivated and consumed as a staple in many regions of the developing world (Figure 1 and Figure 2). Africa produced 101.6 million Mega-tonnes of cassava in 2003, making cassava the most important root crop (FAO, 2004) and a major source of dietary calories. The importance of cassava to the livelihoods of many millions of poor people has made the commodity a target for interventions. Cassava is a major staple crop in Nigeria, as cassava itself and its products are found in the daily meals of Nigerians. Currently, cassava crop is undergoing a transition from a mere subsistent crop found on the field of peasants to a commercial crop that will be grown in large quantities in plantations (IITA, 2003). This unprecedented expansion on an African crop is attributed to the discovery of cassava as a cheap source of edible carbohydrate that could be processed into different forms of human delicacies and animal feeds (FAO, 2006). Furthermore, cassava could be source of raw materials for a number of industrial products which include starch, flour and ethanol. The production of cassava is relatively easy as it is tolerant to the biotic and edaphic encumbrances that hamper the production of other crops. Cassava could be

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grown in commercial quantity in most agro-ecologies in Nigeria; it could tolerate marginal soil fertility status, where other crop will fail completely. Although, cassava is best adapted to the rainforest agro-ecology, research activities over the years have identified varieties that are tolerant to drought and low moisture conditions.

Figure 1 Cassava plants

Figure 2 Cassava roots

Approximately 65% of all cassava produced is used for human consumption, 25% for industrial use, mostly as starch (6%) or animal feed (19%), and 10% is lost as waste (Fish and Trim, 1993). More than 40% of cassava is currently processed, mainly into traditional food products. There are many opportunities to extend the traditional uses of cassava and introduce it into a wide range of new food products, particularly in the rapidly urbanizing societies of the developing countries. A concerted effort to realize the promise of cassava roots could give it a more central role in socio-economic development. The key to establishing the potential role of cassava is to establish a strong link between small-scale producers and new products. Numerous barriers obstruct this ideal. Cassava is perishable and bulky. To overcome these limitations requires appropriate strategies and technology for postharvest processing and utilization. Processing provides a means of producing shelf-stable products (thereby reducing losses), adding value at a rural level, and reducing the bulk to be marketed (Dufour et al., 2002). Cassava flour is popular in the food industry because of its special characteristics - clarity of appearance, low flavour overtones, and ideal viscosity. It has been shown to have potential for use as filler in comminuted meat products (Annor-Frempong et al., 1996).

1.1 Objectives of the research

The main objective of this research is to develop a durable and easy to operate dryer for peasant farmers and small sale industrialist. The specific objectives of the study are to:

i. Design parts of the dryer.

ii. Fabricate the dryer using locally available materials

iii. Evaluate the performance of the dryer to determine the best operating conditions.

1.2 Justification of the project

Mashed cassava do not store long when wet. To store as long as up to one or two weeks, requires daily changing of water which leads to the lost of quantities and qualities. This dryer will process the mash into powder that can be packaged into manageable packets easy to prepare products that can be stored longer and yet retained its nutritional values.

2 Main body

2.1 Cassava production in Nigeria

Nigeria is one of the largest producers of cassava in the world and its production is currently put at about 33.8 million tonnes a year (IITA, 2003). Total area harvested of the crop in 2001 was 3.1 million ha with an average yield of about 11 t/ha. Cassava plays a vital role in the food security of the rural economy because of its capacity to yield under marginal soil conditions and its tolerance to drought. It is the most widely cultivated crop in the country; it is predominantly grown by smallholder farmers and dependent on seasonal rainfall. Rural and urban communities use cassava mainly as food in both fresh and processed forms. Cassava production is still carried out by manual labour using local simple farm implements such as hoes and knives in most parts of the country because it is yet to be mechanized (FAO, 2006). Cassava roots are processed at household and cottage levels in the rural areas of the major cassava producing states by traditional methods handed down through time as cassava was adopted as food by the people. Processing at these levels involve mainly the production of garri, fermented and unfermented flour, as well as *fufu* (local delicacy) for both domestic consumption and industrial uses (FAO, 2006).

2.2 Cassava processing and utilization

Cassava is a very versatile commodity with numerous uses and by-products. Each component of the plant can be valuable to its cultivator. The leaves may be consumed as a vegetable or cooked as a soup ingredient or dried and fed to livestock as a protein feed supplement (IITA, 1990). The stem is used for plant propagation and grafting. The roots are typically processed for human, animal and industrial consumption. In Nigeria, the consumption pattern varies according to ecological zones. Garri, a roasted granule is the dominant product and is widely accepted in both rural and urban areas. It can be consumed without any additives, or consumed with a variety of additives such as sugar, groundnut, fish, meat and stew. *Fufu* or *Akpu*, a fermented wet paste from cassava is also widely consumed throughout the country especially in the southern zones (Ajao and Adegun, 2009).

2.3 Drying of agricultural products

Drying is the application of heat to remove the majority of water normally present in a food by evaporation (Fellows, 2003). Drying of Agricultural Product is used to prevent germination of grains, to retain maximum quality of product to reach a level of moisture content which does not allow the growth of bacteria, fungi and considerably retards the development of insects. Drying affects the quality of products and so its values to purchasing organizations. Drying is a unit operation aimed at removing nearly all water present in foodstuff. Cassava is dried when water contained within them is removed into the surrounding air. This drying is associated with water present in cassava for prolonged shelf life of food. Water needs to be removed or reduced to a certain amount which hinders both biochemical and microbial activities Desroseir (1970) acknowledged that sun drying is an adequate method of food preservation under most conditions in developing economy, while dehydration denotes drying effected by artificial means; it is usually reserved for artificial drying methods employing a forced draft of conditioned air by mean of fans. The capacity of air for moisture removal depends on its humidity and its temperature. For Agriculture, drying air is used usually as the drying medium to conduct heat to the produce and to convey the vapour away from the drying produce (Johnston and Mello, 1961).

3 Materials and methods

3.1 Design considerations

The following factors were considered for the development of the dryer.

i. The dryer will be simple in design and easy to fabricate.

ii. Simple operational and maintenance requirements to meet the need of the local farmers and small scale industrialists.

iii. The dryer should be cheap and affordable.

iv. Portability and detachability for easy transportation.

v. The dryer will be fabricated with locally available materials to reduce cost.

vi. Minimal power requirement

vii. Easy to replace components

viii. It should not require a lot of technical know how to operate

ix. It should reduce labour requirement associated with mash drying.

3.2 Design analysis

Flash dryer is a dryer to dry and separate the dried product from the air. To effectively carry out this operation, it requires some functional component as shown in the Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7:

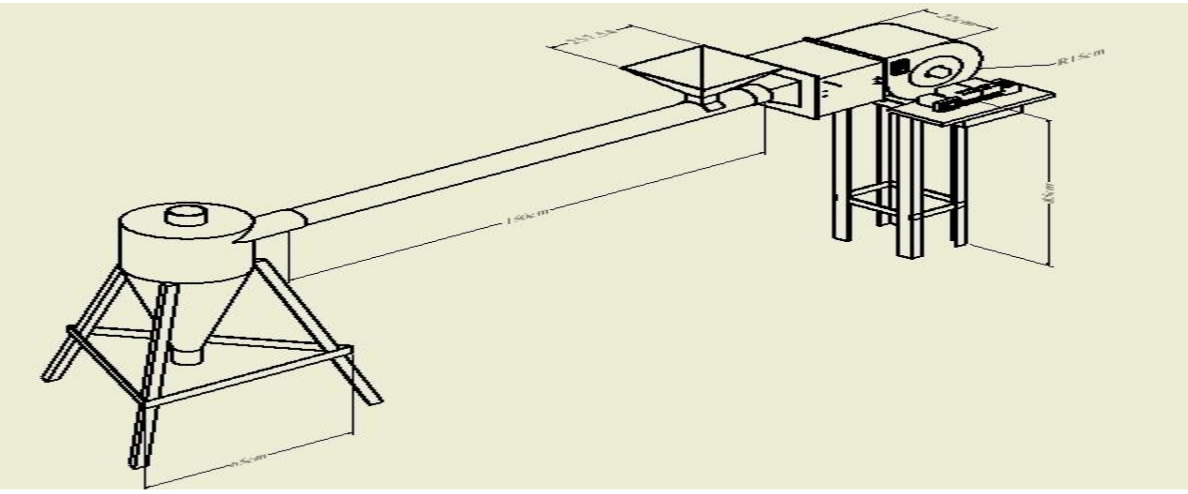

Figure 3 Isometric view of the flash dryer

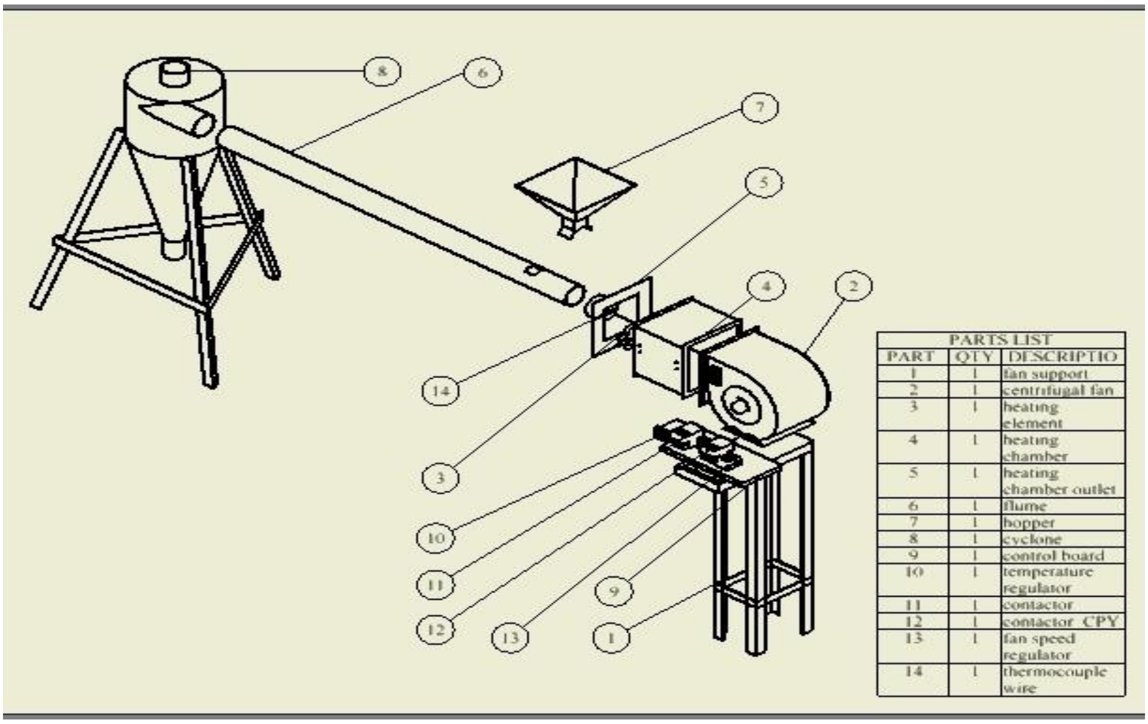

Figure 4 Exploded view of the flash dryer

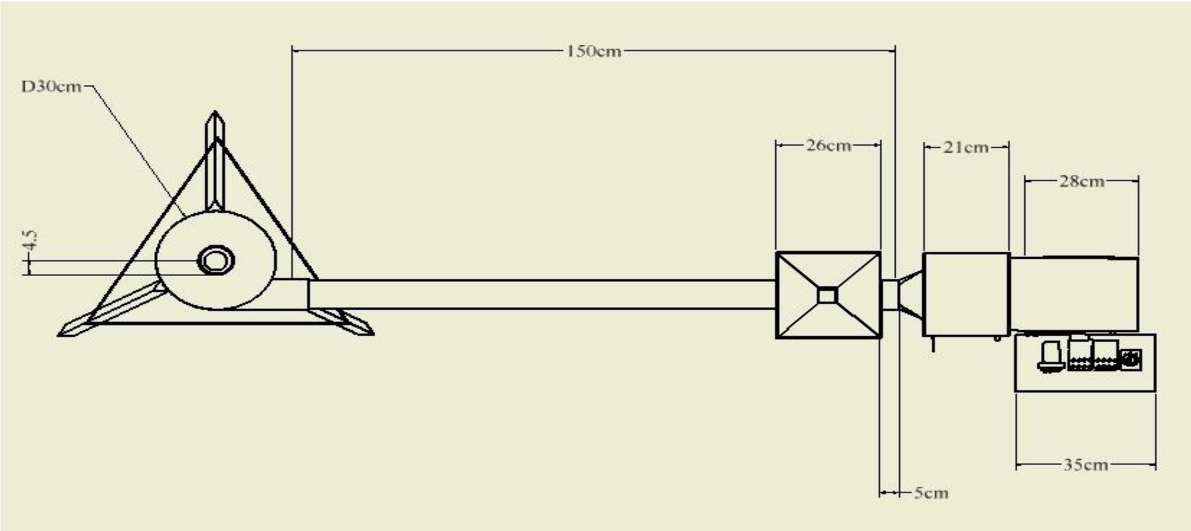

Figure 5 Plan view of the flash dryer

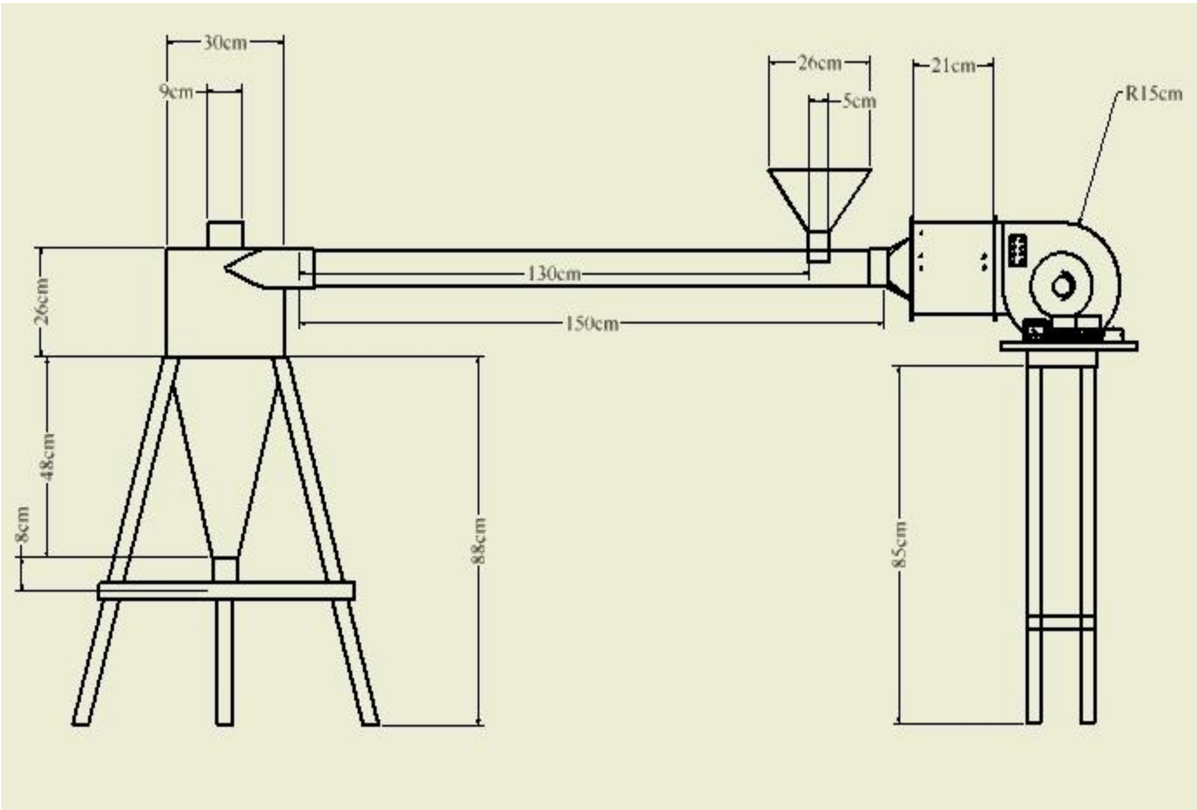

Figure 6 Front view of the flash dryer

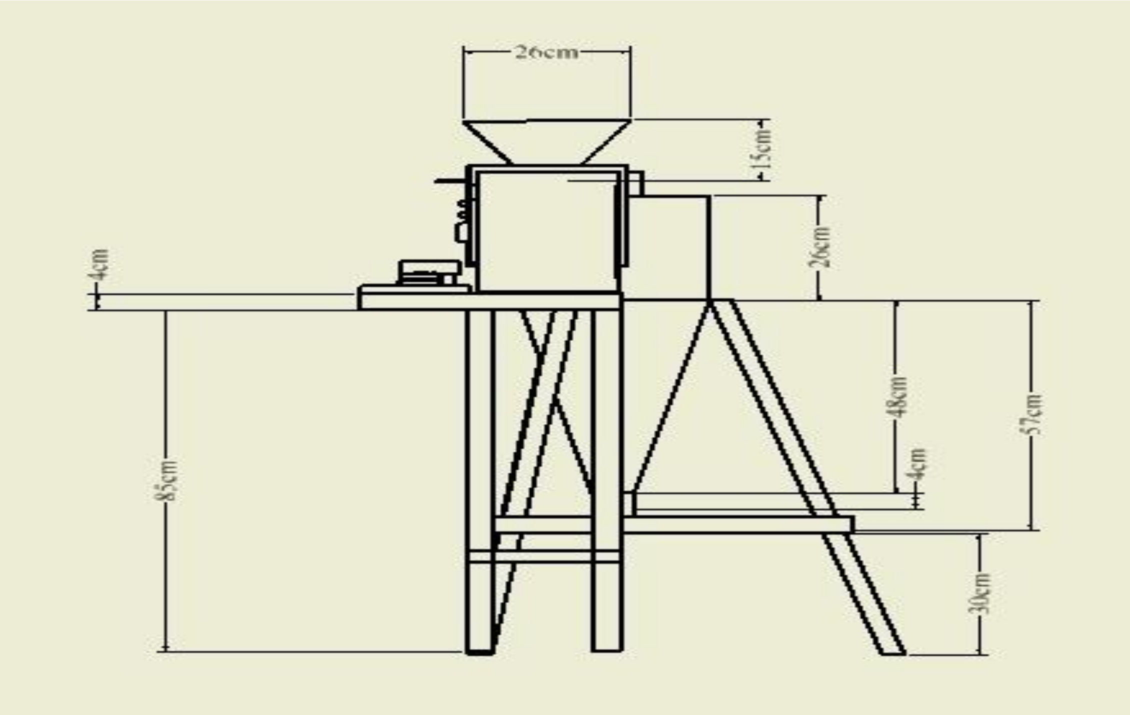

Figure 7 Side view of the flash dryer

3.2.1 Fan

The fan used in this dryer is forward curved blade centrifugal fan which is a bought out material. It has the advantage of moving more air than both propeller and axial fans of the same diameter and speed. It has the following dimensions; housing, 300 mm × 340 mm and diameter of 170 mm. This fan has an in built fan drive having a motor of 2 kW, where it is connected to the source of electricity. This helps to eliminate the use of a separate electric motor, motor sitting, belt and pulleys, which should have otherwise made the dryer more bulky, occupy more space, more costly to fabricate and have more power requirement.

3.2.2 The heating chamber

The heating chamber was constructed from the following materials:

- Mild steel sheet
- Wooden blocks
- Heating elements
- Angle bar.

The mild steel sheet was cut to size and welded to get two sections. Wooden blocks were installed in between to act as insulator. Angle bars cut to size were welded to the sides of the box to provide room for nuts and bolts to couple the fan and the drying duct to this unit. The dimensions of the heating unit are as guided by Tung and Steinbrecht (2008). Two heating coils or heating elements of 2 kW each were installed for rapid heat generation.

3.3 The drying chamber

The drying unit which is a pipe was constructed from a sheet of mild steel. The dimensions used were guided by the geometry of the cyclone. The diameter of the drying chamber is 7 cm and 1. 5 m long. This was welder to a flat metal sheet cut to size to enable this unit to be coupled to the heating chamber with nuts and bolts.

These are bought out materials connected to vary the operation of the dryer. They are:

1. Two temperature control switches connected to the heating chamber.

2. Two thermocouples or sensors.

3. One fan speed control switch connected to the fan.

3.4 The Cyclone

For high efficiency, the cyclone was designed using the cyclone geometry given by Ayoade et al. (2006).

3.4.1 Height to diameter ratio (H:D ratio)

The length to diameter ratio $\frac{H}{D}$ is the total cyclone height (cylinder length + cone vertical length) divided by the diameter of the cone body.

This ratio is between 3 and 6 (Ayaode et al., 2006).

In the design of the cyclone, H = 900 mm and D = 300 mm were used.

$$\therefore \frac{H}{D} = \frac{900}{300} = 3$$

3.4.2 Discharge port diameter (Do) to Cyclone Diameter (D_s) Ratio

This is given by Ifadah, 2005 as $\frac{D_O}{D_s}$

Here, D_s is taken as 300 and Do as 70 mm

$$\therefore \frac{D_o}{D_s} = \frac{70}{300} = 0.23$$

3.4.3 Angle of inlet pipe

Angle of inlet pipe to the cyclone body is given to be between 10^o and 20^o, but smaller angle give high efficiency unit (Ayoade et al., 2006). Therefore 10^{o}was used here.

3.4.4 Outlet pipe length (Gas)

The outlet pipe should extend below the bottom of the inlet by 10%- 60% of the inlet height.

Inlet height used here = 75 mm.

$$60\%\ of\ 75 = \frac{60}{100} \times 75 = 45$$

$\therefore$ Outlet pipe length = 75 + 45 = 120 mm

3.4.5 Cone shape

To design and construct the cone, the following are needed:

- The base diameter which is the diameter of the cone. This is 300 mm.
- The cone height which is twice the cone diameter. That is 300 $\times$2 = 600 mm.
- A frustum of the cone was constructed by development.
- The cyclone discharge diameter was found to be 70 mm

$\therefore$ 70 mm was used as the discharge diameter

3.5 The feeding unit

3.5.1 The hopper

A square frustum was constructed from a sheet of mild steel by development method with the following dimensions, 300 mm^2 $\times$ 360 mm. The frustum was cut at a height of 300 mm to give an outlet of 40 mm^2.

3.5.2 The drying chamber inlet

A square mild steel pipe of 40 m^2 cut to a length of 60 mm was wedded to the outlet of the hoper and the drying chamber to form the neck of the feeding chamber.

3.5.3 The sieve

This was constructed of a wooden frame of 304 mm $\times$304 mm $\times$150 mm. A fine wire sieve was fitted to the frame such that it is easily coupled to the hoper.

3.6 Assembly of the fabricated dryer

The components were fabricated and coupled in the workshop of the Department of Agricultural Engineering, Federal University of Technology, Akure. The assembled flash dryer is shown in Figure 8.

Figure 8 The assembled flash dryer

3.7 Machine testing

The machine was tested in the workshop of the Agricultural and Environmental Engineering Department of the Federal University of Technology Akure, Ondo State.

3.7.1 Sample preparation

The procedures of processing cassava tubers into cassava mash used for the testing of the dryer involves: peeling, washing of tubers, cutting into pieces, soaking in clean container which last for between three and four days, filtering, putting in a bag and de-watering using jack to reduce the moisture content from 80% to 40%. The moisture content was determined using the triode Digital moisture meter AG – 3.

Twenty-five samples of 1000g each was prepared by weighing using the mettler toredo SB 32000 digital balance. The samples were categorised into five groups according to air velocities and temperatures for which the fan and heaters have been calibrated to operate. The samples were labelled accordingly. Air velocities used were 5m/s, 10m/s, 15m/s, 20m/s, and 25m/s. Temperatures used were: 70 ℃, 80 ℃, 90 ℃, 100 ℃ and 110 ℃. The rate of feeding of the machine was 1 kg of material per minute, thereby giving a feeding rate of 60 kg/h.

3.7.2 Operation of the dryer

The dryer was connected to a 220/240 V electricity source. The circuit breaker and the heat generation/distribution units were turned on. The heater element glow and fan blew simultaneously. As the temperature inside the heating chamber increased and was about to rise above the pre-set temperature, the thermocouple or sensor inside the chamber cut off the current supply and sent signal to the electronic temperature controller, which disengaged automatically. This enhanced uniform heat development in the heating chamber. The blowing of fresh air across the heater elements result in heated air been passed through the drying chamber. If the air is carrying materials to be dried, separation takes place resulting to the escape of the air through the gas outlet and the dried material through the dust or particle outlet.

The mixture of the cassava flour passes through the inlet line and then to the flash duct. In the flash duct, drying take place due to reduction in pressure and the larger space for the air and cassava flour to mix together. From the flash duct through the inlet line, the mixture of cassava flour and hot air enters the cyclone. Due to large pressure drop in the cyclone, cassava flour drops by gravity and the dried product is then collected at the exit port while hot air proceeds through the exhaust line.

4 Results and discussion

The conditions under which the flash dryer was tested are; ambient temperature of 30℃, mean relative humidity of 65%, initial air temperature of 90℃, initial moisture content of the material 40%, initial weight of sample of 1000g and particle size of material was 0.0725 mm. The results obtained during the evaluation of the dryer at different air velocities are as shown in Table 1, Table 2, Table 3, Table 4 and Table 5. A sample of 1000 g was also oven dried, oven dry moisture content was found to be 9.8%.

Table 1 Velocity at 5m/s

Temperature of air, °C					Weight, g					Moisture content m/c, %				
T_0	T_1	T_2	T_3	T_4	w_0	w_1	w_2	w_3	w_4	mc_0	mc_1	mc_2	mc_3	mc_4
70	30	32	35	38	1000	300.2	350	400	460.3	40	35	32.2	30	28.4
80	35	38	40	45	1000	304.5	360.1	430	487.8	40	33	30	29	27
90	50	40	45	48	1000	310	368	388	506	40	32	28	29	26
100	54	56	60	62	1000	320	376	484	512	40	30	28	28.2	25
110	60	68	72	74	1000	350	388	510	520	40	30	27	25	24

Table 2 Velocity at 10m/s

Temperature of air, °C					Weight, g					Moisture content m/c, %				
T_0	T_1	T_2	T_3	T_4	w_0	w_1	w_2	w_3	w_4	mc_0	mc_1	mc_2	mc_3	mc_4
70	40	42	45	50	1000	450	550	564	572.4	40	30	28	26	25
80	60	68	70	75	1000	510	555.3	571	580	40	30	27	25	24
90	75	77	81	82	1000	572.4	582	589	592	40	29	25	24	23
100	80	83	85	87	1000	576	580.2	591	599	40	28	26	23	22
110	92	93	96	98	1000	581.1	592.4	608.6	616	40	28	25	23	22

Table 3 Velocity at 15m/s

Temperature of air, °C					Weight, g					Moisture content m/c, %				
T_0	T_1	T_2	T_3	T_4	w_0	w_1	w_2	w_3	w_4	mc_0	mc_1	mc_2	mc_3	mc_4
70	38.2	42	48.3	58	1000	752.5	625	600	500	40	30.1	25	24	20
80	46	55.1	60	65	1000	705	575	475	400	40	28.2	23	19	16
90	50	64.3	67	70	1000	700	500	390	310	40	28	20.3	15.6	12.4
100	72.2	77	80.1	86.4	1000	700	487.5	353	310	40	28	19.5	14.2	12.4
110	83	89	93	95	1000	675	450	350	310	40	27	18	14	12.4

Table 4 Velocity at 20m/s

Temperature of air, °C					Weight, g					Moisture content m/c, %				
T_0	T_1	T_2	T_3	T_4	w_0	w_1	w_2	w_3	w_4	mc_0	mc_1	mc_2	mc_3	mc_4
70	50	52	58	60	1000	910	894	866	746	40	35.1	34	32	28.4
80	61	73	73	75	1000	887.5	850	800	710	40	32.2	30.8	30.3	27
90	72	84	85	86	1000	805	770	757	675	40	30	28.6	25.4	24
100	80	86	86	88	1000	750	685	625	600	40	30	27.4	25	24
110	91	95	97	99	1000	725	682.5	605	555	40	29	27.3	24.2	22.2

Table 5 Velocity at 25m/s

Temperature of air, °C					Weight, g					Moisture content m/c, %				
T_0	T_1	T_2	T_3	T_4	w_0	w_1	w_2	w_3	w_4	mc_0	mc_1	mc_2	mc_3	mc_4
70	53	56.1	58	61.8	1000	906	900	889	844	40	36.2	36	35	33.4
80	61.2	64	68	70	1000	875	850	800	775	40	35	34	32	31
90	72	78	80	83	1000	825	775	715	677.5	40	33	31	28.6	27.1
100	83	85	87	89	1000	800	785	675	650	40	32	31.4	27	26
110	92	96	99	100	1000	775	675	632	605	40	31	27	25.3	24.2

At velocity one (V_1) of 5 m/s, the air velocity was not sufficient to move all the material fed through the dryer. Over half of the materials were clogged in the dryer that variation in temperature had no or little effect Figure 9. Clogged material was removed by dismounting the dryer due to the moisture retention and the weight of the material as contributed by the moisture content (Table 1). Since at air velocity of 5 m/s over half of the material got clogged in the dryer, it then indicate that the heat supplied to the dryer had no effect on the material as all the materials were not available for drying. For the same reason, the temperature had no effect on the weight of the material as very little water was evaporated. Also because most of the material could not pass through the dryer for drying, little water was evaporated. Therefore the temperature had no significant effect on moisture content of the material Figure 10.

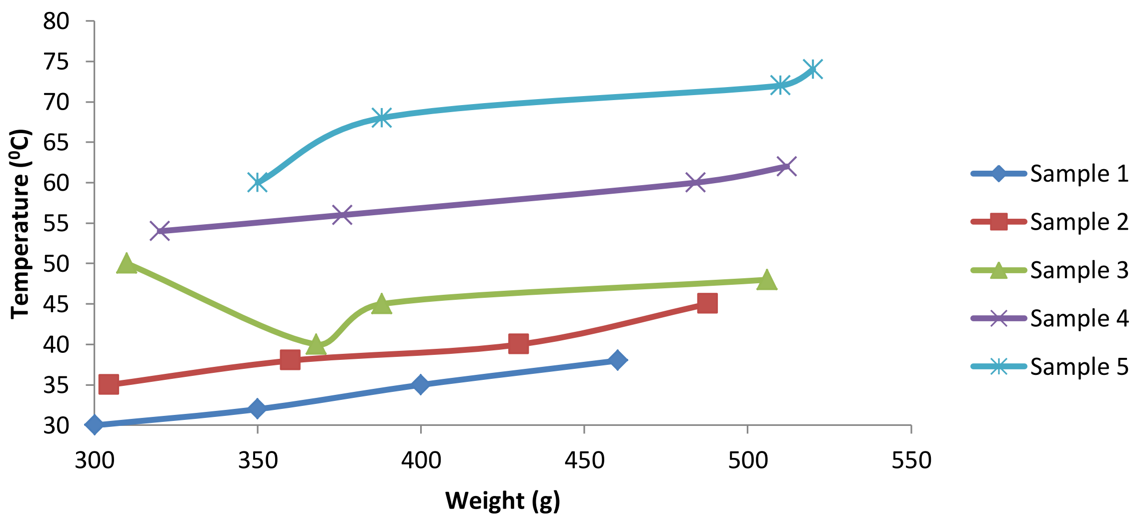

Figure 9 Effect of temperature on weight at 5 m/s

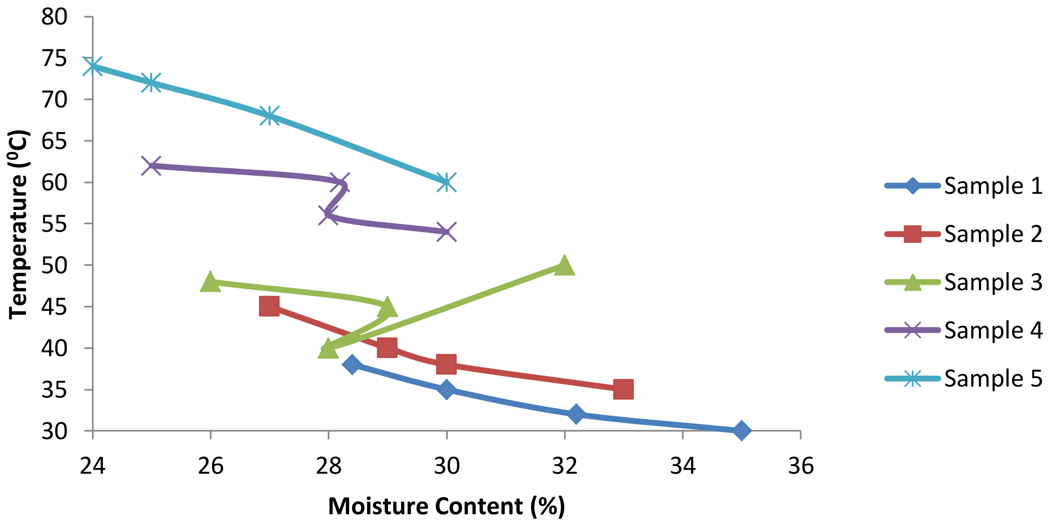

Figure 10 Effect of temperature on moisture content at 5 m/s

At velocity two (V_2) of 10 m/s, the air velocity was not also sufficient to move all the material fed through the dryer but work much better than the air velocity of 5 m/s. The moisture retention is also high at this velocity as a result of the insufficient air velocity (Table 2). As the temperature increases, the quality of dried materials through the cyclone increases. However, the left over clogged materials in the drying chamber was also removed when the cyclone was dismounted from the drying chamber.

Figure 11 shows that temperature variation had no significant effect on weight of the material was connected to the fact that some materials were not readily available for drying as it got stocked in the dryer.

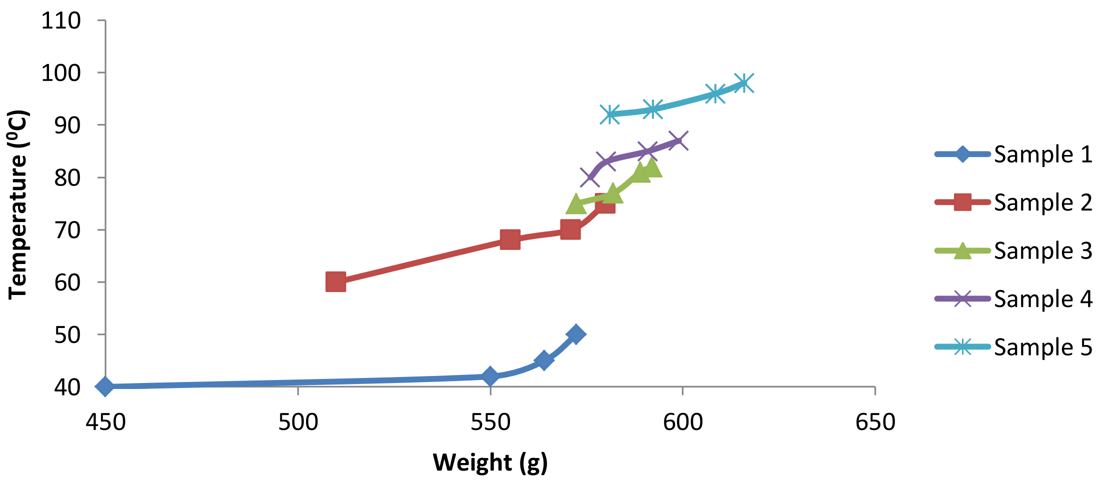

Figure 11 Effect of temperature on weight at 10 m/s

Figure 12 confirmed that although not all the materials went through, the temperature did have effect on the moisture content as it was reduced from 40% to 22% as the temperature increased from 70 ℃ to 110 ℃.

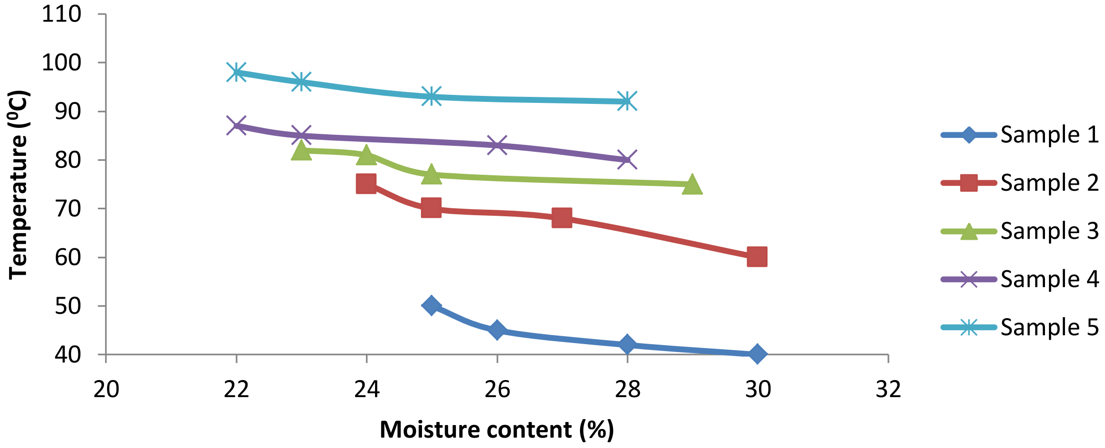

Figure 12 Effect of temperature on moisture content at 10 m/s

At velocity five (V_5) of 25 m/s, the material also had no sufficient time to dry Figure 13 and Figure 14. Though all materials fed into the machine went through the dryer fully. However, as the temperature increases, sign of burnt was visible. Air velocity of 25 m/s is too high and do not allow enough drying time and therefore the rate of drying is slow with evidence of burnt material which resulted in waste of materials as described in Table 5 and Figure 13 and Figure 14. Then, these velocities (5, 10, and 25) m/s and their corresponding temperatures are not appropriate for use in this dryer.

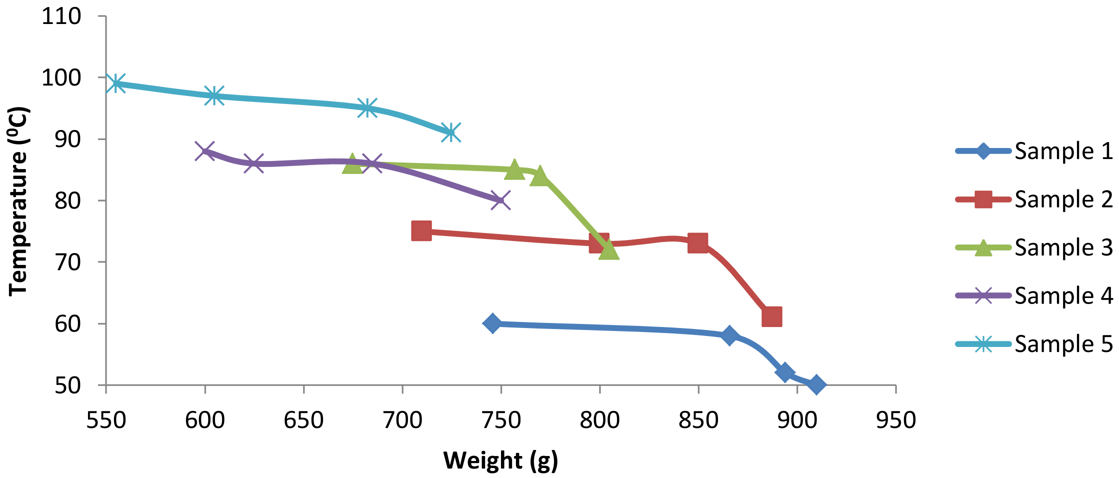

Figure 13 Effect of temperature on weight at 25 m/s

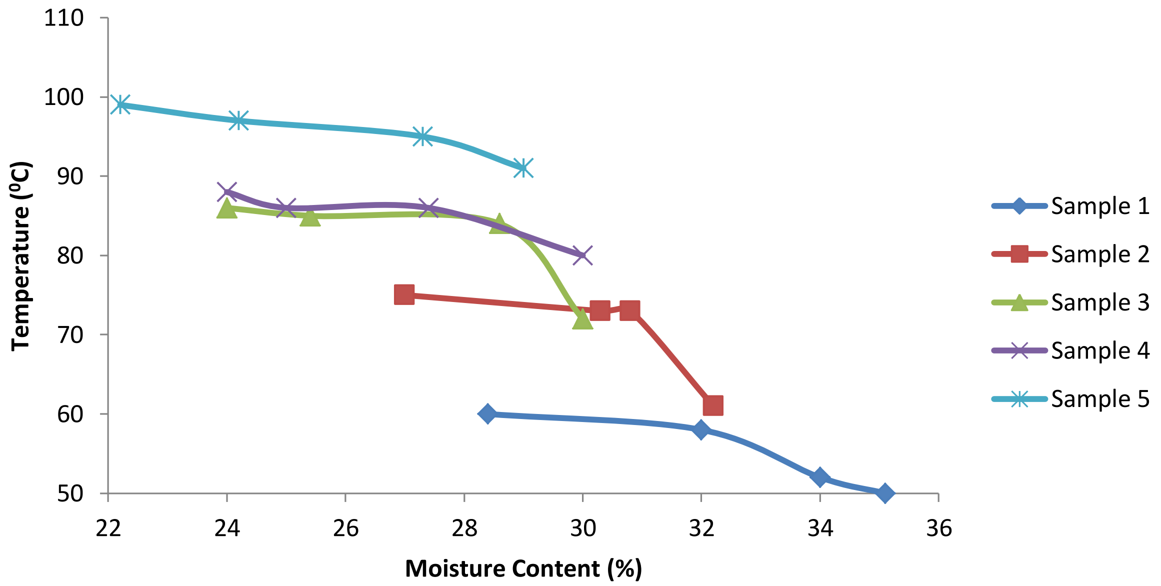

Figure 14 Effect of temperature on moisture content at 25 m/s

At air velocity three (V_3) of 15 m/s all the materials fed into the dryer were carried through the drying chamber (Table 3). Results obtained are displayed in Figure 15, Figure 16 and Figure 17.

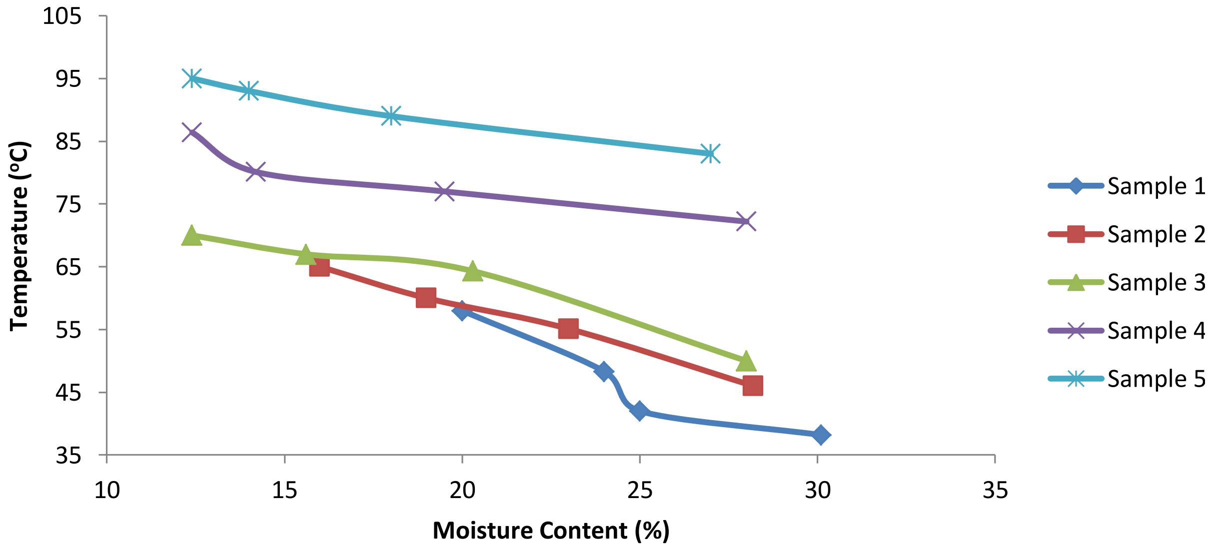

Figure 15 Effect of temperature on moisture content at 15 m/s

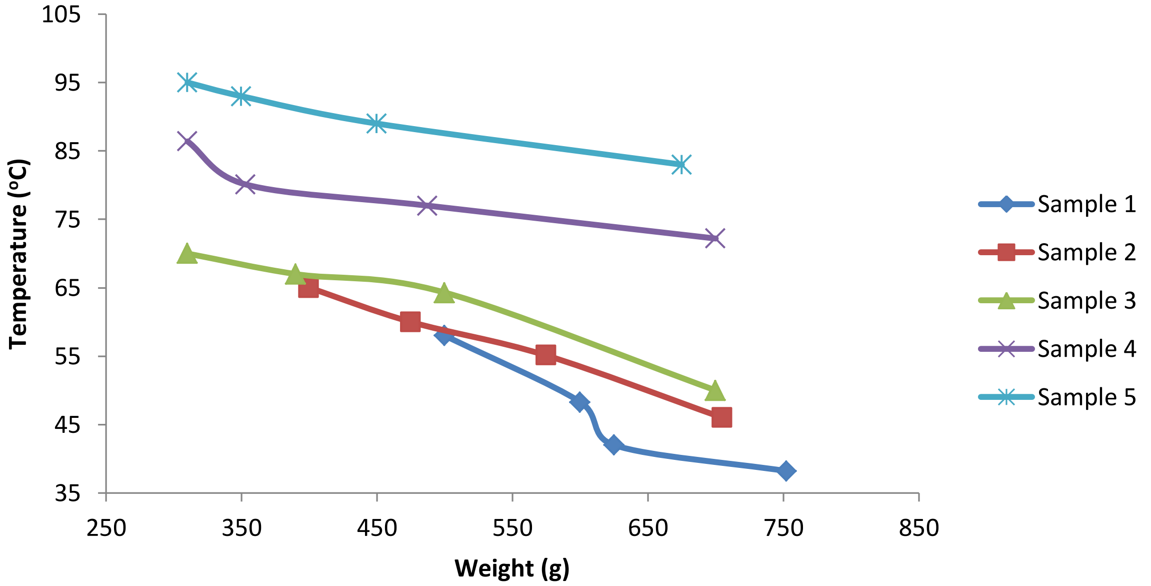

Figure 16 Effect of temperature on weight at 15 m/s

In Figure 15 and Figure 16 it was shown that temperature has significant effect on the weight of the materials being dried. As the temperature increases, weight decreases and more water was evaporated. This is in agreement with Rajput (2011) that in dryers, weight of material decreases with increase in temperature for such material received at the outlet. All the samples fed into the dryer confirmed this as the weight was reduced from 1000g to 310g in Sample 4 at a temperature of 90 ℃. The same weights were also obtained at temperatures 100 ℃ and 110 ℃ respectively.

Materials fed into the dryer came out well and dried, no clogging or burning of material. The moisture content of 12.4% that was obtained is good for storability of the product (Figure 15).

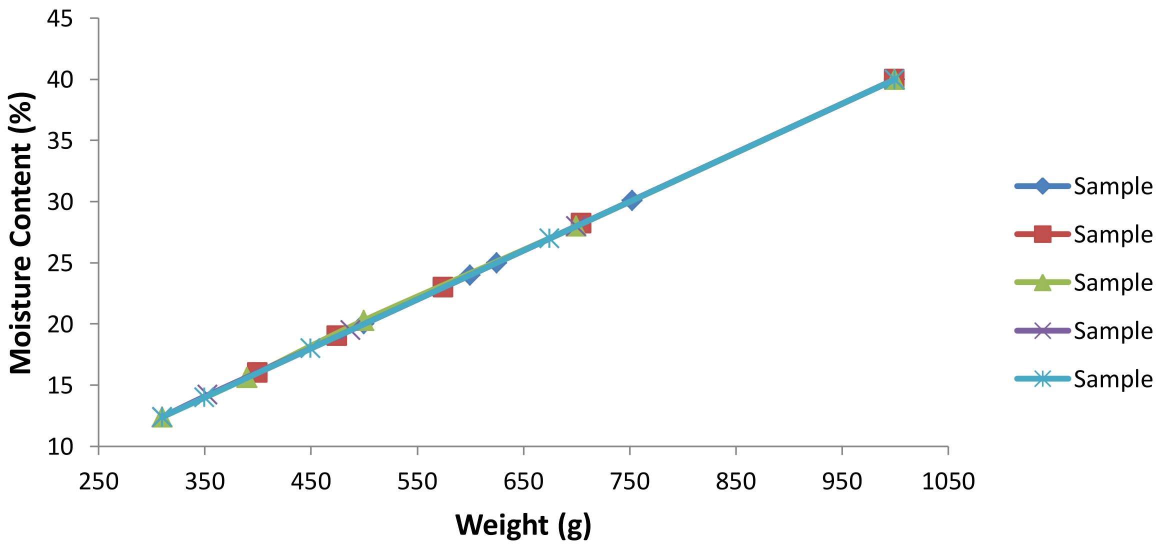

Figure 17 Effect of moisture content on weight at 15 m/s

At velocity four (V_4) of 20 m/s, the material fed into the dryer was carried through the drying chamber but in a faster rate than that of the 15 m/s. Variation in temperature had no sufficient effect on the material at the initial stage (Table 4). But as temperature increases from 100 ℃ to 110 ℃, the material begins to show sign of burnt.

It was shown in Figure 18 and Figure 19 that increase in temperature resulted in corresponding decrease in moisture content. However, because of the high air velocity, the effect of temperature on moisture content was not as effective as in 15 m/s.

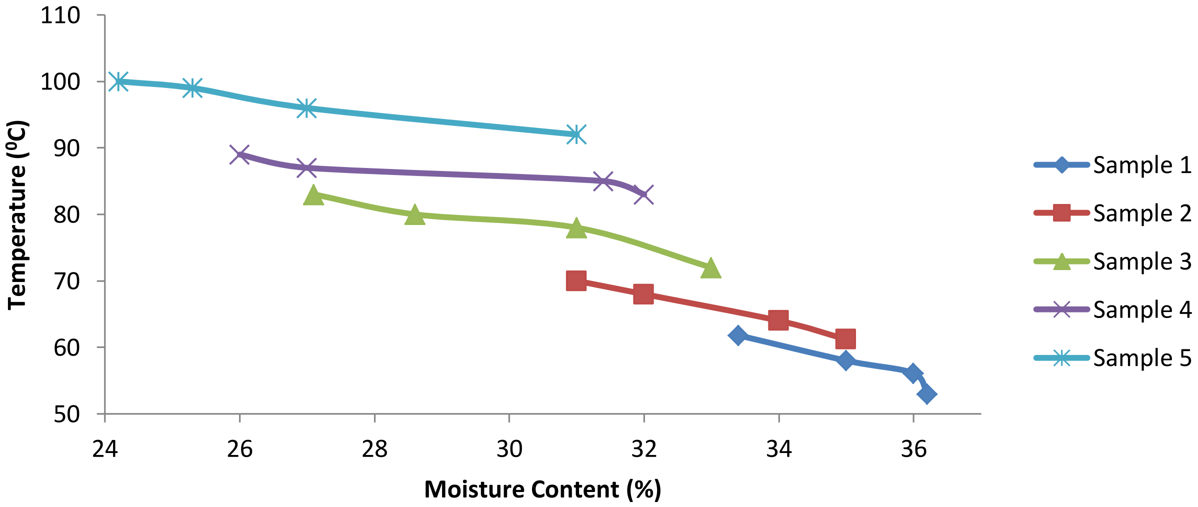

Figure 18 Effect of temperature on moisture content at 20 m/s

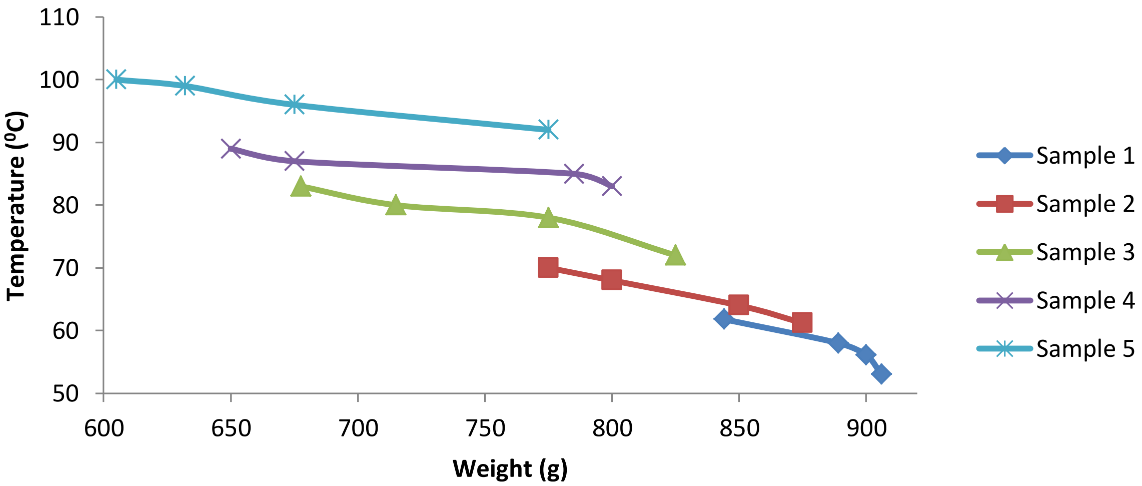

Figure 19 Effect of temperature on weight at 20 m/s

The effect of moisture content on weight is moderate (Figure 20). This attests to the fact that as weight was reduced from 1000g to 555g with corresponding moisture contents of 40% to 22.2%. If the material is exposed to heat for enough period of time, it has a significance effect on moisture content.

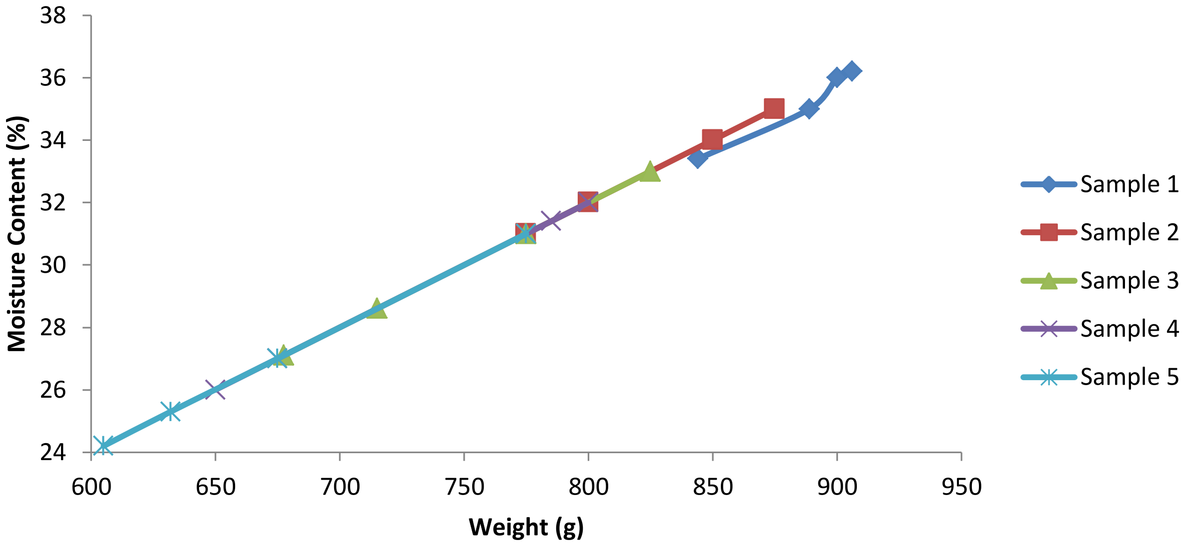

Figure 20 Effect of moisture content on weight at 20 m/s

The results displayed in Figure 9, Figure 11, Figure 13, Figure 16 and Figure 19 showed the effect of temperature on weight of the cassava mash. The least ambient temperature was recorded in the first sample (sample 1) in all the air velocities (5, 10, 15, 20 and 25 m/s). At air velocity of 5 m/s the temperature was between 30 ℃ and 35 ℃ (Figure 9). The temperature was between 40 ℃ and 50 ℃ was recorded at air velocity of 10 m/s (Figure 11). The trends displayed in Figure 9 and Figure 11 confirmed that the machine cannot work effectively at these air velocities because as the temperature increases also the weight of the cassava mesh produced increase. The linear relationship that was revealed between the temperature and the weight of the mesh negates the principle of drying. This result is due to the congestion in the machine formed as a result of the low air velocities which are not capable of moving the materials through the dryer and implies that at air velocities of 5 m/s and 10 m/s, not all the material fed into the dryer went through.

The same trends of temperature-weight relationship were recorded in Figure 13, Figure 16 and Figure 19. As the temperature of the cassava mash increased reasonable drops in weight were observed and recorded. This shows that the machine can perform better using any of the air velocities (15 and 20 m/s). At air velocity of 15 m/s and a temperature of 90 ℃ the first constant moisture content of 12.4% was obtained. A moisture content of 12.4% was also obtained at a temperature of 100 ℃ and 110 ℃ (Figure 15 and Figure 18). This has the advantages of reducing extra cost of power if the temperature was to be increased further. Also material fed into the dryer came out dried and fine, with no clogging of material and burning of material. The moisture content of 12.4% obtained is good for storability of the product as this is in the same trend with what was obtained by Ajao and Adegun (2009). They reported that cassava chip is stored well at moisture content of between 11.48% and 12%. However, since the moisture content of 12.4% was first obtained at 90 ℃, it means that the best operating air and temperature combinations for this dryer is air velocity of 15 m/s at 90 ℃.

The effect of temperature on moisture content showed a linear relationship as shown in Figure 15 and Figure 18. Increase in temperature resulted in corresponding decrease in moisture content. Figure 16 and Figure 19 showed the effect of temperature on weight and it could be deducted that increase in temperature resulted in decrease in weight. This agrees with the findings of Antekhai and Ozakhome (2005) who observed that a wet cassava chip exposed to heated air experiences progressive loss of weight due to removal of three forms of water; first is the free water, then the absorbed and finally the chemically bound water. Figure 17 and Figure 20 showed the influence of moisture content on the weight of product; it is shown that the increase in moisture content resulted in the increase in weight of the product.

The result showed that during drying of the cassava mash, there was reduction in the weight of the cassava mash, although the reduction in weight is not at a regular time interval. This could be attributed to the wind velocity which affects the drying rate and moisture removal. This statement agrees with Yayock and Coubin (1988). They reported that when drying with air, the main role of the air is to pick up the moisture from the surface of the product and this is further affected by its speed and amount of moisture it originally contains. Yayock and Coubin (1988) further reported that air serves as a medium in picking up moisture from the surface of cassava chip, hence, the free moisture is the one involve in the drying process. Drying becomes apparently difficult if all the free water in cassava have been removed. Because the moisture left in the product remains bound in it by hydration which has to be broken. It could be observed that there was a decrease in the free moisture contained in the cassava mash for the 15 m/s, 20 m/s, and 25 m/s respectively over the drying period. It was also observed that the central moisture loss for the 15 m/s air velocity remains the highest. The moisture loss for the 15 m/s was negligible after one hour whereas for 20 m/s and 25 m/s it took two hours. This is because the 15 m/s attains the constant period over a short period of two hours of drying followed by the falling rate period for the remaining periods. The observed difference in the two cases can be attributed to retention period in the drying chamber and therefore, the rate of moisture loss. From the result obtained during drying process it was observed that the higher the temperature the lower the moisture content and the higher the water evaporated. Also, the lower the weight, the lower the moisture content, and the higher the water evaporated. Furthermore, the higher the moisture content the higher the weight of produce, and the lower the water evaporated.

5 Conclusions

From the result obtained it can be deduced that:

- This dryer is very effective in drying cassava mash
- The dryer can be used to dry cassava produce to safe storage moisture content level
- This can be used to dry other similar agricultural products
- The dryer is relatively cheap and easy to use.
- The heating elements installed can generate enough heat to meet the heat requirement of the dryer.
- High moisture content mash cannot be dried in this dryer.
- The thermal efficiency of the dryer of 86%.

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