Mechanism of Pulse Drying

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Abstract: Drying, is the removal of relatively small amount of water or other liquid from the solid material to reduce the residual liquid content to an acceptable low value. In general drying, hot stream of air or steam is being supplied continuously over the material to be dried directly or indirectly irrespective of types of dryer. In this case the main heat transfer takes place by convection and the conductional heat transfer is negligible. For the sake of conservation of energy, pulse drying is an alternative of drying technique in the present time where the main objective is to provide time for heat conduction

In this study of "Mechanism of Pulse Drying" drying experiments were carried out in both continuous and pulsating manner by varying temperature of heating medium and pulse duration to demonstrate the technique. Trial experiments were carried out using card-board varying temperatures (69^0C, 58^0C& 47^0C) & pulse (10/10s, 20/20s, 30/30s) and then the experiments were continued for green peas (*Pisum sativum*) with variation of pulses (without pulse, 5/5s pulse, 10/10s pulse, 15/15s pulse & 20/20s pulse). It was seen that both high & low pulse durations of drying are not preferable. The experimental data were co-related with various thin layer drying models and it was found that the Modified Page model is the best model for the obtained experimental data with coefficient correlation of more than 0.997

Keywords— *pulse drying,*

I. INTRODUCTION

Drying, is the removal of relatively small amount of water or other liquid from the solid material to reduce the residual liquid content to an acceptable low value. It refers to the final removal of water or water like solutes which follows evaporation, filtration or crystallization. While handling a crystalline product it is essential that the crystals are not damaged during the process. In the case of drying of pharmaceutical products special attention should be taken to avoid contamination. Similar care should be taken during drying of food materials. Extra care should be taken for shrinkage as with paper, cracking as with wood, loss of flavor as with fruits [2].

During drying both mass and heat transfer occurs simultaneously. Heat is transferred from the bulk of the gas phase to the solid phase and mass or moisture is transferred from solid phase to the gas phase in the form of vapor. In the process industries the majority of the dryers employed forced convection. In case of indirectly heated rotary dryer and film drum dryer heat is transferred by conduction in batch process. Radiation or infra-red heating is rarely used in drying materials such as fine chemicals, pigments, clay & synthetic rubber. However, radiation is often used for drying of surface coatings on large plane surfaces.

II. LITREATURE SURVEY

There does not exist a single theory of drying, that will cover all materials and all dryer types as various types of dryers are used to dry various types of materials. Variation in shape & size of stock, moisture equilibria, the mechanism of flow of moisture through the solid and the method of providing heat required for vaporization- all prevent a unified treatment [4].

There are various drying techniques which may be classified as follows on the basis of advancement of the technology.

Conventional drying technique these technologies of drying refer to those techniques which human know from his creation. Natural methods of drying come under this group.

Pulse drying technique: Conservation of energy during drying is an important aspect to save energy and cost of drying. It is impossible to operate any machinery without supply of energy. In the case of drying by applying the intermittent supply of heating medium instead of continuous supply will save a minimum of 50% energy. The technique with reduced energy requirements is the pulse mode drying. The supply of energy in pulse manner is adopted to make better utilization of energy. It gives time to penetrate the heat inside the material to be dried.

III. METHODOLOGY

Conservation of energy during drying is an important aspect to save energy and cost of drying. It is impossible to operate any machinery without supply of energy. In the case of drying by applying the intermittent supply of heating medium instead of continuous supply will save a minimum of 50% energy. The technique with reduced energy requirements is the pulse mode drying. The supply of energy in pulse manner is adopted to make better utilization of energy. It gives time to penetrate the heat inside the material to be dried.

Raw materials ranging from 1 to 99 percent moisture can be dried using the pulse drying techniques. Particle size ranging from microns to 1/4 inch can be dried with the help of this technique. The raw materials can dried to the desired moisture content with very little operator involvement. As much (up to 99%) or as little water (up to 1%) can be removed from the products using pulse drying [22].

Experimental Setup

The schematic diagram of the experimental set-up is shown in Figure-3.1. It consisted of drying & weighing system with power supply unit. The dryer was a 91.3 cm long rectangular cabinet having width & height, 23 cm & 25.7 cm respectively as shown in the figure. At one end heater was placed and the other end of the dryer is equipped with a blower (Cooler fan, Sony International, 230V, 50 Hz, 1440 rpm, Class-A). The sample was placed at a distance of 43.3 cm from heater side. An arrangement was made to place the sample in such a way that weight of the sample could be measured continuously without taking the sample out of the dryer (Figure-3.6). This arrangement consisted of a double plate and rod arrangement. The material to be dried was kept on one plate whereas the other plate was placed on the weighing machine (XB 620M Precisa Max-620g e=0.01g, Min-0.02g d=0.001g). A door made up off perspex is provided for loading and unloading of sample to be dried. A temperature sensor was provided for the measurement and control of temperature inside the chamber. An electric on-off switch is connected with the blower for intermittent supply of hot air.

The heater consisted of six rod heaters in two rows. The first row contained four rod heaters while the second row contained two rod heaters as shown in the Figure-3.2. The temperature of the inlet air could be varied by changing the heat flux.

Two perforated asbestos sheets were placed between the heater and the sample to be dried in such a way that the sample does not receive any heat due to radiation. It was made possible to arrange holes in both the asbestos sheet in a particular manner so that the holes were not aligned. The hole diameter and the distance of the plates were chosen to ensure it. The arrangement of the two asbestos sheets is shown in the Figure-3.3.

The arrangement for continuous measurement of mass of the sample is shown in Figure-3.4-3.6. It consisted of two plates with the help of two rods. The lower plate was kept on the weighing machine placed outside the dryer. The material to be dried was kept on the upper plate.

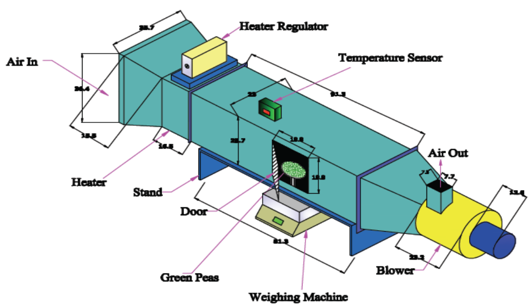

Figure 1: Side View of Drying Unit

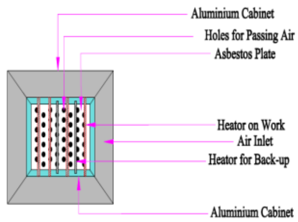

Fig-3.2 Front View of Drying Unit

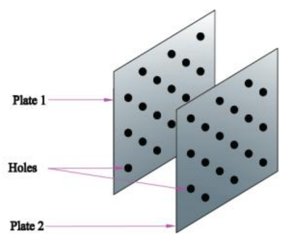

Fig-3.3 Arrangement of Asbestos Sheets

Experimental Procedure

The experiments were carried out in pulsed mode as well as in continuous mode for the purpose of comparison. The experimental procedure for continuous & pulsed mode is described below.

Before starting the drying operation, the unit was run for half an hour to get constant drying conditions. After that the temperature at the outlet, inlet, inside the chamber was noted. The wet bulb temperatures were also measured. From the wet bulb and dry bulb temperatures the humidity of air was determined using psychometric chart. The initial weight of the material was noted before running the apparatus. The surface area of the material was also calculated.

The sample was kept inside the drying chamber. The mass of the sample was measured at a regular interval of time until the end of the experiment. When three consecutive weights were equal, then the constant reading was taken as the equilibrium moisture content and drying was stopped. The dried material was taken out from the drying chamber and was kept in electric furnace at a temperature of 110^0C for one hour. The weight of the material was noted as weight of moisture free solid material. Those data were used for drawing various drying curves.

Same procedure was followed by supplying the hot air in intermittent manner by operating the electric switch to obtain the drying data for pulse manner. The obtained data were used to estimate various drying curves.

During the experiments, it was assumed that the weight lost due to blowing of air was negligible while continuous weight of the drying material was taken. The surface area of each green peas which were dried were assumed to be same with spherical shape. Heat transfer from the container plate to the peas by conduction was negligible.

Run No.	Temperatures (Inlet Air)			Weights (Drying Sample)			Remark
	Ambient	Dry Bulb	Wet Bulb	Initial	Equilibrium	Dry	
	Material Dried Card-board				Drying Area 0.0125m²		
1	21-23	69	44	11.301	6.657	6.5754	Continuous
2	20-22	58	26	11.543	6.805	6.613	Continuous
3	22-24	47	23	13.781	6.885	6.628	Continuous
4	15.5-22	51	26	14.601	7.143	6.476	Continuous
5	20-23	52	22	12.95	6.637	6.476	10/10s Pulse
6	19-22.5	49.5	24	14.745	6.963	6.476	20/20s Pulse
7	19-22	48	20	12.228	6.903	6.476	30/30s Pulse
	Material Dried Green Peas				Drying Area 0.006694829 m²		
8	27-33	48	23	13.723	3.332	3.332	Continuous
				Drying Area 0.006415878 m²			
9	32-36	50	24	13.016	3.414	3.414	5/5s Pulse
				Drying Area 0.006136927 m²			
10	32-36	51	23	12.630	3.281	3.281	10/10s Pulse
				Drying Area 0.006136927 m²			
11	27-30	53	26	12.282	3.312	3.312	15/15s Pulse
				Drying Area 0.005857976 m²			
12	28-34	53	23	12.462	3.090	3.090	20/20s Pulse

Sample Calculation

Few preliminary runs are being carried out to validate the experimental procedure and to adjust the heat flux so that the experimental errors will be minimized.

The sample calculation is carried out for second row of Table-A1.1 (Run-1)

The moisture content was calculated by subtracting the weight of the moisture free sample from the current weight.

9.522 -6.5754 = 2.946

X is the fraction of moisture content in dry basis calculated by dividing the moisture content by the weight of the moisture free sample. 3.882 / 6.5754 = 0.447993

Average X is calculated as $(X_1+X_2)/2$, where X_1 & X_2 are two successive weights weight fraction of sample,

(0.718522 + 0.447993)/2 = 0.583258

The rate of drying, N is calculated as $(W_1-W_2)/A\ \Delta t)$

[(11.301- 9.522)/ (0.0125) (0.083)]/1000 = 1.7147 kg/m^2hr

IV. RESULTS AND DISCUSSIONS

A) Effects on variation of temperature

Moisture content Vs Time

Moisture content as a function of time for drying of card-board at different dry-bulb temperatures (69^0C for Run-1, 58^0C for Run-2 & 47^0C for Run-3) is presented in Figure-4.1. At higher air inlet temperature drying is faster. After a certain time as moisture content decreases rapidly it attains equilibrium quickly.

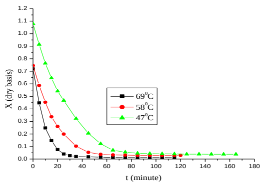

Fig-4.1 Moisture Content vs. Time (for Run-1 to 3)

Rate of Drying vs. Moisture Content

Rate of drying as a function of dry basis moisture fraction for drying of card-board at different dry-bulb temperatures (69^0C for Run-1, 58^0C for Run-2 & 47^0C for Run-3) is shown in Figure-4.2. It is seen that by decreasing the dry bulb temperature the rate of drying decreases.

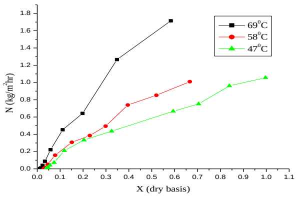

Fig-4.2 Rate of Drying vs. Moisture Content (for Run-1 to 3)

Rate of Drying vs. Time

Rate of drying as a function of time for drying of card-board at different dry-bulb temperatures (69^0C for Run-1, 58^0C for Run-2 & 47^0C for Run-3) is described in Figure-4.3. The rate of drying decreases with time by decreasing the dry bulb temperature.

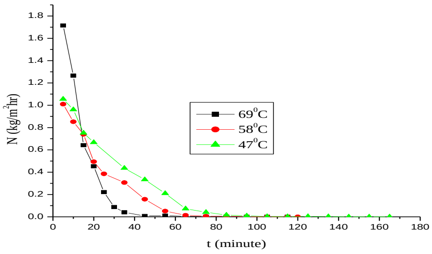

Fig-4.3 Rate of Drying vs. Time (for Run-1 to 3)

B) Effects on variation of pulse

Moisture Content vs. Time

Moisture content as a function of time for drying of card-board at constant dry-bulb temperature for varying pulse durations (No pulse for Run-4, 10/10s pulse for Run-5, 20/20s pulse for Run-6 & 30/30s pulse for Run-7) is presented in Figure-4.4. Here it was found that increasing pulse duration equilibrium moisture content received slowly.

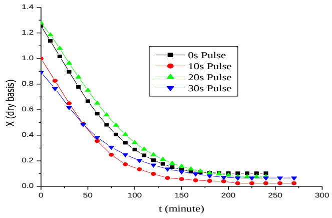

Fig-4.4 Moisture Content vs. Time (for Run-4 to 7)

Rate of Drying vs. Moisture

Rate of drying as a function of dry basis moisture fraction for drying of card-board at constant dry-bulb temperature for varying pulse durations (No pulse for Run-4, 10/10s pulse for Run-5, 20/20s pulse for Run-6 & 30/30s pulse for Run-7) is provided in Figure-4.5. As the pulse duration increases the rate of drying decreases. Much information could not detect due to different initial moisture fractions

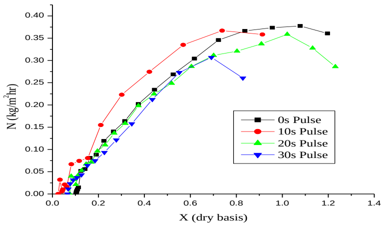

Fig-4.5 Rate of Drying vs. Moisture Content (for Run-4 to 7)

Rate of Drying vs. Time

Rate of drying as a function of time for drying of card-board at constant dry-bulb temperature for varying pulse durations (No pulse for Run-4, 10/10s pulse for Run-5, 20/20s pulse for Run-6 & 30/30s pulse for Run-7) is presented in Figure-4.6. Much information could not detect due to different initial moisture fractions.

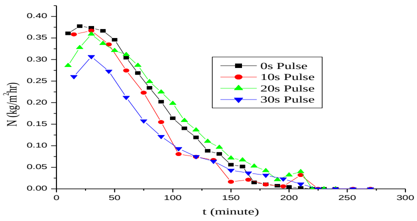

Fig-4.6 Rate of Drying vs. Time (for Run-4 to 7)

C) Effects on Variation of Pulse for Green Peas

Moisture Content vs. Time

Moisture content as a function of time for drying of green peas (Pisum sativum) at constant dry-bulb temperature for varying pulse durations (No pulse for Run-8, 5/5s pulse for Run-9, 10/10s pulse for Run-10, 15/15s pulse for Run-11 & 20/20s pulse for Run-12) is presented in Figure-4.7. The rate of decrease of moisture content for 5s pulse is lowest as the supply of hot air was cut before the drying material got a slight increase in temperature. So it takes a larger time to get sufficient heat for better evaporation. Similarly the rate of decrease of moisture content of 20s pulse curve is quite lower. Because hot air supply cut-off time is so large that the hot material became cooler by conduction & radiation of supplied heat.

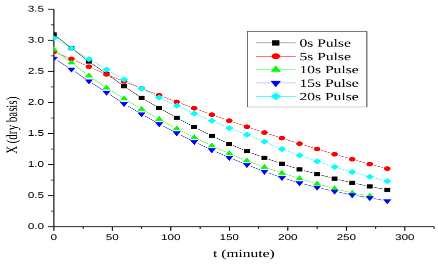

Fig-4.7 Moisture Content vs. Time (for Run-8 to 12)

Rate of Drying vs. Moisture Content

Rate of drying as a function of dry basis moisture content for drying of green peas (*Pisum sativum*) at constant dry-bulb temperature for varying pulse durations (No pulse for Run-8, 5/5s pulse for Run-9, 10/10s pulse for Run-10, 15/15s pulse for Run-11 & 20/20s pulse for Run-12) is plotted in Figure-4.8. As the duration of pulse increases, the rate of drying decreases simultaneously. Similarly by decreasing the pulse duration to very small the rate of drying also decreases the rate of drying So very low pulse durations are also not preferable for optimum drying.

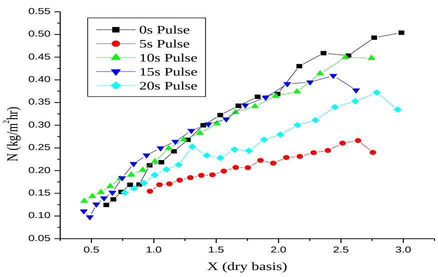

Fig-4.8 Rate of Drying vs. Moisture Content (for Run-8 to 12)

Rate of Drying vs. Time

Rate of drying as a function of time for drying of green peas (*Pisum sativum*) at constant dry-bulb temperature for varying pulse durations (No pulse for Run-8, 5/5s pulse for Run-9, 10/10s pulse for Run-10, 15/15s pulse for Run-11 & 20/20s pulse for Run-12) is drawn in Figure-4.9. Enhancement of knowledge about variation of rate of drying with duration of pulse can be done with the help of following graph. The rate of drying is initially lower lower for pulse drying as the drying material takes a larger time to be heated upto it's vaporization temperature due to the cut-off of hot air supply. The rate of drying is lower for higher & lower supply period of hot air. A medium intermittent supply such as 10s pulse & 15s pulse shows a better rate of drying with reference to the 0s pulse.

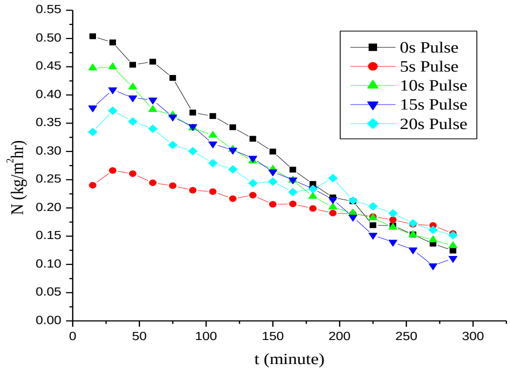

Fig-4.9 Rate of Drying vs. Time (for Run-8 to 12)

D) Data Co-relation

Several equations are there to co-relate the obtained data of moisture content with time for thin film drying. To obtain the co-relation the moisture content is first converted to dimensionless moisture ratio (MR) using the formula given below

$$\boxed{MR = \frac{(M - M_e)}{(M_0 - M_e)}}$$

Where M represents the moisture fraction in dry basis at time t, M_e is the equilibrium moisture fraction in dry basis & M_o stands for initial moisture fraction in dry basis.

CONCLUSION

Based on present investigation following conclusions were observed.

- The rate of drying & time of drying increased with increase in temperature for drying of card-board.
- As the duration of pulse increased, the rate of drying also decreased with increasing the drying time.
- Similar effects on rate of drying and drying period were also observed for less duration of pulse.
- Drying for 10s-15s pulse range was advantageous.
- Modified Page model (with model constants n=1.17 & drying constant k=0.00534s-1) was the best model among the models studied with coefficient of co-relation (R2) > 0.997.

Recommendations

Some of the recommendations for the further study of this these topics are

- The analysis of pulse drying characteristics of the drying material should be done applying certain pre-treatments.
- Modeling of the drying instrument may also be done by considering shrinkage.
- Mixed manner drying should be used to optimize drying time in pulse drying.
- The pulse drying should be studied further for various types of fruits and vegetables.
- The effects on surface morphology and developments of cracks etc. should be studied.

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