A

THESIS

ON

STUDIES ON DRYING KINETICS USING FLUIDIZED BED DRYER

In partial fulfilment of the requirements of

Bachelor of Technology (Chemical Engineering)

Submitted by

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Under the Guidance of

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NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

CERTIFICATE

This is to certify that this report entitled, "**STUDIES ON DRYING KINETICS USING FLUIDIZED BED DRYER**" submitted by Babita Soren in partial fulfilments for the requirements for the award of Bachelor of Technology Degree in Chemical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by her under my guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ABSTRACT

A study has been conducted on the drying kinetics of vegetables in a fluidized bed drier. Some physical characteristics of different vegetables were determined as a function of moisture content. Parameters like time of drying, temperature of air, flow velocity of air and material to be dried were varied and the drying rates were determined. The effects of different parameters like temperature, time and velocity on drying kinetics were determined. Critical moisture content was also determined. The drying kinetics of vegetables was thus obtained from these data by considering the different experimental conditions. Effect of diffusivity also observed.

KEYWORDS: Temperature, Drying, Moisture Content, Physical Properties.

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NOMENCLATURE

t	:	Drying time, second
L	:	Length, mm
D_a	:	Arithmetic Diameter, mm
D_g	:	Geometric Diameter, mm
W	:	Width, mm
T	:	Thickness, mm
ρ	:	True density, gm/m^3
ϒ	:	Bulk density, gm/m^3
ϕ	:	Sphericity
ε	:	Porosity
MC	:	Moisture Content, (gm water/gm dry solid)
G_1	:	Weight of Beaker, gm
G_2	:	Weight of beaker with sample, gm
S	:	Surface area, m^2
V	:	Volume of sample, m^3
M_s	:	Weight of liquid, gm.
M_w	:	Weight of air dried sample, gm.
V_b	:	Volume of bulk beaker, m^3
Vs	:	Volume of liquid, m^3
Temp	:	Temperature, ˚C

ABBREVIATIONS:

MC	:	Moisture content
Cal	:	Calculated
Exp	:	Experimental
LM	:	Loss of moisture
Temp	:	Temperature

Chapter 1

INTRODUCTION

Dehydration operations are important steps in the chemical and food processing industries. The basic objective in drying food products is the removal of water in the solids up to a certain level, at which microbial spoilage and deterioration chemical reactions are greatly minimized. The wide variety of dehydrated foods, which today are available to the consumer (snacks, dry mixes and soups, dried fruits, etc.) and the interesting concern for meeting quality specifications and energy conservation, emphasize the need for a thorough understanding of the drying process.

Drying refers to the removal of moisture or liquid from a wet solid by transferring this moisture into a gaseous state. In most drying operations, water is the liquid evaporated and air is the drying medium. Drying is a process of simultaneous heat and mass transfer. Heat required for evaporation, is supplied to the particles of the material and moisture vapor is removed from the material into the drying medium. Heat is transported by convection from the surroundings to the particle surfaces, and from there, by conduction, further into the particle. Moisture is transported in the opposite direction as a liquid or vapor on the surface; it evaporates and passes on by convection to the surroundings.

Drying requires high energy input because of the high latent heat of vaporization of water andlow energy efficiency of industrial dryers. Lot of energy is wasted in inefficient drying.
Drying of solids is an important process in many chemical, food, and transformation industries because of the many advantages i.e. the reduction of moisture in solids presents the following advantages:

(a) Improves the solid handling.
(b) Improves the use of the solid as raw material.
(c) Reduces the loading and transport costs.
(d) Increases the storage capacity.
(e) Reduces fermentation processes inside the solid during storage and transport.

Fluidization is the operation by which fine solids are transformed into a fluid like state through contact with a gas or solid. The process of fluidization with hot air is highly attractive for the drying of different materials. Fluidized bed driers are used extensively for the drying of wet particulate and granular materials that can be fluidized and even slurries, pest and suspensions that can be fluidized in beds of inert solutes. It is operated at superficial gas velocities higher than the minimum fluidization velocity. They are commonly used in processing many products such as chemicals, powder formation, carbohydrates, food stuff, bio materials, beverage products, ceramics, health care products, detergents, surface active agents, fertilizers, waste management process and environmental protection process. Fluidized bed operation gives important advantages such as good solid mixing, high rates of heat and mass transfer, and easy material transport. An induced draught is created by means of blower and fresh air is sucked into the unit. This hot air stream expands the material at certain velocity and creating turbulence in the product.

Advantages:

- In fluidized beds, the contact of the solid particles with the fluidizing medium (a gas or a liquid) is greatly enhanced when compared to packed beds. This behavior in fluidized combustion beds enables good thermal transport inside the system.
- Good heat transfer between the bed and its container which can have a significant heat-capacity whilst maintaining a homogeneous temperature field.
- High heat and mass transfer rates, because of good contact between the particles and the drying gas.
- Uniform temperature and bulk moisture content of particles, because of intensive particle mixing in the bed.
- Excellent temperature control and operation up to the highest temperature.
- High drying capacity due to high ratio of mass of air to mass of product.

Fluid bed drying offers advantages over other methods of drying of particulate materials. Particle fluidization gives easy material transport, high rates of heat exchange at high thermal efficiency while preventing overheating of individual particle.

Chapter 2

LITERATURE REVIEW

Watano et al.(1998) experimentally studied the drying of wet granules in an agitating fluidized bed type dryer that has a tapered fluidized bed with an agitator blade turning on a central axis installed at the bottom of the cylindrical vessel to impart a tumbling and circulating motion to the granules. The effects of the conditions on the properties of the granules such as the mass media diameter, yield, shape and density of the granules were investigated under various air temperatures, air velocities and agitator rotational speeds. The relationships between the operating conditions and the drying rates were also examined.

Palancz et.al (1983) proposed a mathematical model for continuous fluidized bed drying based on the two-phase theory of fluidization. According to this theory, the fluidized bed is divided into two phases, a bubble phase and an emulsion phase, which consists of gas and solid particles. Thus, higher inlet temperatures of drying air can be used which lead to shorter drying times. The enthalpy and the entropy of drying air also increase leading to higher energy efficiency. But increasing inlet air temperature should be limited to obtain good quality dried material. It was experimentally observed by **Hajidavalloo et.al (2000)** that as the inlet air temperature increased.

Many studies have been conducted to determine the parameters that affect drying. The way these parameters affect the drying has also been analysed. The main parameters that have been studied have been temperature of air, velocity of air, material to be dried, size of the particles, time of drying etc. These parameters help us in optimizing the drying process to reduce the cost and drying times. Also, the increasing cost of energy over recent years has prompted and received great attention in order to increase the convective heat transfer rates in the process equipment.

The effect of temperature was more critical than that of the other parameters and could reduce the drying time substantially. **Thomas and Varma (1992)** experimentally investigated fluidized bed drying of granular cellular materials and compared the experimental results for batch and continuous fluidized bed drying investigated at different temperatures and flow rates of the heating medium, particle size and mass of solids in a fluidized bed type dryer.

As the product is in close contact with the drying air at low temperature, and also for short duration, the physical and chemical properties of the products are generally not affected and therefore the dryer can effectively be used for heat sensitive products. Due to the continuous movements of product during drying, lump formation, case hardening etc. are minimized.

Numerous analytical and numerical models have been proposed by various authors to study heat and moisture transfer analysis during drying of different solid objects. Reviews of several different mathematical models have been published. In most cases, the authors employed the finite element method (FEM) for studying temperature and moisture distributions within the wet solids during the drying and control volume (CV) technique to study hydrodynamics and transfer phenomena in fluidized and spouted beds**[Białobrzewski et. al(2008)]**

Drying is essentially a process of simultaneous heat and mass transfer. Heat necessary for evaporation is supplied to the particles of the material and moisture vapor is removed from the material into the drying medium. Heat is transported by convection from the surroundings to the particle surfaces and from there by conduction, further into the particle. Moisture is transported in the opposite direction as a liquid or vapor on the surface; it evaporates and passes on by convection to the surrounding**.**

Drying characteristics of grains are complex. The moisture associated with seeds is of many forms viz. a) Chemically bonded b) physic-chemically bonded and c) mechanically bound form, depending on the bond strength of moisture. The nature of drying depends on the formation of its bond with the seed. For instance macro-capillary water enters in by liquid flow; on the other hand swelling moisture is removed or dried by diffusion through the cell wall. Hence the removal of moisture from seed becomes difficult.

Recent developments of the regime of fluidization and subsequent design modifications have made fluidized bed drying a desirable choice among other dryers. However, like other types of conventional convective drying process, fluidized bed drying is a very energy intensive process in industry. The efficiency of a conventional drying system is usually low depending on the inlet air temperature and other conditions. It is therefore, desirable to improve the efficiency of the drying process to reduce the overall consumption of energy.

2.1 Formula Used For Calculation

Size and shape

The axial dimensions of length (L), width (W) and thickness (T) of samples were measured at each moisture level by a digital slide clipper with an accuracy of 0.01 mm.

Mean diameter of sample was calculated by the following equation:

$$\text{Arithmatic mean diameter } (Da) = \frac{L+W+T}{3} \quad (1)$$

$$\text{Geometric mean diameter } (D_g) = (L * W * T)^{0.333} \quad (2)$$

The sphericity of sample was calculated by the following equation:

$$\text{Sphericity}(\phi) = (D_g / L)*100 \quad (3)$$

The surface area (S), of each sample was determined by the relationship below:

$$(S) = (\pi * B * L * L)/(2 * L - B) \quad (4)$$

Bulk and true densities

The bulk density based on the volume occupied by the bulk sample was measured using a standard hectometre.

The true volume was determined using the liquid displacement method. Toluene (C_7H_8) was used because sample absorbs it to a lesser extent than water. In addition, its surface tension is low, so that it fills even shallow dips in the sample, and its dissolution power is low.

$$\text{Bulk density}(\Upsilon) = \frac{G2-G1}{Vb} \quad (5)$$

Where G_1 is the weight of bulk density beaker in kg and G_2 is the weight of bulk density beaker with sample in kg.

$$\text{True density } (\rho) = \frac{Ms+Mw}{Vs+Vw} \quad (6)$$

Where M_s is the weight of liquid in kg,$V_s$is the volume of liquid in m^3,M_w is the weight of air dried sample in kg, V_w is the volume of air dried sample in m^3.

Porosity

The porosity (ε) defined as the percentage of void space in the bulk grain which is not occupied by the grain was calculated using the following equation

Porosity *(ε)* = [1-(bulk density/true density)]*100 (7)

Where bulk density and true density are in kg/m^3.

Analysis of Diffusivity

Attempt has been made to study the diffusivity of different vegetables (ladyfinger, kovakkai and radish bean) dried through a fluidized bed drier in the present study. The following equation **[Jena, S. and Sahoo, A**. **(2013)]** has been used for the calculation of effective moisture diffusivity of samples.

$$D_{eff} = 0.358 * \left[\left(t^{-1.339} \right) * \left(T \right)^{-0.729} * \left(U_0 \right)^{-0.354} * \left(L / D \right)^{-0.654} \right]^{0.928} \quad (8)$$

Where t is time, T is temperature; U_0 is the velocity of air.

Chapter 3

EXPERIMENTAL SETUP

3.1 Schematic representation of fluidized bed drier

The setup is a tapered fluidized bed drier consisting of Air Compressor, Air Distributor, Heater, Inlet Air Temperature Sensor, Tapered Bed, Outlet Air Temperature Sensor.
Figure 1 Apparatus in the set -up: 1 Air Compressor; 2 Heater; 3 Air inlet to the bed; 4 Inlet air temperature sensor; 5 Tapered Fluidized Bed; 6 Outlet Hot Air Temperature Sensor; 7 Hot Air outlet; 8 Timer

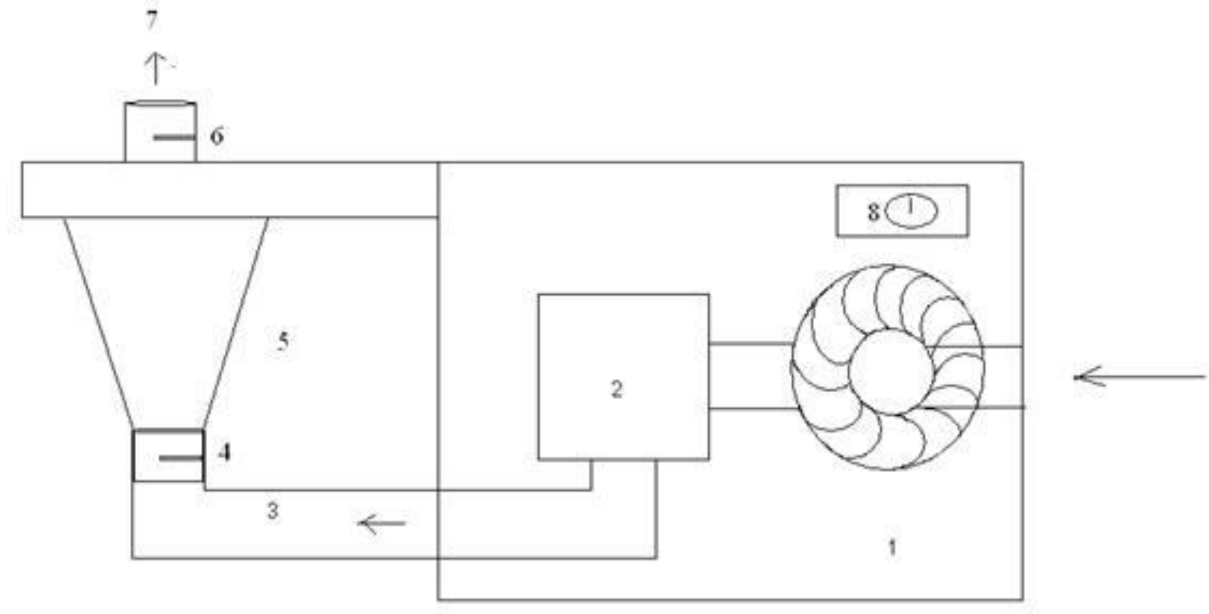

Figure 1: Tapered Fluidized Bed Dryer

3.2 Tapered Fluidized Bed Dryer

The bed is shaped like a truncated cone with bottom diameter is 12.1 cm where as the top diameter is 21.96cm. The reactor height is 20 cm. The tapered angle is 14°.
The gas distributor was 2mm thick with 2mm perforations. A fine wire mesh of 0.2mm openings was spot welded over the distributor plate to arrest the flow of solids from the fluidized bed into the air chamber. Air from the blower was heated and fed into the air chamber and into the fluidization column.

Chapter 4

MATERIALS AND METHOD

4.1 Materials

Fresh green Ladyfinger is taken as sample-1, Kovakkai (locally known as kunduri) is taken as sample-2 and Radish bean (locally known as Barbati) is taken as sample-3. These materials were cut into different shapes before used.

4.2 Method

i. A fluidized-bed was used for the drying of all samples.
ii. The fluidized bed dryer was connected to a heat pump dehumidifier system. The drying conditions of 100°Cwere set by the temperature controller in the heat pump dehumidifier system, and the drying set-up was run for 10 minutes to achieve steady state conditions of drying before material introduction.
iii. The hot air velocity passing through the material bed was kept at a constant value of 3.8 ms^{-1} for a single set experiment.
iv. Then the cut materials were put in to the fluidized bed for drying purpose.
v. Samples were taken out at regular interval of 10 minutes from the dryer for taking the readings of weight reduction and changes in volume.
vi. Physical properties like length with thickness were observed and tabulated. Based on these data other physical properties like arithmetic mean diameter, geometric mean diameter, volume, surface area, sphericity, true density, bulk density of these sample were calculated by above formulas and tabulated below.
vii. For observation of temperature effect of a single material (ladyfinger), procedure was but the temperature was set in 4 different temperatures where time and velocity were constant.
viii. For observation of time effect, time was set in 4 different times where temperature and velocity were constant and same procedure was repeated.
ix. For observation of velocity effect, velocity was set in 4 different times where temperature and time were kept constant and same procedure was repeated.
x. The observed data were calculated, tabulated and plotted below.

Chapter 5

RESULTS AND DISCUSSIONS

Dimensions and different properties of these three materials were measured after drying of10 or 20 minutes and effects of these properties were plotted.

5.1 Observations:

Table1 shows the observation data of sample-1 (ladyfinger) at temperature of 100˚C and velocity of 3.8 m/s.Table2 shows the observation data of sample-1 (ladyfinger) after 10 minutes at same temperature and velocity. Table3 shows the observation data of Sample-1 (Ladyfinger) after 20minutesat same temperature and velocity. Table 4 shows calculation of the observed data of sample-1 using above equation. Table 5 shows the observation data of sample-2 (Kovakkai) at temperature of 100˚C and velocity of 3.8 m/s. Table 6 shows the observation data of sample-2 after 10 minutes at same temperature and velocity. Table 7 shows the observation data of sample-2 after 20minutes at same temperature and velocity. Table 8 shows the calculation of the observation data of sample-2 using above equation.

Table 9 shows observation data for sample-3 (Radish bean) at temperature of 100˚C and velocity of 3.8 m/s. Table 10 shows observation data for sample-3 after 10 minutes at same temperature and velocity. Table 11 shows observation data for sample-3 after 20 minutes at same temperature and velocity. Table 12 shows the calculated data of sample-3 using above equation. Table 13 shows observation data for temperature effect. Table 14 shows observation data for time Effect. Table 15 shows observation data for effect of velocity. Table 16 shows observation data for critical moisture content. Table 17 shows the calculating of diffusivity of sample 1 (ladyfinger) by using equation no. 8 at constant temperature and velocity.

Table 1: Dimensions of sample-1 measured before drying.

Sl. No.	L (mm)	W (mm)	T (mm)
1	53.3	16.06	14.92
2	63.42	20.14	18.29
3	59.26	18.79	17.47
4	46.85	15.53	13.43
5	49.2	14.28	14.12
6	60.19	14.95	13.26
7	66.25	14.58	14.21
8	56.48	16.48	14.45
9	35.48	14.44	14.16
10	50.9	15.04	14.9

Table 2: Dimensions of sample-1 measured after drying of 10 minutes under temperature of 100^0C.

Sl. No	L (mm)	W (mm)	T (mm)
1	51.15	13.83	14.05
2	60.1	18.53	16.9
3	57.2	16.5	16
4	45.7	13.4	12.02
5	47.3	13.18	13.12
6	59	13.96	12
7	64.2	12	13.02
8	54.3	14.02	13.04
9	33.25	13.04	12.06
10	48.82	13.04	12.9

Table 3: Dimensions of sample-1 measured after dried under 100^0C for time of 20 minutes.

Sl. No	L (mm)	W (mm)	T (mm)
1	49.7	12.5	12.03
2	58.2	16.2	14.2
3	55.19	14.25	14.3
4	43.5	12.8	11.9
5	45.2	11.28	12.2
6	57.02	11.25	11
7	62.53	11	12.05
8	52.2	12.02	11.04
9	31.2	11.29	11.05
10	45.7	11.54	11.9

Table4: Calculated data of different physical properties of sample-1.

L (mm)	W (mm)	T (mm)	D_a (mm)	D_g (mm)	ϕ	ρ (gm/m^3)	ϒ (gm/m^3)	ε	Wt (gm)	Mc (gm)
54.133	16.029	14.921	28.4	23.4	43.22	760	676.6	10.9	546.12	7.24
52.102	14.15	13.511	26.6	21.45	41.17	700.3	663.3	5.3	541.23	9.57
50.044	12.413	12.167	24.8	19.56	39.08	680.5	646.6	4.97	537.3	30

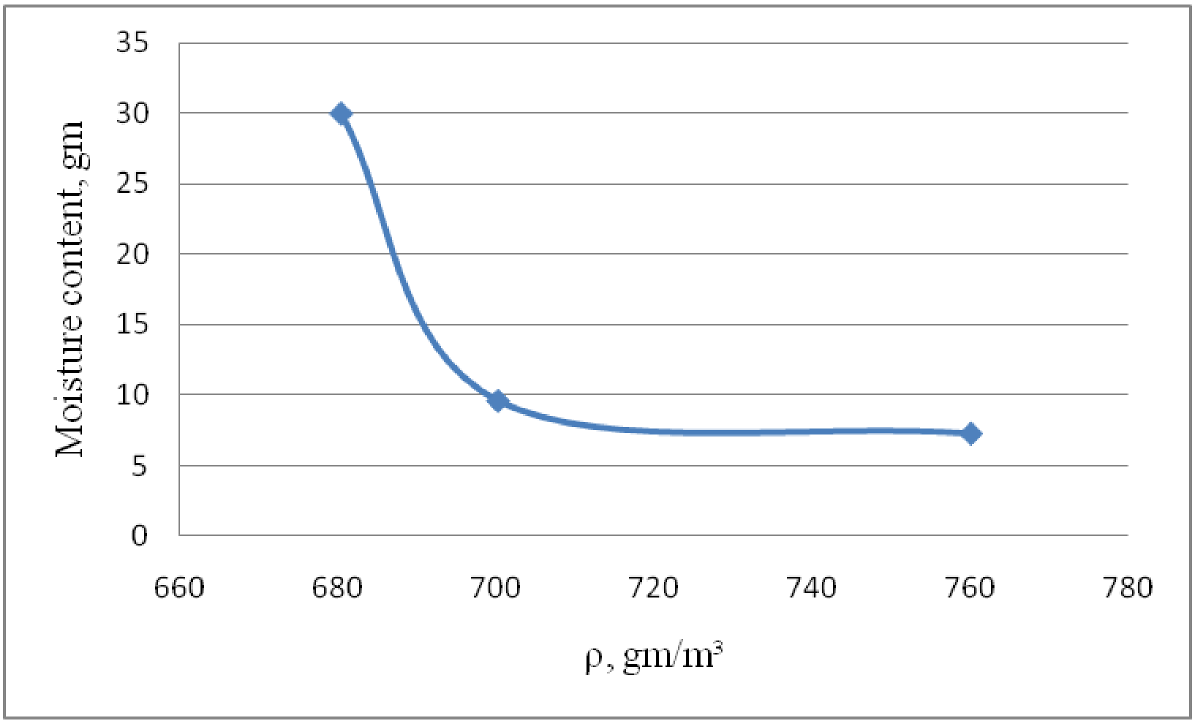

Figure 2: Plot between Moisture Content and True density of sample-1 at Temperature of 100˚C.

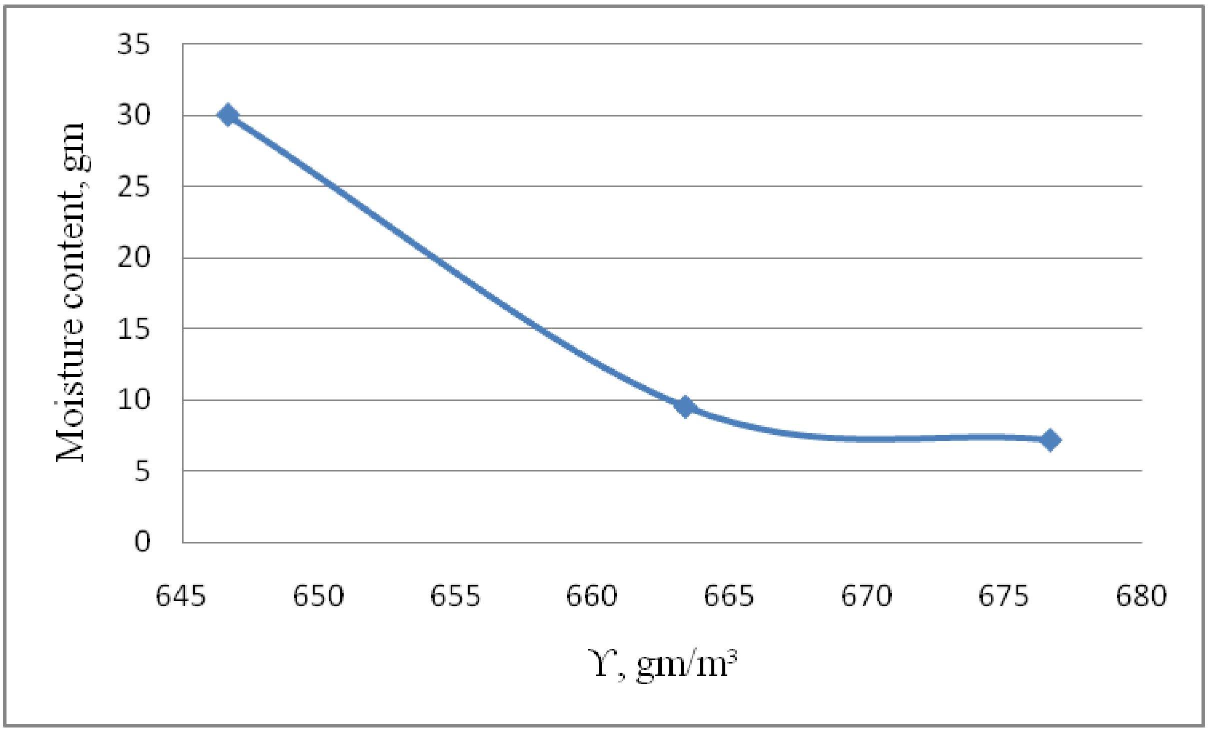

Figure 3: Plot between Moisture Content and bulk density of sample-1 at Temperature of 100˚C.

Table 5: Dimensions of sample-2 measured before drying.

Sl. No.	L (mm)	W (mm)	T (mm)
1	70.18	21.53	21.05
2	54.61	19.07	18.14
3	53.64	18.37	16.1
4	65.6	17.91	16.46
5	49.94	19.75	19.92
6	44.57	25.26	11.48
7	52.88	21.62	22.08
8	59.17	21.53	20.93
9	62.02	21.41	21.13
10	60.08	18.83	18.38

Table 6: Dimensions of sample-2 measured after drying of 10 minutes under temperature of 100^0C.

Sl. No.	L (mm)	W (mm)	T (mm)
1	70	20.78	20.96
2	54	18.92	18
3	52.62	17.45	15
4	64.74	17.34	16
5	47.91	19.36	18
6	43.2	14.34	11
7	51.28	21	21.85
8	58.2	20.94	19.2
9	61.54	20.92	20.37
10	58.94	17.54	17.74

Table 7: Dimensions of sample-2 measured after dried under 100^0C for time of 20 minutes.

Sl. No	L (mm)	W (mm)	T (mm)
1	69	20	19.52
2	53.53	18	17.5
3	50.6	16.85	14.59
4	63	17	15.6
5	45.06	18.9	17.62
6	42.02	13.54	10.94
7	50.71	20.06	21.13
8	57	20.01	18.25
9	60.24	19.94	19.79
10	57.52	17.02	17.02

Table 8: Calculated data of different physical properties of sample-2.

L (mm)	W (mm)	T (mm)	D_a (mm)	D_g (mm)	ϕ	ρ (gm/m^3)	ϒ (gm/m^3)	ε	Wt (gm)	Mc (gm)
57.26	20.52	18.56	32.121	147.7	257.9	1335	843.3	36.82	559.2	8
56.24	18.85	17.81	30.9713	137.4	244.3	1312.9	826.6	37.03	585.92	9
54.86	18.13	17.19	30.06	130.8	238.39	1000.89	806.7	40	582.2	20

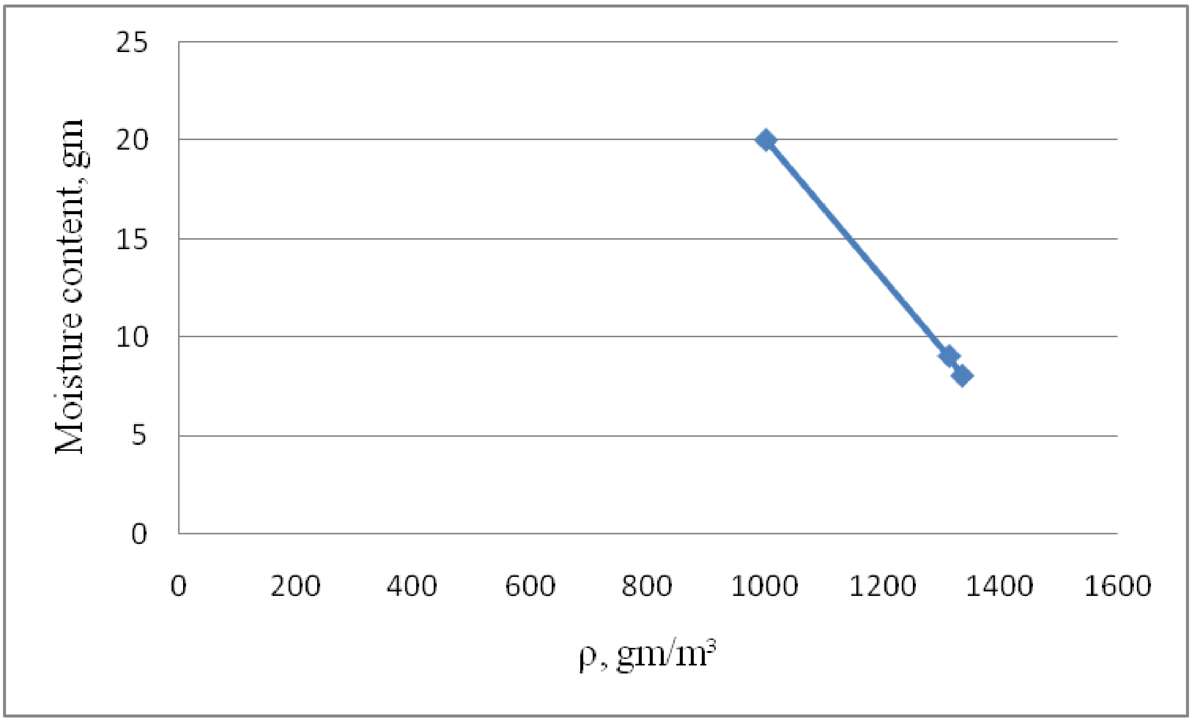

Figure 4: Plot between Moisture Content and True density of sample-2 at Temperature of 100˚C.

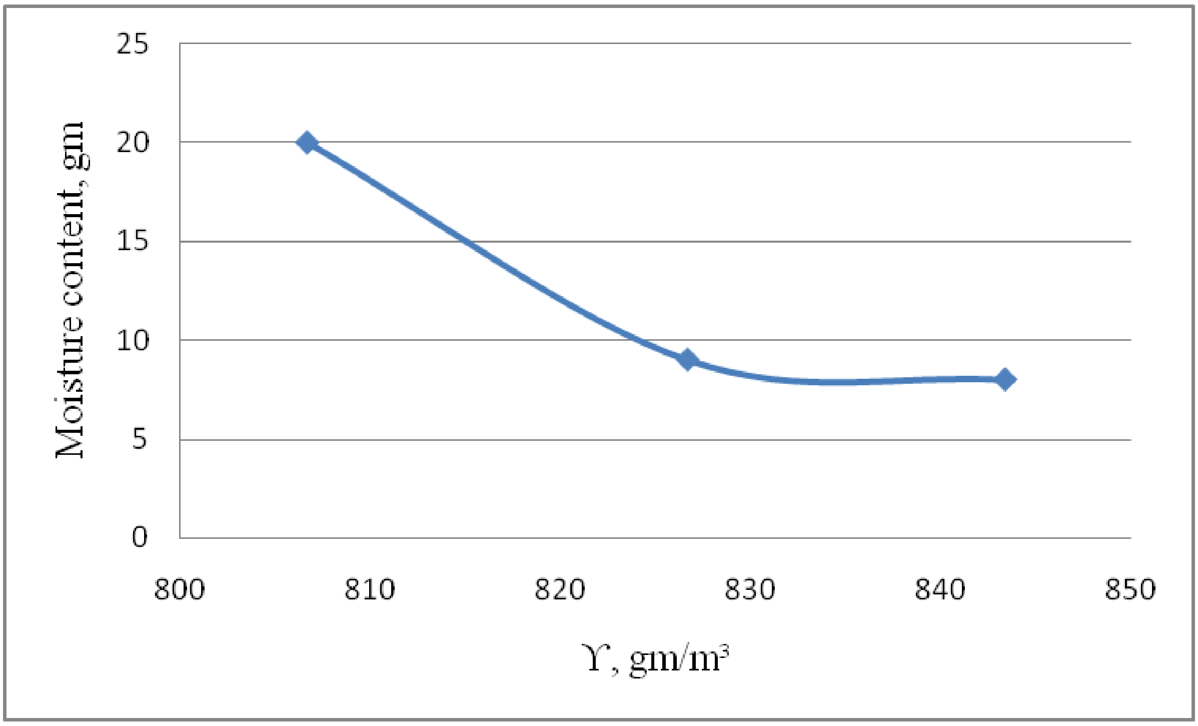

Figure 5: Plot between Moisture Content and bulk density of sample-2 at Temperature of 100˚C.

Table 9: Dimensions of sample-3 measured before drying.

Sl. No	L (mm)	W (mm)	T (mm)
1	59.53	6.21	5.93
2	55.4	5.5	4.8
3	58.81	4.4	3.39
4	47.17	4.68	4.66
5	58.61	5.15	5.29
6	61.69	5.9	5
7	72.05	5.75	5.38
8	61.54	6.44	5.3
9	56.86	6.67	4.71
10	61.54	5.71	5.37

Table 10: Dimensions of sample-3 measured after drying of 10 minutes under temperature of 100^0C.

Sl. No	L (mm)	W (mm)	T (mm)
1	57.91	6	5.53
2	52.91	5.7	4.7
3	58.58	4.21	3.21
4	43.68	4.38	4.59
5	57.16	4.95	4.52
6	60.9	5.4	4.9
7	70.08	5.5	4.93
8	59.72	6.434	5.02
9	54.71	5.72	4.03
10	59.24	5.03	4.95

Table 11: Dimensions of sample-3 measured after dried under 100^0C for time of 20 minutes.

Sl. No	L (mm)	W (mm)	T (mm)
1	53.02	5.34	4.7
2	50.04	4.2	3.92
3	53.29	3.92	3
4	40.5	3.53	3.84
5	52.2	3.74	3.62
6	55.7	4.2	3.92
7	62	4.29	3.2
8	52.74	5.4	4.7
9	47.29	4.53	3.03
10	50.24	4.54	3.72

Table 12: Calculated data of different physical properties of sample-3.

L (mm)	W (mm)	T (mm)	D_a (mm)	D_g (mm)	ϕ	ρ (kg/m^3)	ϒ (kg/m^3)	ε	Wt (gm)	Mc (gm)
59.32	5.641	4.983	23.31467	11.83	19.94	740.8	303.3	45	234.21	8
57.489	5.332	4.638	22.48633	11.22	19.52	671.8	287.9	57	228.5	9
51.7	4.37	3.765	19.945	9.45	18.28	385	249	78	217.06	20

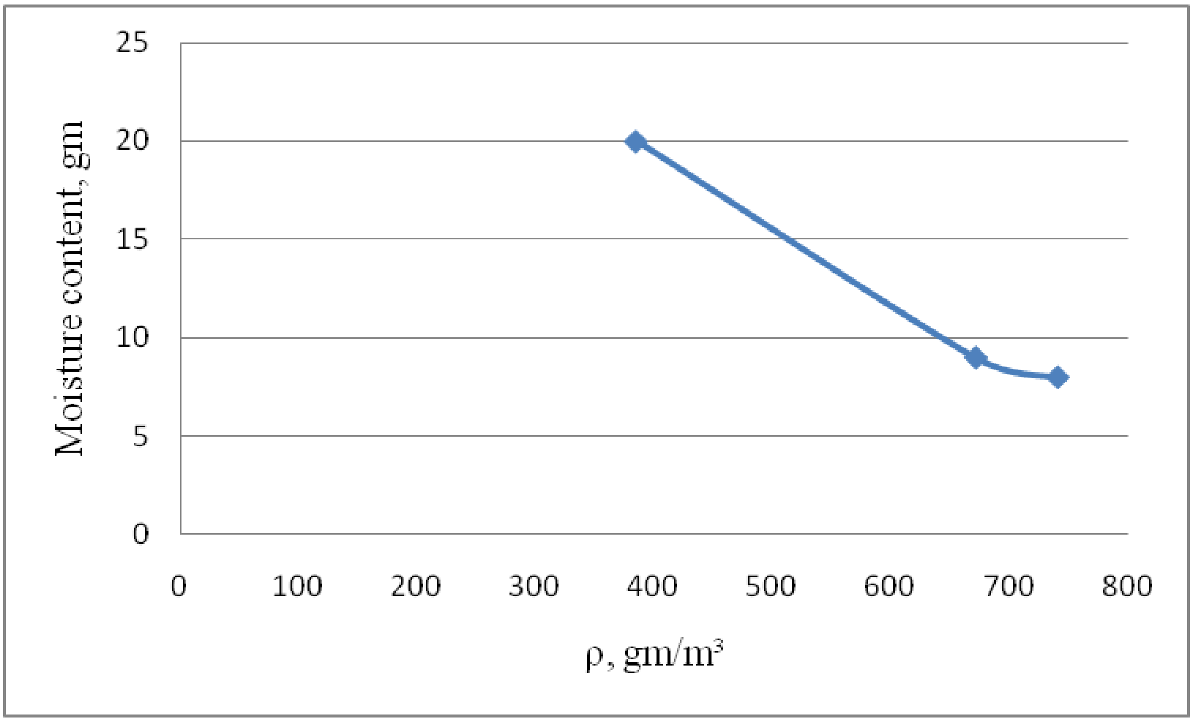

Figure 6: Plot between Moisture Content and True density of sample-3 at Temperature of 100˚C.

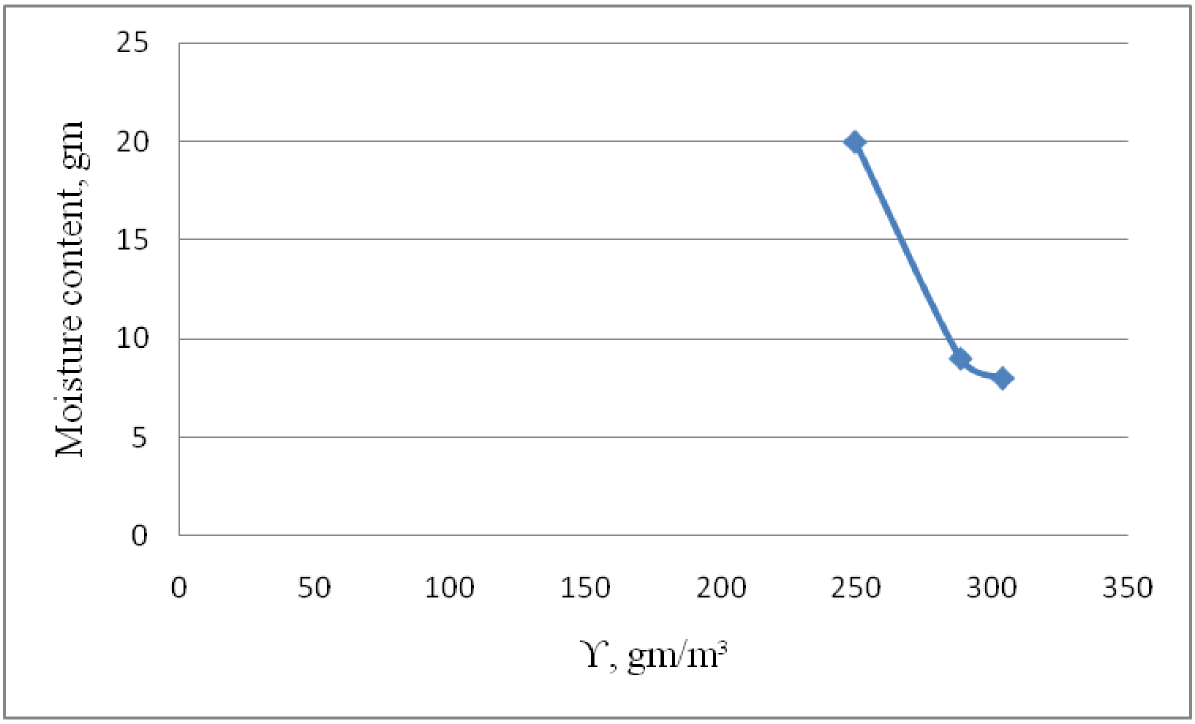

Figure 7: Plot between Moisture Content and bulk density of sample-3 at temperature of 100˚C.

Table 13: Observation data for temperature effect at constant time and velocity.

Sl. No	T (minutes)	Wt (gm)	LM (gm)
1	20	286	14
2	50	271	29
3	75	251	49
4	100	244.33	55.6

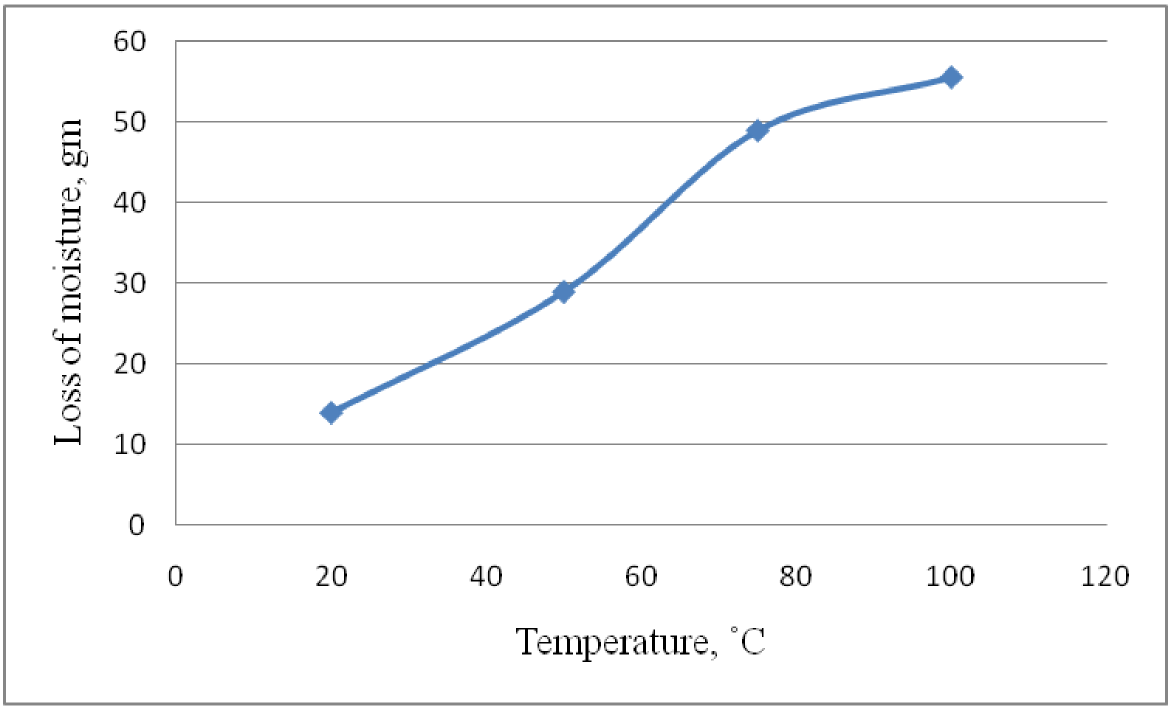

Figure 8: Plot between loss of moisture on temperature at constant velocity and time.

Table 14: Observation data for time effect at constant temperature and velocity.

Sl. No	Time (minutes)	Wt (gm)	LM (gm)
1	20	250	50
2	35	200	100
3	50	180	120
4	60	155.6	144.4

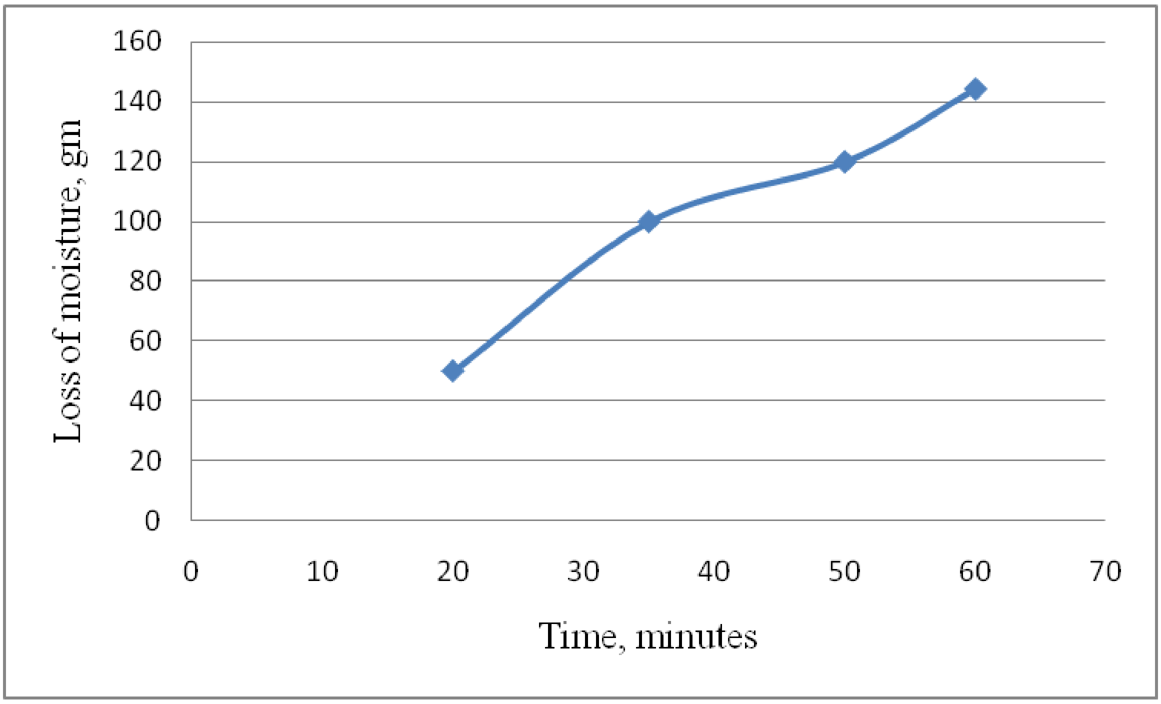

Figure 9: Plot between loss of moisture and time at constant velocity and temperature.

Table 15: Observation data for velocity effect at constant temperature and time.

Sl. No	V (ms^{-1})	Wt (gm)	LM (gm)
1	0.975	280	20
2	1.95	230	70
3	2.875	200	100
4	3.8	190	110

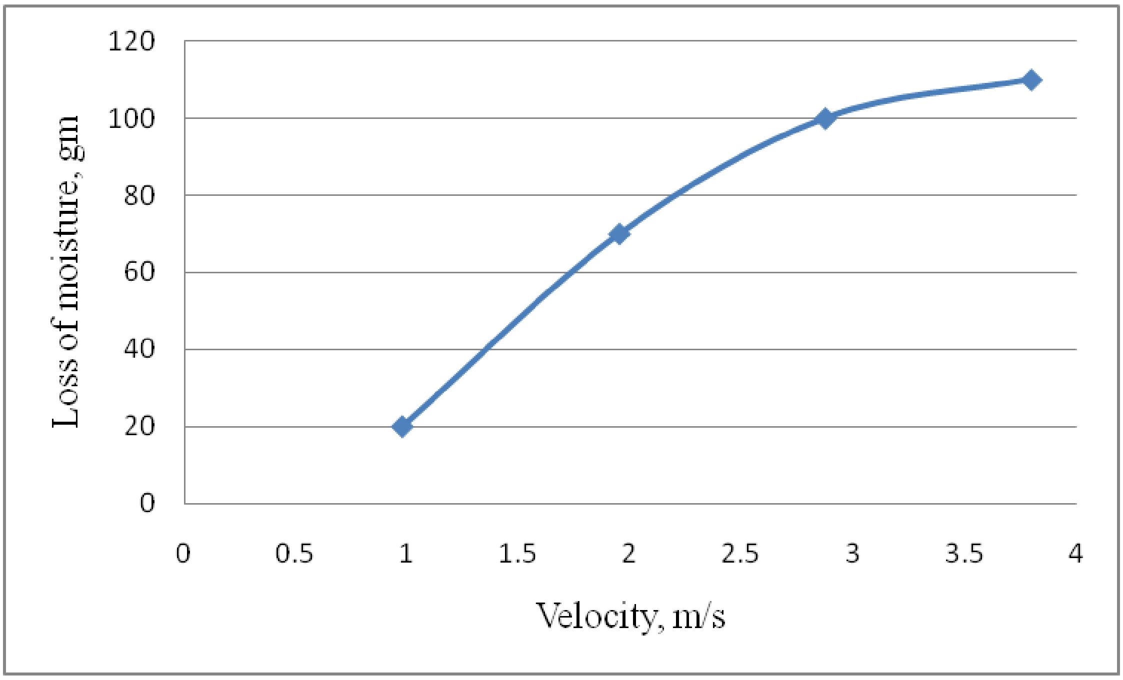

Figure 10: Plot between loss of moisture and velocity at constant time and temperature.

Table 16: Observation data for critical moisture content.

Sl. No	t (minutes)	Wt (gm)	LM (gm)
1	20	270	11.23
2	40	240	25
3	60	200	50
4	80	165	81.8
5	90	155	93.54
6	100	153	94.3
7	120	154	94.8

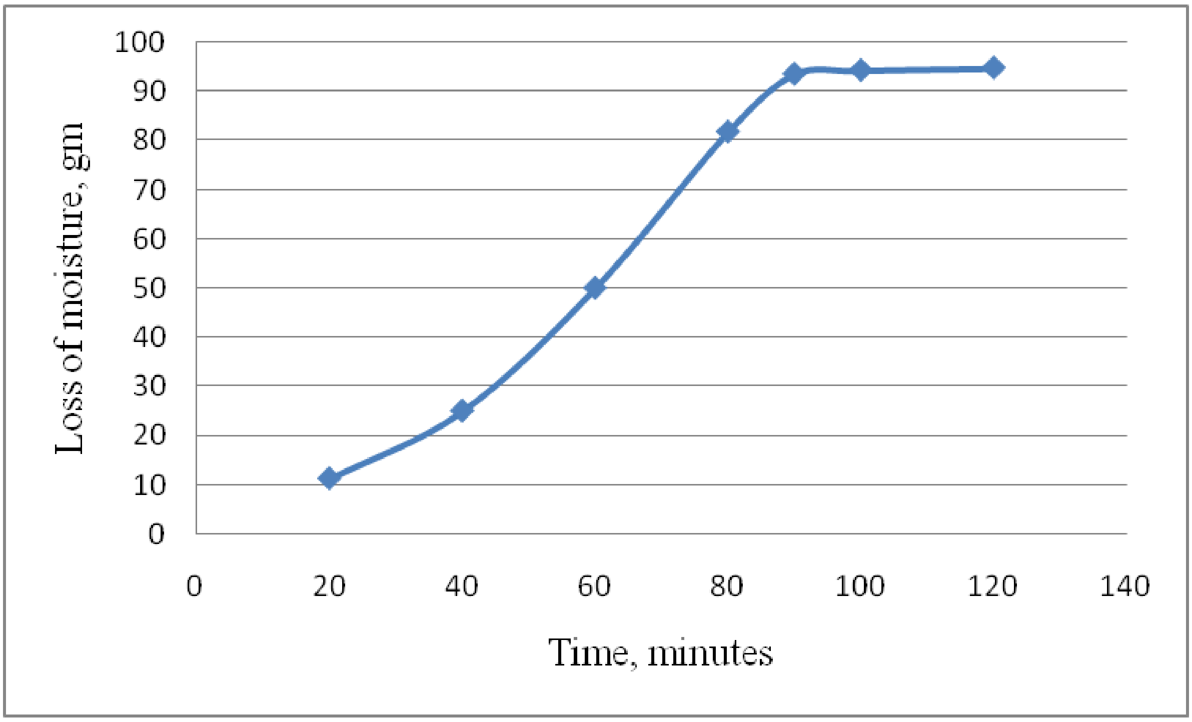

Figure 11: Plot between loss of moisture and time showing the critical moisture content of sample-1 at constant temperature and velocity.

Table 17: Calculated data of diffusivity of sample 1 (ladyfinger) by using equation no. 8.

Sl. No	t (minutes)	Diffusivity (m^2/s)
1	10	0.0017
2	20	0.0009
3	30	0.0005
4	40	0.0002
5	50	0.00015

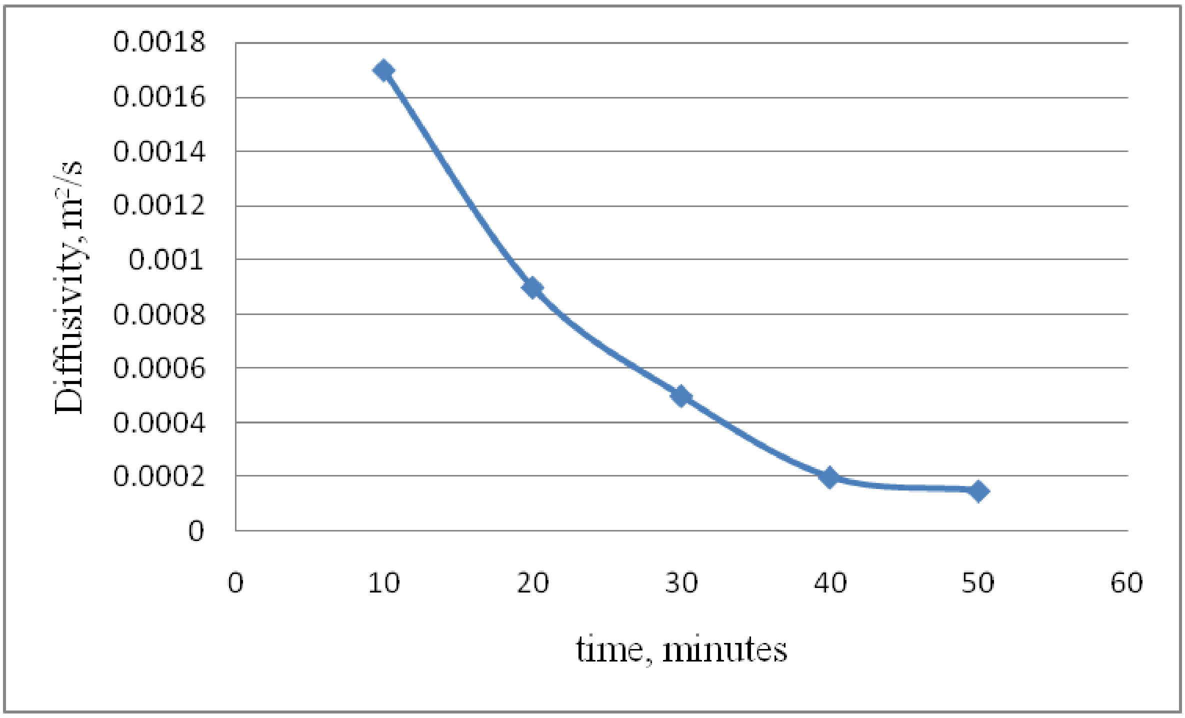

Figure 12: Plot between diffusivity and time of sample-1at temperature of 100˚C.

5.2 Results and discussion

- In table 1, table 2 and table 3 it is observed that due to loss of moisture the length, width and thicknesses of the sample-1 (Ladyfinger) were reducing slightly after drying of 10 minutes but after drying of 20 minutes these data were reducing significantly at same temperature.
- From table5, table 6 and table 7 it is observed that the properties of sample-2 (Kovakkai) were reduced due to loss of moisture after drying of 10 or 20 minutes but in this case the rate of moisture removed was slower than from sample 1 and sample 3.
- For sample 3 (Radish bean) the rate of moisture removed was faster from sample-1 and sample-2 as it is observed in table 9, table 10 and in table 11.Form figure 2,figure 4 and figure 6 it is observed that the true density of the samples were decreasing with increasing of moisture content for a particular time or temperature.
- From figure 3, figure 5 and figure 7 it is observed that the bulk density of these materials was decreasing with increasing of moisture content.
- It was also observed that an increase in air temperature increases significantly the drying rate for all the materials as seen in figure 8.
- From figure 10 it is observed that the drying rate increases with increase in gas velocity rate due to a decrease in gas film resistance surrounding the particle. It was also observed from figure 9 that removal of moisture increased with time.
- Critical moisture content was also observed which is seen in figure 11 where the moisture content remains constant after certain time even if drying time increases. 93% was the calculated as critical moisture content for sample-1.
- Effect of Diffusivity also observed from fig.12 as it is seen that diffusivity of the sample-1 was decreasing with increasing of time.

Chapter 6

CONCLUSION

In present studies the drying performances of fluidized bed dryer were observed experimentally by varying three different system parameters i.e. temperatures, time of drying and velocity of air. The drying performance of fluidized bed drier has been studied by analyzing moisture content and diffusivity of the sample during drying operation. Knowledge of such effects gives the base for the design by which the efficiency of the fluidized bed dryer can be improved or the process can be effectively optimized. Finally it can also be suggested that the observed data can be suitably used for the industrial drying purpose with a suitable scale-up factor and can be considered as the base design for any industrial fluidized bed dryer (large scale) with an optimum drying process.

The different physical properties of three vegetables were observed in different conditions of drying i.e. temperature, air velocity and time. The results thus obtained from this study will help for the storage and packaging of food materials and vegetables. Accordingly storage unit can be designed so that materials will not damage which can be used whenever required when there is no cultivation. This data will also help during the preservation of food in food industry.

Chapter 7

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Chapter 8

APPENDIX

Temperature = 25 ºC

Time (minutes)	Flow Rate = 3.85 m/s		Flow Rate = 2.86 m/s		Flow Rate = 1.92 m/s Flow Rate		Flow Rate=0.957 m/s	
	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (GM)	Moisture Lost (gm)
0	300	0	300	0	300	0	300	0
10	293	7	295	5	296		297	3
20	283	17	285	15	286	14	288	12
30	280	20	281	19	282	12	285	15

Temperature = 50 ºC

Time (minutes)	Flow Rate = 3.85 m/s		Flow Rate = 2.86 m/s		Flow Rate = 1.92 m/s Flow Rate		Flow Rate=0.957 m/s	
	Weight (gm)	Moisture Lost (gm)	Weight (GM)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)
0	300	0	300	0	300	0	300	0
10	283	17	285	15	288	12	290	10
20	270	30	273	27	275	25	280	20
30	260	40	265	35	268	32	272	22

Temperature = 75 ºC

Time (minutes)	Flow Rate = 3.85 m/s		Flow Rate = 2.86 m/s		Flow Rate = 1.92 m/s Flow Rate		Flow Rate=0.957 m/s	
	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)
0	300	0	300	0	300	0	300	0
10	270	30	275	25	278	22	282	18
20	250	50	255	45	260	40	265	35
30	233	67	240	60	252	48	262	38

Temperature = 100 ºC

Time (minutes)	Flow Rate = 3.85 m/s		Flow Rate = 2.86 m/s		Flow Rate = 1.92 m/s Flow Rate		Flow Rate=0.957 m/s	
	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)	Weight (gm)	Moisture Lost (gm)
0	300	0	300	0	300	0	300	0
10	268	32	270	30	274	26	279	21
20	249	51	253	47	258	42	262	38
30	222	78	230	70	248	52	255	45