The International Journal Of Engineering And Science (IJES)
||Volume||2 ||Issue|| 6 ||Pages|| 45-53||2013||
ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805

Experimental Evaluation of A Fluidized Bed Dryer Performance

[1]OKORONKWO C.A, [2]NWUFO, O.C, [3]NWAIGWE K.N, [4]OGUEKE N.V, AND [5]ANYANWU E.E
[1,2,3,4,5,]Department Of Mechanical Engineering,Federal University Of Technology,Owerri,Imo State, NIGERIA.

ABSTRACT

Results of an experimental study on the drying characteristics of fluidized bed dryer are presented. The experimental rig comprises of the air blower, heater, drying chamber and chimney. The materials used in the drying study were; cassava, yam and maize. The drying experiments were carried out according to the following parameters: initial moisture content of the material (High and Low), drying time and various optimum temperatures. The results obtained show that it took a total of 150minutes with an optimum temperature of 60^oC to reduce the moisture content of the cassava and yam from 75.4%(w.b) to the equilibrium moisture content of 11% which is suitable for storage and preservation while maintaining the external conditions. While the optimum temperature that gives faster drying time for maize was 40^0C. Similarly, a preliminary sun drying experiment was carried out to ascertain the drying time of the cassava and yam chips. It was observed that in the case of sun drying of cassava, it takes a total of 72hrs with an average ambient temperature of 30^oC to reduce the moisture content from 75.4 % (w.b) to the equilibrium moisture content of 11 % (w.b). Similarly, the effect of temperature at 30^0C on the drying curves for the maize shows that the value of the constant rate period of the experiment was smaller than the value obtained at the temperatures of 35^0C and 40^0C respectively. The drying rate of products below their optimal temperature was affected by the lower rate of moisture removal and the equilibrium moisture content by mass was high. While drying at temperatures above the optimum temperature, ultimately may cause the thermal degradation of the products been dried. This could be in form of physical defects, such as, decoration, cracking, shrinking and non-uniform drying. From the drying kinetic curves and visual observations during the experiments, it could be concluded that the fluidized bed dryer is an alternative for the processing of cohesive solids that preserve the final quality of the dry solids.

KEYWORDS: *drying, optimum temperature, fluidized*

Date of Submission: 09 May 2013, Date of Publication: 18.June.2013

I. INTRODUCTION

Generally, drying may be referred to as a process of removing relatively small amounts of water, or other liquid from a solid material in order to reduce the content of residual liquid to an acceptable value. The main purpose of drying farm products is to reduce its water level from the harvest level to the safe storage level in order to extend its shelf life. Once the products have been dried, its rate of deterioration due to perspiration, insect infestation, microbial activities and biochemical reactions should diminish leading to maintenance of the quality of the stored product [1].The evaluation of the drying process requires knowledge of a number of parameters of drying techniques, such as the characteristics of the material, optimum drying temperature, the coefficient of conductivity and transfer, and the characteristics of shrinkage. In most cases these parameters cannot be evaluated using analytical method hence the use of experimental procedure is much preferred. Such parameters as global conductivity and transfer coefficients, which reflect the total effect on the partial processes, are frequently interpreted as experimental parameters.[2, 3]

II. CONCEPT OF FLUIDIZATION

Fluidization is chiefly an expanded condition in which the solid particles are supported by drag forces caused by the gas phase passing through the interstices among the particles at some critical velocity. It is an unstable condition in that the superficial gas velocity upward is less than the terminal settling velocity of the solid particles. The gas velocity is not sufficient enough to entrain and convey continuously all the solids [4]. When a group of particles is described as being fluidized, it is said that they are suspended through the drag caused by the upward flow of a fluid. As the upward flow of fluid in a packed bed of solids is increased, the pressure drop increases proportionally. At certain velocity, the force of drag on the particles is sufficient to counteract the force of gravity. Beyond this velocity, resistance to the flow is at a maximum and the bed pressure drop becomes constant with an increasing flow. This velocity is denoted as the minimum fluidization velocity and is a fundamental parameter used to characterize fluidization behavior [5]. The use of a fluidized bed dryer for drying farm products is widely known and accepted, and literally thousands of fluidized bed dryers are operating throughout the food and chemical processing industries. In contrast with this industrial development, the fundamental research on fluidized bed dryer has not made similar progress and the design of an industrial fluid bed dryer is still very much an art based on empirical knowledge.

III. STAGES OF FLUIDIZATION

Gas flow through the column from the blower to the drying chamber is characterized with increased gas flow as fixed bed, delayed bubbling, bubbling fluidization, slugging fluidization, turbulent fluidization, and fast fluidization and dilutes pneumatic conveying regimes as shown in fig 1. The transition from fixed bed to fluidization is delineated by the minimum fluidization velocity U_{mf}, which correspond to the lowest gas velocity at which all bed particles are suspended by the gas [7].

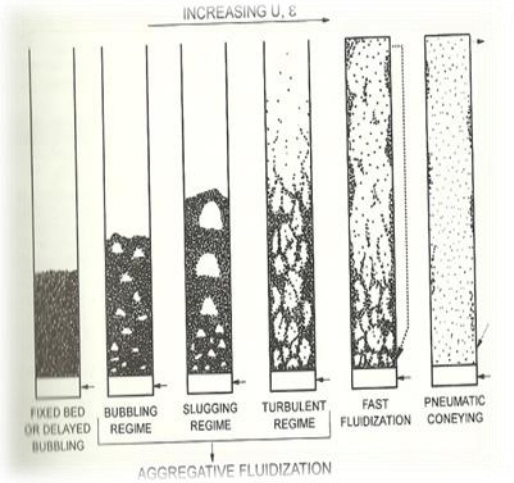

Fig 1flow pattern in gas –solids fluidized beds [6]

The value of U_{mf} is obtained experimentally by determining the level of pressure drop across the bed as the superficial gas velocity in the fixed bed regimes increases. Several relationships for the evaluation of the minimum fluidization velocity have been developed. Examples include the relationship developed by Linoya et al., [7]. This equation is shown below in equation 1as:

$$Umf = \eta gas \frac{(\beta_{E1}^2 + \beta_{E2}.Ar)^{\frac{1}{2}} - \beta_{E1}}{\rho_{gas} d_p} \ldots\ldots\ldots\ldots (1)$$

Where η_{gas} is the gas velocity,ρ is the gas density, dp the diameter of particles and β_{E1} and β_{E2} are the Ergun parameters depending on the particles sphericity and bed void age at incipient fluidization. Ar is the Archimedes number defined as:

$$Ar = \frac{\rho_{gas} d_p^3 (\rho_p - \rho_{gas}) g}{\eta_{gas}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where ρ_p the particle density and g is is the gravity. According to Teunou and Poncelet [8], the Ergun expression can be approximated when the particle's diameter exceeds 100µm. in that case, Umf becomes:

$$Umf = \frac{\eta_{gas}\left\{(1135.7 - 0.04084 A_r)^{\frac{1}{2}} - 33.7)\right\}}{\rho_{gas} d_p} \quad , dp > 100\mu m \ldots\ldots\ldots\ldots (3)$$

The onset of bubbling is indicated by the minimum bubbling velocity, U_{mb}. The minimum bubbling velocity strongly depends on the particles properties being dried. This velocity is usually greater than the U_{mf} for fine particles[7] .In this case, a bubble free fluidization regime between U_{mf} and U_{mb} thus exist for particles with fine aggregates where due to their size, an inter-particle forces plays a significant role. For a fine particle solid, Geldart and Abrahamsen [9] gave a relationship for U_{mb}as:

$$U_{mb} = 33dp \left(\frac{\rho gas}{\mu g}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

For particles with larger diameter, experimental results have shown that U_{mb} is usually less than U_{mf}. When the superficial gas increases further, gas bubbles become larger and slugging is said to occur when the bubbles grow larger to size comparable to the column diameter. The minimum slugging velocity U_{ms} can be estimated by an equation given by Stewart and Davidson [10] as

$$U_{ms} = U_{mf} + 0.07\sqrt{gD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5)$$

However this equation is applicable for beds with dimension $H/D > 1$.

The turbulent and fast fluidization regimes are considered to be high velocity fluidization regimes. Two different definitions are used to distinguish between the bubbling regime and the turbulent regime. The first defines U_c, the superficial gas velocity at which the standard deviation of the pressure fluctuations reaches a maximum. At the onset of turbulent regime, [10] U_c is believed to reflect the condition at which bubbles coalescences and break up reach a dynamic balance. The second definition indicates a transition from bubbling to turbulent fluidization based on U_k , a superficial velocity at which the root mean square standard deviation of pressure fluctuation begins to level off with increasing U. The implication of the above is that the bubbles coalescence and breaking up is stabilized.

The transition from the turbulent to fast fluidization is said to occur at the transport or settling velocity U_t, where a significant number of particles are carried out from the top of the column. The settling velocity is the air velocity over which transportation by dragging or pneumatic conveying occurs. At this stage, a sudden change of pressure drop with increasing solids flow rate disappears when the superficial gas velocity exceeds U_{tr}. The transition from fast fluidization to pneumatic conveying is characterized by the disappearance of a dense –phase region and large amplitude pressure fluctuation in the bottom sector of the riser as shown in fig 2. [10]. The settling velocity Ut for non-spherical particles can be evaluated using the equ6 as suggested by Kunii and Levenspei [11] as:

$$Ut = \frac{U_t^{*}\left\{\eta_{gas}\left(\rho_p - \rho_{gas}\right)g\right\}^{1/3}}{\rho_{gas}^{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where U_t^{*} is the dimensionless terminal velocity approximated by Kunii and Levenspei [11] as

$$U_t^{*} = \left\{\frac{18}{d_p^{*2}} + \frac{2.335 - 1.744.\emptyset}{d_p^{*0.5}}\right\}^{-1}, 0.5 < \emptyset < 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$\emptyset$ is the shape factor, which accounts for non-spherical particle shape, it is also known as the particle sphericity and dp is the dimensionless particle diameter .it is pertinent to note that besides the gas particle ,it is the size and density of the particles that determines the fluidization velocity needed to obtain a homogeneous fluidized bed. The larger and denser the particle are, the higher the fluidization velocity must be to keep the particle fluidized, Guignon et al [12].

IV. SYSTEM DESCRIPTION

The fluidized bed dryer system used is shown in the fig 2 below. It comprises the blower with air discharge capability between 0 – 130m^3/mm of air flow, two heating band, a drying chamber and a vent at the top of the chamber. The properties of the air flowing around the drying product are a major factor in determining the rate of removal of moisture. The capacity of air to remove moisture is principally dependent on its initial temperature and humidity, the greater the temperature and lower the humidity, the greater the moisture removal capacity of the air.

The air from the blower passes through the heater which in conjunction forms hot air. The changes in air conditions when air is heated and passed through a bed of moist products, produces a drying process.As air moves through the grain bed, it absorbs moisture under adiabatic drying; sensible heat in the air is converted to latent heat. The absorption of moisture by air would be the difference between the absolute humidity's at each point.

When a gas is passed upwards through the material as shown in the fig 2, the gas will at low flow rates merely enters through the fixed bed of the particles. As the gas velocity increases, the pressure drop across the particle layer will increase in proportion to the gas velocity until the pressure drop reaches the equivalent of the weight of the particles in the bed divided by the area of the bed. At this point, all particles are suspended in the upward flowing gas and the frictional force between particles and gas counter balances the weight of the particles. The layer of particles is now said to be incipiently fluidized, although the homogenous particle layer behaves like a liquid, only moderate particle mixing takes place. When the gas velocity is increased further above U_{mf}, the gas velocity for incipient fluidization, any additional fluidization gas will pass through the particle layer as bubbles. The gas bubbles will be small at the gas distributor, however they coalesce rapidly and rise through the particle layer, causing vigorous mixing of the fluidized particles. At still higher gas velocities, a point is reached at which the drag forces are increased to a degree that the particles becomes entrained within the gas stream and are carried from the fluid bed.

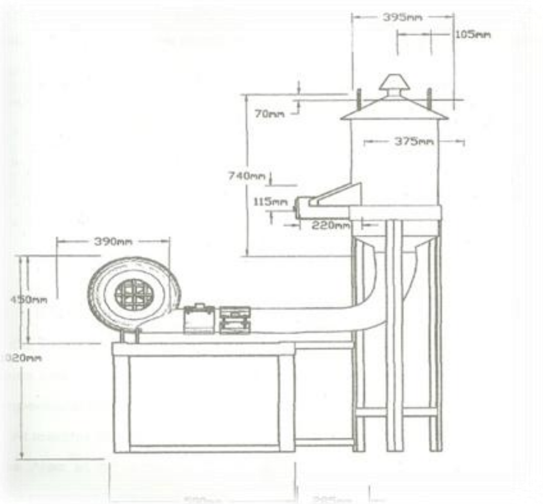

Fig 2 Fluidized Bed Dryer system used

4.1.THEORETICAL ANALYSIS OF DRYING

Energy Required For Drying

In drying, the total amount of heat required is a summation of the heat energy needed to:
To preheat the dry matter and moisture;
Remove moisture from wet materials;
Compensate for the heat loss to the environment.
The energy needed in removing the moisture from the wet material depends on the drying potential of the heated air and is expressed as:

$$\mathrm{Ea.} = \frac{\mathrm{dm}}{\mathrm{dt}} \mathrm{Lt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (8)$$

When the heated air supplies the energy required for the evaporation of moisture, the enthalpy balance is given as [4]:

$$\frac{dm}{dt} L = \dot{m} Cp (Tin - Tout) \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

By combining eqns3 and 4, the energy needed for the drying becomes:

$$Ea = \dot{m} Cp \, (Tin - Tout)\, t \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (10)$$

Rate of mass transfer

The rate of mass transfer from the surface of the drying materials is equals to the rate of heat transfer to the material when the temperature of the drying surface remains constant.
The rate of mass transfer can thus be expressed as:

$$\frac{dw}{dt} = hpA\,(Ps - Pa) \ldots\ldots\ldots\ldots\ldots\ldots. (11)$$

Where $\frac{dw}{dt}$ is the drying rate.
Eqn (6) could also be written as:

$$\frac{dw}{dt} = hpA\ (Hs - Ha) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (12)$$

Similarly, the rate of heat transfer to the surface may also be expressed as

$$\frac{dQ}{dt} = \mathrm{hcA}\,(\theta a - \theta s) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (13)$$

For convective heating only$\theta_a$is the wet bulb temperature of air.
Since a state of equilibrium exists between the rate of heat transfer to the body and the rate of mass transfer from it, these rates may be related as follows:-

$$\left[\frac{dw}{dt}\right] \mathrm{cL} = \left[\frac{-dQ}{dt}\right] \mathrm{c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

By substituting the value of $\frac{dQ}{dt}$into equ (8), we have

$$\left[\frac{dw}{dt}\right]c = \frac{\mathrm{hc}\ A\ (\theta a - \theta s)}{\mathrm{L}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots .(15)$$

L is the latent heat of evaporation

4.2.Rate of Water /Moisture Removal

The estimation of the amount of water to be removed from the solid material is obtained using the expression below

$$X = w\left(\frac{M1 - M2}{100 - M2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

The initial moistureM_1 and M_2 were obtained by direct measurement in the laboratory.

Fluidized bed Dryer Efficiency

The potential for using fluidized bed dryers is strongly dependent on an efficient use of energy. In this section, the energy efficiency method based on the first law of thermodynamics will be employed to determine the efficiency of the fluidized bed dryer.Energy efficiency of the dryer column based on the first law of thermodynamics can be derived by using the energy balance equation. The thermal efficiency of the drying process can be defined as

$$\eta_{th} = \frac{\text{Energy Transmitted to the Solid}}{\text{Energy incoporated in the Drying Air}} \qquad (17)$$

Thermal efficiency can be expressed in terms of energy efficiency using the energy rate balance equation as

$$\eta_e = \frac{W_d\{h_{fg}\,(M_{p1} - M_{p2}) + C_m(T_{m2} - T_{m1})\}}{\dot{M}_{da}(h_1 - h_0)\Delta t} \quad (18)$$

$$\eta_e = \frac{\dot{M}_{out}g\{h_{fg}\,(X) + C_m(T_{bed} - T_a)\}}{\dot{M}_{da}C_{p_a}(T_{bed} - T_a)\Delta t} \ldots\ldots (19)$$

Where, W_d is the weight of material after drying, M_p is the moisture content of the material, h_{fg} is the latent heat of vapourisation of water, C_m is the specific heat of the material after drying, T_m is the material temperature, $\dot{M}_{da}$ is the mass flow rate of air, t is time, h is specific enthalpy, X is the moisture removal rate, T_{bed} is the bed temperature, T_a is the ambient air temperature and C_{p_a} is the specific heat capacity of air.

For $\dot{M}_{out} \approx 0.8Kg$, $g = 9.81\ m/s^2$, $h_{fg} = 2.26\ {}^{KJ}/_{Kg}$, $C_m = 1.3\ KJ/Kgk$, $\dot{M}_{da} = 1.5\,Kg/s$, $C_{p_a} = 1.005\ KJ/Kgk$, $\Delta t = 10min$, $T_a = 25°C$, and for a given bed temperature, the various values of η_e for various values of X are tabulated in table 1.

Table 1: Moisture Removal Rates and Efficiencies for the Drying of Cassava

Time	T_{bed}=50°C		T_{bed}=55°C		T_{bed}=60°C	
	X_1	η_1(%)	X_2	η_2(%)	X_3	η_3(%)
10	0.0700	68	0.0700	67.95	0.0700	67.92
20	0.0650	67.97	0.0635	67.93	0.0620	67.89
30	0.0594	67.95	0.0520	67.88	0.0540	67.86
40	0.0545	67.93	0.0500	67.87	0.0460	67.83
50	0.0500	67.92	0.0435	67.85	0.0370	67.8
60	0.0449	67.88	0.0353	67.82	0.0315	67.79
70	0.0411	67.87	0.0330	67.81	0.0275	67.77
80	0.0380	67.85	0.0290	67.79	0.0240	67.76
90	0.0335	67.83	0.0260	67.78	0.0220	67.75
100	0.0310	67.82	0.0230	67.77	0.0195	67.74
110	0.0280	67.81	0.0215	67.76	0.0170	67.74
120	0.0254	67.8	0.0190	67.75	0.0150	67.73
130	0.0230	67.78	0.0170	67.74	0.0135	67.72
140	0.0222	67.77	0.0155	67.74	0.0105	67.72
150	0.0206	67.76	0.0140	67.73	0.0080	67.71

V. METHODOLOGY

In drying, the heat transfer coefficient h, the mass transfer coefficient k between the drying gas and the wet material, the heat diffusivity coefficient, the moisture (mass) diffusivity coefficient, thermal conductivity coefficient, moisture conductivity coefficient, optimum temperature T_{op} and the drying rate are the parameters of interest.In this experiment, the heat and mass diffusivity properties of the drying materials are also needed, a technique of investigation and measurement is applied such that the distribution of temperature and moisture content can also be measured during drying along with the thickness of the dried materials.However, during the investigation, the above mentioned distributions were not measured and only the integral-average moisture content of the dried material and eventually the temperature of the drying surface are measured, the model used to analyze the data is the so called “lumped parameter” type as opposed to the “distributed parameter” model applied when local values are measured.The fluidized bed dryer was used for drying cassava, yam and maize. The aim of the experiment is to obtain the optimum temperature for drying the above listed products.The experiments were done at different stages of each product. This is to enable the comparison of various temperatures at each stage to obtain the optimum temperature required for drying.However, only one of the experiments will be described in this paper.

VI. DRYING OF CASSAVA

Fresh cassava roots were obtained from a farm and used in this study. They were peeled and sliced using a special slicing machine into flakes of thickness, 5mm. The flakes were dried in thin layers in the fluidized bed dryer that was specifically designed and fabricated for the purpose at the Department Of Mechanical Engineering, Federal University of Technology Owerri, Imo State. The drying time ranges from zero minute until the sample attained equilibrium at intervals of ten minutes. The response variable was the moisture content of the cassava flakes and the weather conditions during the experiments were also monitored.For the fresh cassava that was used in the experiment, a duplicate sample was placed in an oven at 75°C for 7 hours in the laboratory at The Department Of Food Science And Technology, Federal University Of Technology Owerri, to determine the initial moisture content. The result indicates that the average moisture content of fresh cassava roots was about 75.4 %(wb).Prior to the drying, the dryer bowl (bed) was thoroughly cleaned, dried and preheated until it reached the operating conditions. The container used for weighing were thoroughly cleaned and dried too. The mass of the empty container was weighed and recorded. The cassava was cut into flakes and added to the dryer bowl between consecutive runs. During drying, the cassava samples were placed in the container and the weight was recorded. The product samples were withdrawn every ten minutes. Air flow velocity and drying temperature were set, data of inlet and outlet temperature, bed temperature, wet bulb and dry bulb temperature were collected during the drying process.At the first stage, during the experiment, the operating conditions of the fluidized bed dryer for cassava are; mass load 800g, the rotational speed of the blower is 2800rev/min and the air flow is $28m^3$/min. The inlet air temperature and outlet air temperature are 55°C and 45°C respectively, the bed temperature is approximately 50°C and the ambient temperature was maintained at 30°C. At this stage, the samples were withdrawn from the bed at regular time intervals and the time varying weight was measured and recorded.

At the second stage, the operating conditions of the fluidized bed dryer for cassava are; inlet and outlet temperatures are 60°C and 50°C, while the bed temperature is approximately 55°C. The ambient temperature, rotational speed, mass load and air flow remains constant at stage 1. At this time, the time varying weight was measured and recorded. At the third stage, the operating conditions of the fluidized bed dryer for cassava are; inlet and outlet temperatures are 65°C and 55°C, while the bed temperature is approximately 60°C. The ambient temperature, rotational speed, mass load and air flow remains constant as stage 1 and stage 2. At this time, the time varying weight was measured and recorded. Similar experimental procedure was adopted for the yam and maize respectively.The average moisture content of yam is about 74.6% (w.b) and that of maize is about 35% (w.b). On the other hand, a parallel sun drying experiment was carried out at an average ambient temperature of about 30.5°C to compare thin layer drying in the sun and thin layer drying in the fluidized bed dryer.

VII. RESULTS AND DISCUSSION

From the experiment carried out above, the following results were obtained as shown in figs 3-6. Comparing the results presented in the figs 3-6 below, it can be deduced that maintaining the external condition constant, the variation in the value of X_2 had an effect on the drying time during the constant rate period because the larger the value of X of the solid studied, the longer the drying constant rate period. The effect of temperature at 50^oC on the drying curves for the cassava and yam show that the value of the constant drying rate period of the experiment was smaller than the value obtained at the temperatures of 55^oC and 60^oC. The moisture reduction is longer at the temperature of 50^oC and 55^oC but faster at 60^oC. Similarly, the effect of temperature at 30^0C on the drying curves for the maize shows that the value of the constant drying rate period of the experiment was smaller than the value obtained at the temperatures of 35^0C and 40^0C respectively.

At the temperature of 60°C, the cassava and the yam dries slightly more rapidly to lower moisture content. When considering the effect of ambient temperature, increasing the cassava and yam temperature to 60°C increases the diffusion rate within the cassava and this effect increases the drying rate. The value of the constant drying rate period for X_3 was shorter than the value obtained in X_1 and X_2. This is because at that temperature, it facilitates the movement of the particles and improves the change in heat and mass during the drying process. The result obtained in X_3 gives optimum temperature for drying cassava and yam without changing the physiological configuration of the product.

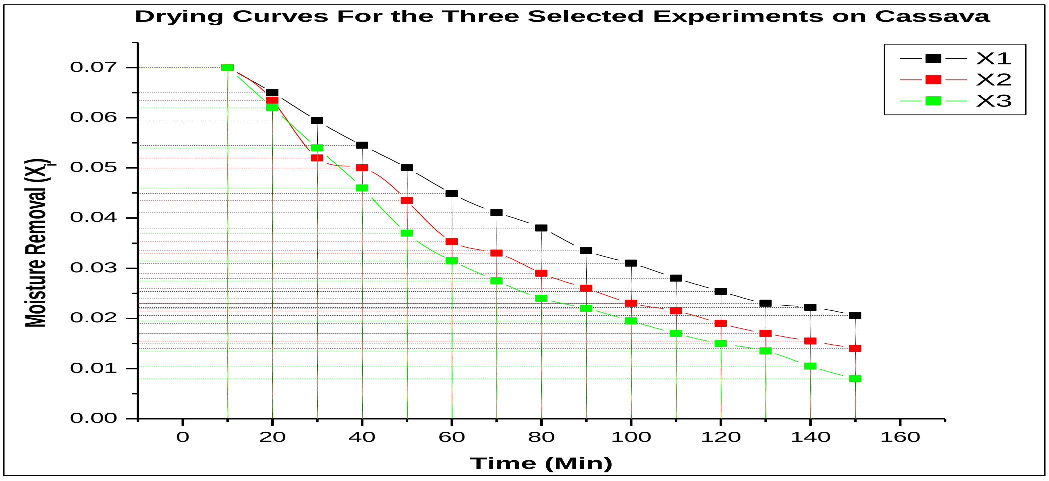

Fig 3 Drying Curves For the Three Selected Experiments on Cassava

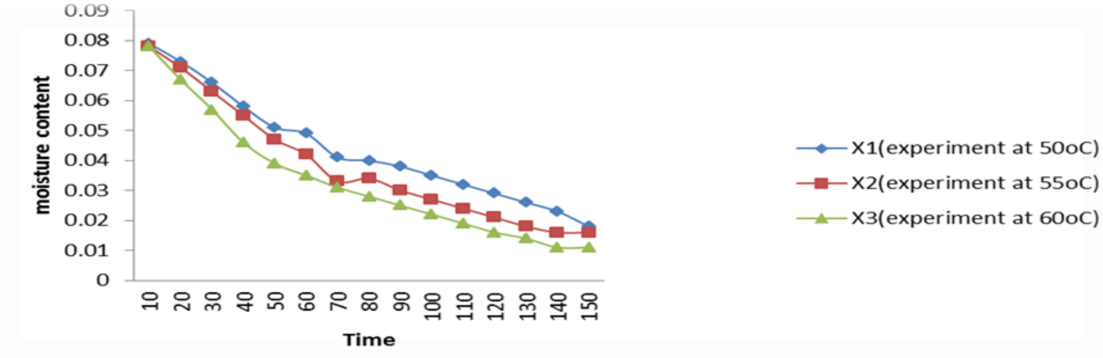

Fig 4 Drying Curves for the Three Selected Experiments on yam

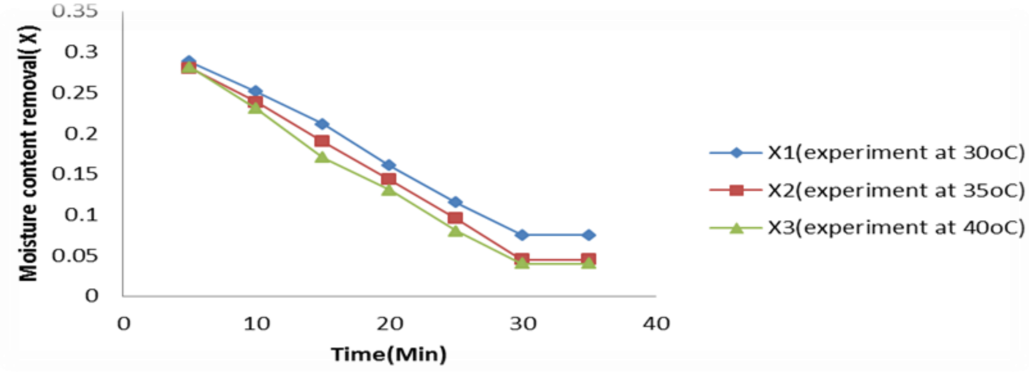

Fig 5 Drying Curves for the Three Selected Experiments on maize

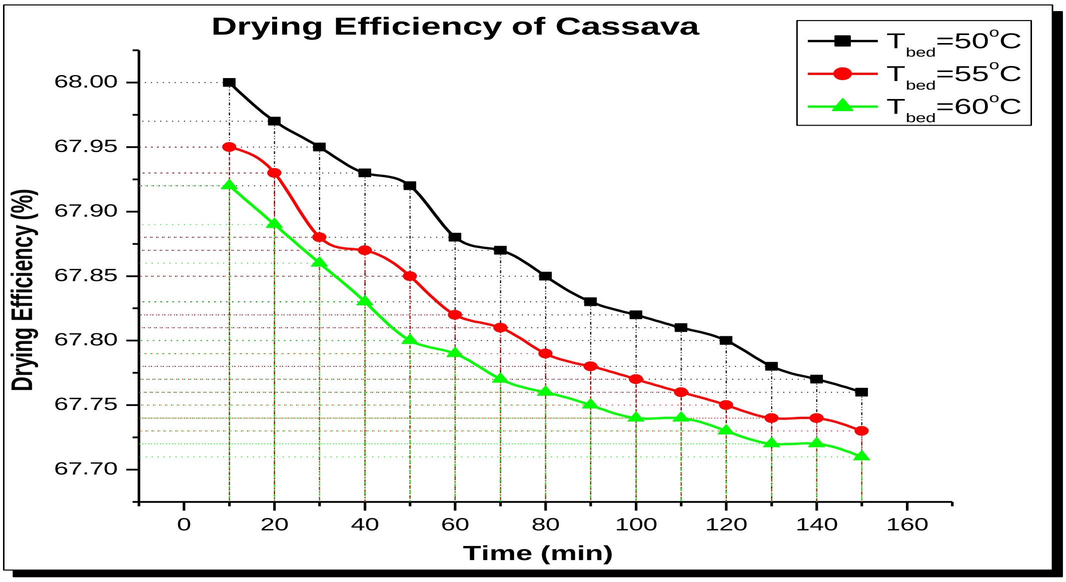

Fig 6 Drying efficiency of the fluidized bed at different drying temperatures.

VIII. CONCLUSIONS

The study of drying in a fluidized bed dryer showed that this equipment can be used to dry cohesive particulate materials, resulting in uniform distribution of the gas inside the bed thus providing a uniform drying of the solid. Generally, the optimum temperature and the suffering time of the material should be confirmed first when it comes to the drying of products. During the drying process of the various products in fluidized bed, the actual temperature of the material or bed should not exceed its optimum temperature.Analyzing the effect of the temperature, T_{bed} and moisture content X in relation to the time of drying in the constant and falling period, it can be deduced that it takes a total of 150minutes with an optimum temperature of 60°C to reduce the moisture content from 75.4%(w.b) to the equilibrium moisture content of 11% which is suitable for storage and preservation while maintaining the external conditions.In the case of sun drying cassava, it takes a total of 72hrs with an average ambient temperature of 30°C to reduce the moisture content from 75.4 %(w.b) to the equilibrium moisture content of 11 % (w.b).The drying rate of products below their optimal temperature was affected by the lower rate of moisture removal and the equilibrium moisture content by mass was high. While drying at temperatures above the optimum temperature causes the products to have any physical defects, such as, decoration, cracking, shrinking and non-uniform drying.

REFERENCES

[1] Alden M, P.Torkington and Strutt A.C.R (1988) “Control and Instrumentation of a Fluidized Bed Dryer using Temperature differences Technique”, Development of a working Modelpower Technology.

[2] Ambrosio-Ugri M.C.B and Taranto O.P, (2006) “Drying in the rotating-pulsed Fluidized Bed”. First Edition Maringu PR, Brazil.

[3] Brooker, D.B, Bakker-Arkema, F.W and Hall, C.W (1992) “Drying and Storage of Grains and Oil Seeds”. Van Nostrand Reinhold, New York.

[4] Othomer D.F (1956), “Background, History andFuture of Fluid Bed System Fluidization”. Reinhold Publishing Corporation, New York.

[5] Grace J.R(1982) Fluidized Bed Hydrodynamics Handbook Of Multiphase Flow,Hemisphere, Washington

[6] Stewart P.S.B And Davidson J.F (1967) Slug Flow In Fluidized Beds . Power Technol

[7] Linoya K Gotoh ,K And Higashitani(1990) Power Technology Handbook, 1st Edition ,Marcel Dekker Inc. ,New York

[8] Teunou E And Poncelet, D (2004) Batch And Continous Fluid Bed Coating –Review And State Of The Art ,Journal Of Food Engineering,No 53

[9] Geldart .D and Abrahamsen A.R (1978) Homogenous Fluidization of Fine Powders Using Various Gases and Pressure.Powder Technol.19 133-136.

[10] Yerushalmi.JandCankurt N.T (1979) Further Studies ofthe Regimes of Fluidization. Powder Technol

[11] Kunnii,D And Levenspei,O(1991) Fluidization Engineering 2rd Edition Butterworth-Heinemann Storeham,

[12] Guignon,BDuquenoy,A And Dumoulin,E.D (2002) Fluid Bed Encapsulation Of Particles: Principles And Practice, Drying Technology, No 20.

NOMENCLATURE

A	surface area,
Cp	specific heat,
h	convective heat transfer coefficient,
H	height, m
k	fluid thermal conductivity,
W_d	Weight of material after drying,
M_p	Moisture content of the material,
h_{fg}	Latent heat of vaporization of water
C_m	Specific heat of the material
T_m	Material temperature,
$\dot{M}_{da}$	Mass flow rate of air,
t	Time,
h	Specific enthalpy,
X	Moisture removal rate,
T_{bed}	Bed temperature,
T_a	Ambient air temperature and
C_{p_a}	Specific heat capacity of air
U_t^*	Dimensionless terminal velocity
ρ_p	Particle density
g	acceleration due gravity.
U_{mf},	minimum fluidization velocity
U_{mb}.	Minimum bubbling velocity
U_k ,	superficial velocity
θa	wet bulb temperature of air.
θs	wet bulb temperature of surface.
Ha	enthalpy of air