Experimental Evaluation of a Batch Hot Air Fluidized Bed Dryer

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Abstract: *The experimental evaluation of a batch hot air fluidized bed dryer for cassava particles is presented. The test rig of fluidized bed dryer consists of a vertical column 400mm diameter with a physical height of 2960mm, a regulated centrifugal blower powered by a 1.5 Hp electric motor, and an air heater with a thermostat for selection of drying temperature of the fluidizing medium. A bed of 1.555kg casssva particles were fluidized at three different air flow rates: 043 kg/s, 0.05 kg/s and 0.056 kg/s in succession. The drying temperatures considered are at an interval of 20 ^{o}C. The minimum drying temperature is 60 ^{o}C and the maximum temperature of160 ^{o}C. The resident drying time for cassava particles in the dryer was found to decrease with increase in drying temperature. The heat source for drying came solely from the heated fluidizing air. It was also observed that the drying rate decreases with increase in air flow rate while it increases with drying temperature.*

Keywords: *fluidized; cassava, experimental, hot, air, drying*

I. INTRODUCTION

Fluidization is the phenomenon of the solid-fluid contacting process in which a bed of solid particles is lifted and agitated by a rising stream of process fluid, thereby making the bed of solid particles behaves like fluid [1]. Drying is generally defined as the removals of volatile subsatnces (a liquid) by means of heat from a material (mixture of substances) to yield a solid product. It is a fundamental unit operation in the chemical processing industries and it features prominently also in the food processing and mineral processing industries. Often, though not exclusively, the principal volatile substance is water. Principally, drying is essential to preserve the product from damage during storage i.e to prolong storage life. High moisture level and warm temperatures promote mould growth, insect growth and increase the respiration rate of the product. The products with high moisture percentage at the time of storage are liable to attack by fungal growth and toxic materials, which are harmful to human health [2].

The drying application of fluidization technique to a wide variety of particulate materials in industry dated as far back as 1940s according to Reay [3]. Currently, it is becoming popular for drying crushed minerals, sand, polymers, fertilizers, pharmaceuticals, crystalline materials and many other industrial and agricultural products. Fluidized drying among others has the advantage of high intensity of drying and high thermal efficiency with uniform and closely controllable temperature in the bed promoted by intensive solid mixing due to the presence of bubbles. It requires less drying time due to high rates of heat and mass transfer. The efficient gas-solid contact leads to compact unit and relatively low capital cost. Since there is no moving parts other than feeding and discharge mechanisms, except in the case of vibrating fluid bed, reliability is high and maintenance cost is low.

Cassava is known to contain cyanogenic glycosides (linamarin and lotaustralin) liable to produce hydrocyanic acid [4] which is poisonous. It was reported in literature that sun drying does eliminate a large proportion of the hydrocyanic acid [5]. This makes drying of cassava particles inevitable and significant

The report of Monroy-Rivera et al [6], shows that drying by heated air is more efficient at eliminating hydrocyanic acid. This makes the adoption of fluidization technique that is the direct contact of hot air with cassava particulate in a fluidized state a challenge that would solve perennial local problem associated with gari production. The technique enhances high intensity of heat and mass transfer. The good mixing of the particles in a fluid bed also enhances uniform frying within a short residence time.

A lot of experimental works had been done on the application of fluidized bed for various utilities including. Romamkov [7] according to Hoebink and Rietema [8] proposed design procedures for fluidized bed dryer based on the total heat and mass balance of the whole apparatus. Prasad et.al [9] designed and fabricated a sample laboratory dryer capable of having stationary, semi-fluidized and fluidized drying conditions in a single unit. Drying experiments were conducted for parboiled rough rice with 10, 15, and 20 cm initial bed thickness at 40 to 80 degree Celsius of drying air for each three drying conditions. They observed that parboiled rough rice could be dried under semi-fluidized conditions without any significant milling loss and that drying time would also be largely reduced as compared to stationary- bed conditions. Grabowski et al. [10] developed a special drying method, using a laboratory scale fluidized bed dryer to reduce browning of grapes during drying. Fresh Thompson seedless grapes were initially dried by immersion in a fluidized bed of sugar. The flow rate of hot air at 45-60 degree Celsius was used to fluidized the sugar bed. Due to the simultaneous osmotic and convection drying effects, the drying time was reduced by factor of approximate 1.5 as compared to drying under a similar condition without added sugar. The major problem associated with the osmo-convective drying of grapes on a sugar bed was the stickiness, caused by sugar, on the fruit surface. This was reduced by partially substituting sugar with semolina to create fluidized bed.

Soponronnarit et al [11] conducted a feasibility study of paddy drying by fluidization technique. Operating parameters affecting product quality, drying capacity and energy consumption were investigated. Experimental results showed that drying rate of a paddy kernel was controlled by diffusion. However, drying capacity of dryer increased with specific air flow rates and drying air temperatures. Energy consumption was reduced when specific air flow rate decreased or when fraction of recycled air increased. Maximum temperature should be limited to 115 degree Celsius and final moisture content of paddy at 24-25% dry basis if product qualities were maintained.

Soponronnarit et al [12] carried out a batch fluidized bed dryer design for corn drying. Drying characteristics of corn were investigated. The experimental results indicated that moisture transfer inside a corn kernel was controlled by internal diffusion by the following condition: inlet hot air temperatures of 120-200 degree C, superficial air velocities of 2.2-4 m/s, bed depths of 4-12 cm, fraction of air recycled of 0.5 – 0.9 and initial moisture content of corn of 43% dry-basis.

In this work, the performance evaluation of a batch hot air fluidized bed dryer for drying cassava particulates was carried out at various drying temperatures. The technique of fluidization was adopted following the work of Geldart [13] and Ogunleye [14] that classified cassava particles diameter within the range of 40μ m and 500μm particles, which fluidized easily.

II. MATERIALS AND METHODS

The experimental test rig for the bach fluidized bed drying operation is shown in Figure 1. A drying temperature and flow rate were selected using the temperature and flow rate controllers. After a steady drying bed temperature was attained by monitoring with a chrome-alumunium thermocouple type K, a known mass of cassava particulates were introduced into the bed. The drying process started while the temperatures in the middle and along the height of the dryer column were monitored. Periodically, about 60g of the sample were withdrawn from the dryer and the percentage moisture content of the particles was tested with the aid of a moisture meter. The results obtained as the cassava particles made contact with the stream of hot air within a drying time of less than 60minutes are presented and discussed below.

Figure 1: Experimental set up of fluidized bed dryer model plant

III. RESULTS AND DISCUSSION

Particle and Air Temperature

As the cassava particles were introduced into the dryer, on contact with hot air from the inlet to the dryer, the temperature of the cassava particles gradually increased from room temperature to the drying temperature setting while at the same time their moisture content reduced gradually during the drying. Particle temperature versus drying time at 120^{o}C drying temperature at various flow rates is shown in Figure 2. The particle temperature increases faster at a lower flow rate of the fluidizing air medium.

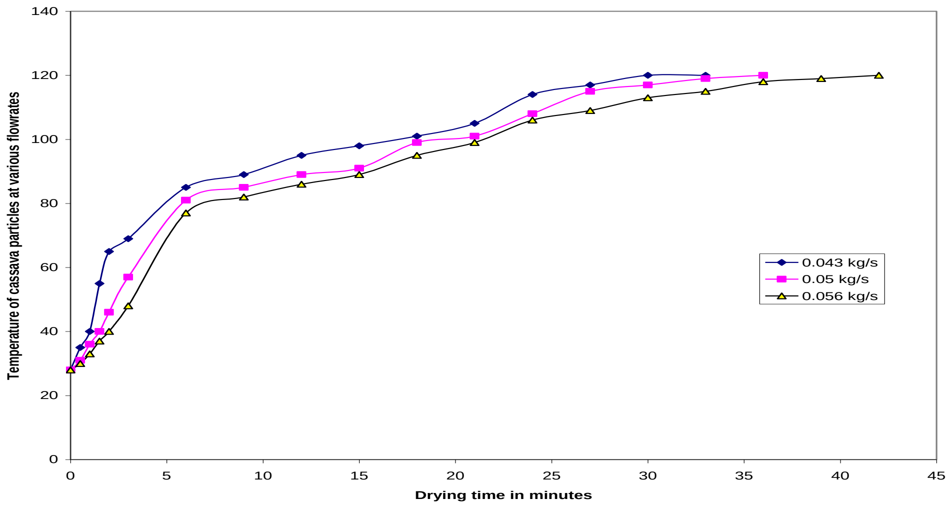

Figure 2: Cassava Particles' temperatures at various air flowrates for a given drying temperature of 120^{o}C

As the hot air made contact with the wet cassava particles, the air temperature dropped sharply and then gradually increased towards the drying temperature setting as shown in Figure 3. It was observed that the air flow at the highest rate took shorter time to attain the temperature setting.

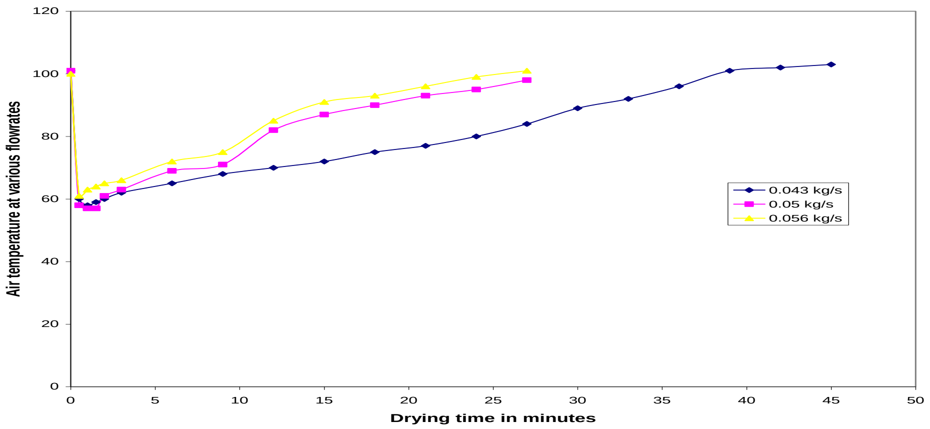

Figure 3: Typical temperature variation of the fluidizing medium after feeding at 120^{o}C and at various flowrates

Moisture ratios versus time

The moisture ratio of the cassava particles versus drying time at various drying temperature is shown in Figure 4a. A typical moisture ratio and the cassava particle temperature at 120^{o}C and at air flowrate of 0.043 kg/s is shown in Figure 4b. At drying temperatures of 60^{o}C and 80^{o}C, the moisture ratios versus times curves are straight lines, indicating that within the drying time considered at these temperatures, the falling rate of drying was not attained. There is not enough heat to remove bound moisture content of the cassava particles. But at temperatures of 100 ^{o}C to 160^{o}C for the same drying time interval, the removal of bound moisture content of the cassava particles is appreciable and sufficient drying actually take place. Figure 4b shows a typical particle temperature rise and the moisture ratio versus drying time for an isothermal heating temperature of 120^{o}C. The three distinct phases of drying processes are clearly seen on the typical heating temperature of 120^{o}C shown and the corresponding moisture ratio with drying times. The diffusion model constant parameters at various drying temperatures are shown in Table I. A moisture ratio curve at a typical drying temperature of 120^{o}C for various flow rates is shown in Figure 5. Table II shows their diffusion model constant parameters. The increase in flow rate of air produces less drying effect because in this experiment, the air flow is the only carrier of heat into the bed. The higher the flow rate of air the lesser the energy it carries into the bed for drying. In a situation where heat for drying is supplied through other means other than the air medium, increase in airflow rate will enhance the drying rate.

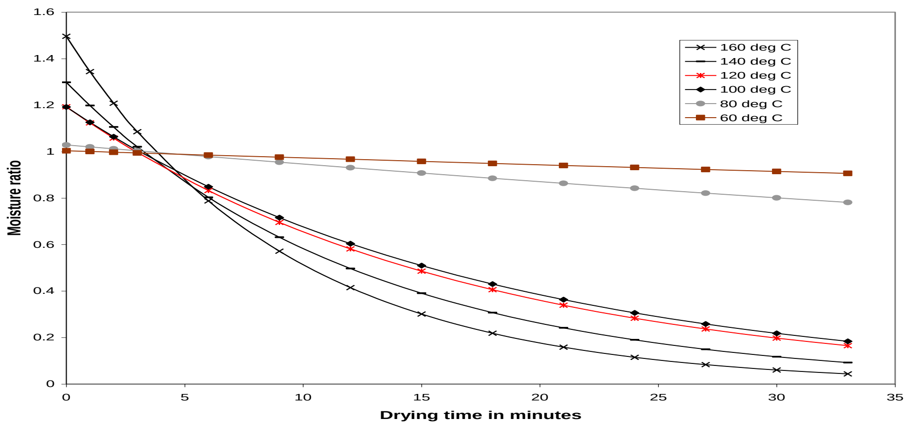

Figure 4a: Moisture ratios versus drying time at various drying temperatures indicated for air flowrate of 0.43 kg/s

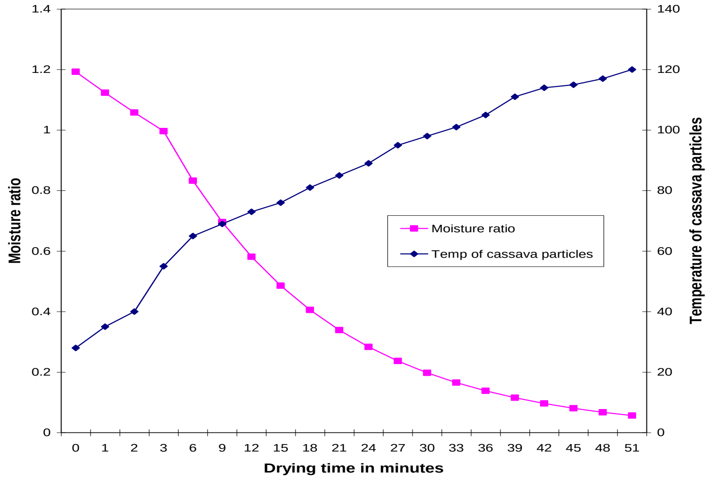

Figure 4b: Typical moisture ratio and particle temperature rise versus drying time at 120°C

Table I: Diffusion Model Constants for fluidized bed drying at different drying temperatures and at 0.043 kg/s obtained from regression analysis

	Drying Temperature °C					
Diffusion Constants	60	80	100	120	140	160
K_0	-0.00624	-0.0157	-0.05421	-0.0582	-0.07803	-0.10688
B_0	1.02798	1.08783	1.15769	1.17694	1.2778	1.496
Coefficient of R	-0.84177	-0.84742	-0.97752	-0.97351	-0.97506	-0.95888

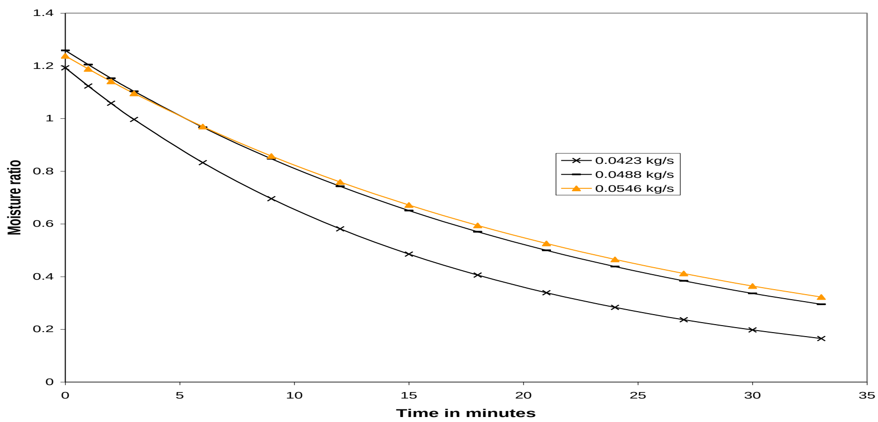

Figure 5: Moisture ratio versus time at various flow rate for a typical drying temperatures of 120°C

Table II: Diffusion Model Constants for fluidized bed drying at isothermal temperatureof 120°C for various air flowrate obtained from regression analysis

Diffusion Constants	Drying Temperature 120°C		
	0.043 kg/s	0.05 kg/s	0.056 kg/s
K_0	-0.0599	-0.04397	-0.040763
B_0	1.192897	1.258697	1.23805
Coefficient of Correlationr	-0.96968	-092227	-0.919349

Drying rate versus free moisture content

The drying rate versus free moisture curve at 0.043kg/s flow rate of hot air, the fluidizing medium and at various drying temperatures is shown in Figure 6. At drying temperatures of 60°C and 80°C, the falling rate period is not reached within the drying period considered. Both constant drying rate and falling drying rate periods are present for drying temperatures 100°C to 160°C. The higher the drying temperatures, the greater the drying rates of the cassava particles. The critical free moisture content, critical drying rate and constant drying rate are found to increase with increase in drying temperatures as shown in Table III. At a typical drying temperature, the drying rates versus free moistures decreased with increase in flow rates of fluidizing medium as shown in Figure 7. In Table IV, the critical free moisture content, critical drying rate and constant drying rate at various flow rates are shown. The higher the air flow rate, lesser the heat is available for drying in the bed.

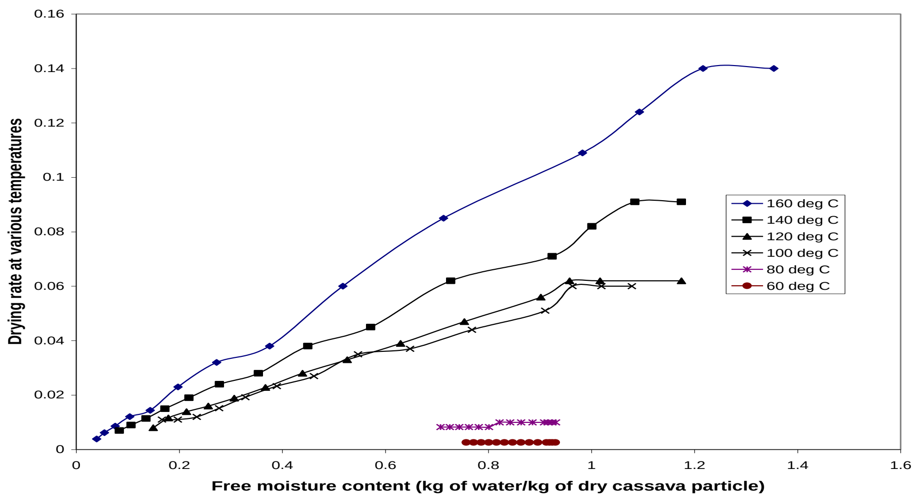

Figure 6: Drying rates of cassava particles with free moisture content at various drying temperatures at air flowrate of 0.043kg/s

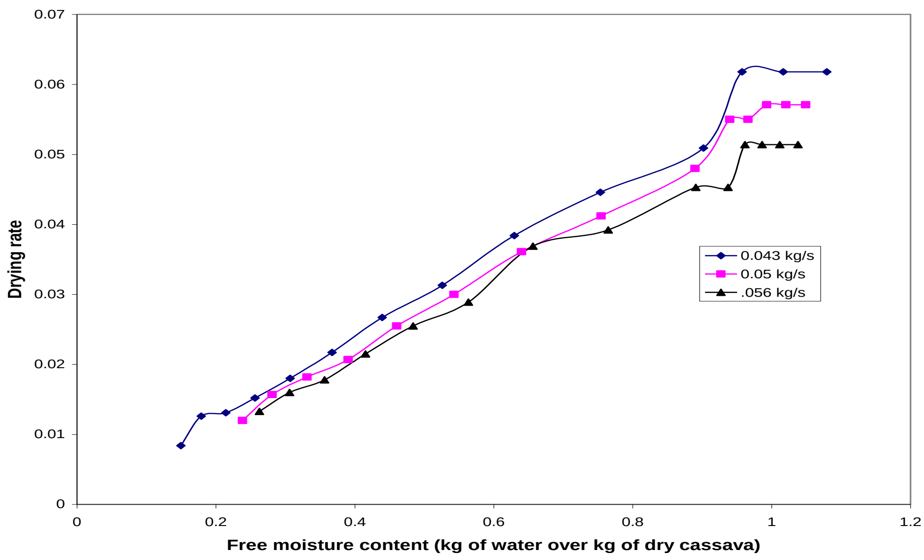

Figure 7: Drying rate of cassava particle at various flowrate for a typical drying temperature of 120°C

Table III: Critical free moisture content and drying rate at various fluidized bed drying temperatures

	Drying temperatures					
	60°C	80 °C	100 °C	120 °C	140 °C	160 °C
Critical free moisture Xc	.757021	0.801209	0.900346	0.901806	1.00091	1.09327
Critical drying rate Rc	0.0026	0.00824	0.051	0.056	0.082	0.124
Constant drying rate	.0026	0.01	.06	.062	.091	0.14

Table IV: Critical free moisture content and drying rate for fluidized bed drying at various air flowrate and at 120 °C

	Air flow rates		
	0.043kg/s	0.05kg/s	0.056kg/s
Critical free moisture Xc	0.957475	0.939879	0.890933
Critical drying rate Rc	0.056	0.055	0.0453

Comparison of oven and fluidized bed drying methods

The moisture ratio of cassava particulates at various drying time for a typical drying temperature of 120°C using oven and fluidized bed drying methods is shown in Figure 8. At a given time, the moisture ratio of the cassava particulate during fluidized drying is greater than that of oven drying sample. This is because the drying rate of cassava sample is greater in oven drying method than that of the fluidized method as shown in Figure 9. This is expected because 60 g of the cassava sample was used for oven drying analysis while 1.555kg of cassava sample was dried using a fluidized bed from which samples were taken at equal time interval for analysis.

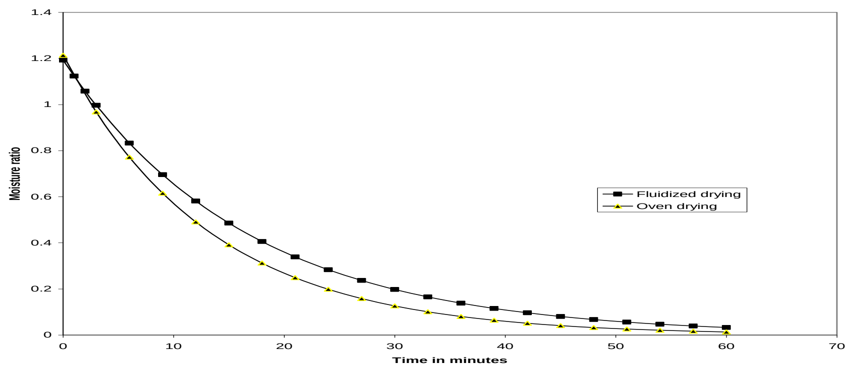

Figure 8: Moisture ratio of cassava particles versus drying time using fluidized bed and oven drying methods at 120°C typical drying temperature

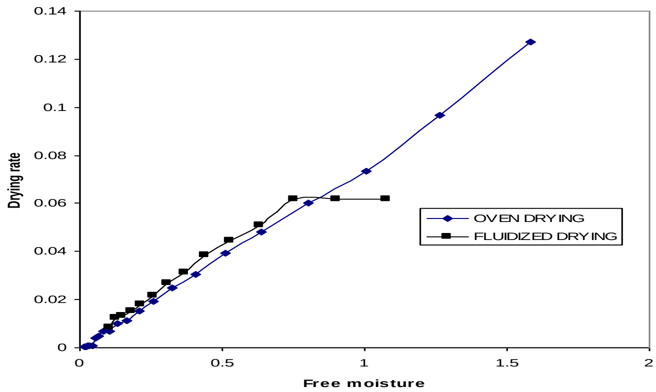

Figure 9: Drying rate of cassava particulates using fluidized bed and oven drying methods at typical drying temperature of 120°C

IV. CONCLUSION

The technique of fluidized bed drying for cassava particles is workable and viable. The product from the fluidized bed dryer is fine and uniformly dried. To ensure the product is hygienic for eating with reduced starch content, the dryer must be covered after the product is introduced for about 20 minuted depending on the drying temperature. A lower air flow rate is required at the initial stage when the product is undergoing a constant drying period. Beyond the constant drying period, the air flow rate must be increased to ensure particle mixing and to prevent localized heating of the cassava particles. This work so far has opened up an alternative technology for the production of gari from cassava particles. The design and the operation methods is simple and can be developed and mass produced to boast food production.

V. ACKNOWLEDGEMENT

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