FE 483 FOOD ENGINEERING OPERATIONS LABORATORY

SPRAY DRYING

Objectives

The objectives of this experiment are to become familiar with a spray drying operation, to calculate the overall efficiency of a spray dryer, to observe how the quality of the final powder is affected by the main process variables.

Introduction

The spray drying process is the simplest method and transforms a pumpable fluid feed into a dried product in a single operation. The fluid is atomized using a rotating wheel or a nozzle, and the spray of droplets comes immediately in contact with a flow of hot drying medium, usually air. The resulting of rapid evaporation maintains a low droplet temperature so that high drying air temperatures can be applied without affecting the product. The time of drying of the droplets is very short (1-20 s) in comparison with most other drying processes. Low product temperature and short drying time allow spray drying of very heat sensitive products such as foods, dairy products, and fruit juices. It is a one-step continuous suspended particle processing operation. The feed can be a solution, suspension or paste. The resulting dried product conforms to powders. Coffee, eggs, milk, soups, baby foods, fruit juices, cheese etc are among the foodstuffs normally spray-dried.

The high hygroscopicity and thermoplastic nature of fruit juice powders give rise to problems such as adhesion to dryer walls, difficult handling, and caking. The use of additives to facilitate drying and improve transport and storage properties of the powder is necessary. The spray drying of fruit juices is very complex. Chemical composition of juices is complex also. About 90% of dry substances in juices consist of different hydrocarbons such as monosaccharides (glucose, fructose), disaccharides (sucrose), and polysaccharides. The presence of organic acid (malic, tartaric, citric acids) in fruit juices causes particles stick to dryer walls. Maltodextrins, gum arabic, sodium caseinate, cellulose derivatives are the usual carriers for drying juices such as orange, apricot, and peach. Low-molecular-weight polymers (sucrose) and monomers (fructose, glucose) have low glass transition temperatures (Tg). Long chain molecules have higher Tg; therefore, the Tg decreases with decreasing molecular weight. The sticky point of food powders decreases with decreasing molecular weight and products with low Tg also have sticky point at low temperature. Stickiness of such products can be reduced and stability increased by adding compounds with higher Tg values. A glass transition event occurs when an amorphous, hard and solid sugar or acid molecule undergoes a transformation to a soft and rubbery phase.

Table 1 shows the glass transition temperature of anhydrous sugars, organic acids, maltodextrins (hydrolyzed starch), and starch. The use of additives such as starch and maltodextrins with high glass transition temperature break up the hydrogen bonds between amorphous materials and water and eliminate stickiness of the particles during spray drying, storage, and handling.

Table 1. Glass transition temperature of various sugars, acids, and carbohydrate materials.

Food Materials	Molecular Weight	Tg Value (°C)
Fructose	180	5
Pure malic acid	134	11
Pure citric acid	192	16
Pure tartaric acid	150	21
Glucose	180	31
Galactose	180	32
Sucrose	342	62
Maltose	342	87
Lactose	342	101
Maltodextrin		
DE 36	500	100
DE 25	720	121
DE 20	900	141
DE 10	1800	160
DE 6	3000	168
Starch	Variable	243

A spray dryer system involves an air heater, drying chamber, system for dispersing material to be dried as droplets in the drying chamber (atomization of feed into a spray and contact between spray and the drying air), system for collecting dry particles from the air and one or more blowers for moving air through the system. These stages roughly are illustrated in Figure 1.

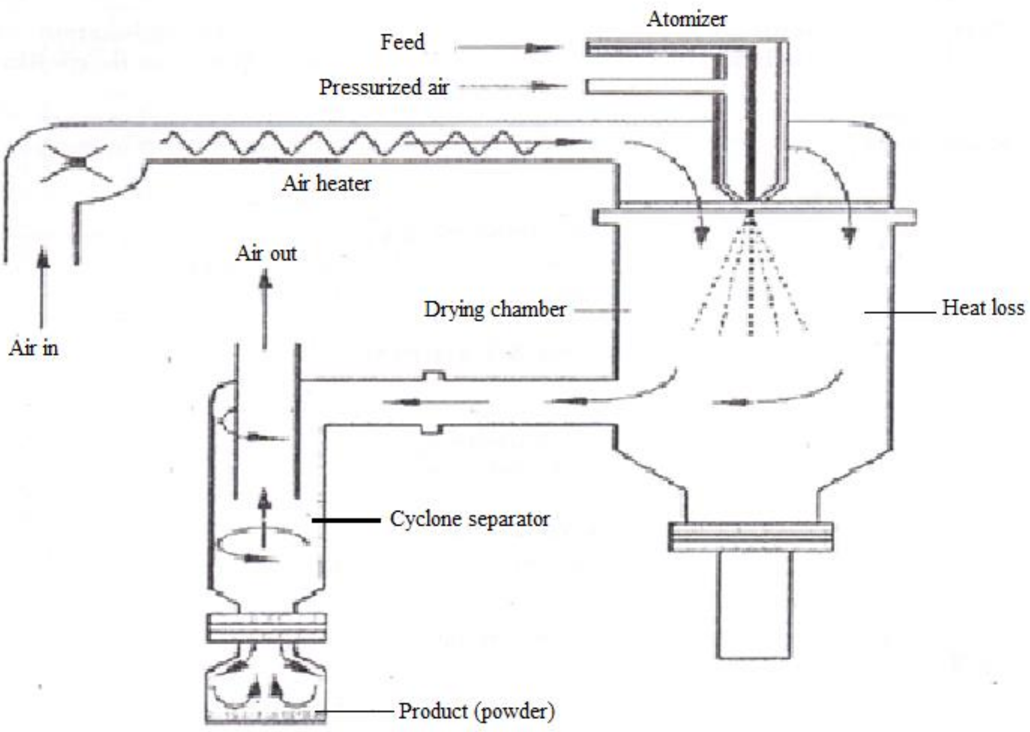

Figure 1. Components of a typical spray dryer.

Procedure

1. Start up the dryer
2. Turn on the air aspiration blower. To start air heating, turn on the heater button
3. Adjust the temperature of the air entrance (between 100 - 200ºC)
4. Start the atomization procedure (turn the compressor button) ensure that the air pressure must be kept constant, in order to obtain an efficient liquid atomization
5. Feed the atomization with distilled water (to adjust the drying conditions). Keep a gradual strain of water until the desired temperature (100ºC) is reached
6. Prepare 200 ml of instant coffee solution with approximately 20% w/w of solids (use commercial coffee powder and hot water).
7. Change the feed water in the spray drier with the sample to be dried
8. Be sure to keep the air exit temperature constant during the drying operation, to maintain the water content constant of the dried product
9. Complete the drying of instant coffee solution
10. Change the atomizer feed with distilled water, and change the product collecting bottle. The quantity of feed water must be regulated not to lower the exit temperature. Keep the unit operating with distilled water for another 5–10 min
11. Turn off the distilled water feed to the atomizer
12. Turn off the heater buton (keep only the air aspiration)
13. After 3 min, turn off the atomizer and keep the cold air circulating in the drier until the exit temperature is approximately 50ºC
14. Turn off the air aspiration blower and stop the dryer.

Calculations

Moisture balance in the spray dryer

- Moisture entering in feed = $M_s(W_s)_1$
- Moisture entering in hot air = $G_a(H_1)$
- Moisture leaving the dryer in the dried product = $M_s(W_s)_2$
- Moisture leaving in the exhaust drying air = $G_a(H_2)$

where,

M_s : dry solids in feed (kg dry solids)
$(W_s)_1$: water content of feed (kg water/kg dry solids)
$(W_s)_2$: water content of the product (kg water/kg dry solids)
G_a : dry air entering the drying chamber (kg dry air)
H_1 : absolute humidity of air entering the drying chamber (kg water/kg dry air)
H_2 : absolute humidity of air leaving the drying chamber (kg water/kg dry air)

Under steady state operations, there is no accumulation in the chamber. The following equation holds for mass balance in the drying chamber:

INPUT = OUTPUT

$$M_s(W_s)_1 + G_a(H_1) = M_s(W_s)_2 + G_a(H_2) \quad \text{OR}$$

$$M_s[(W_s)_1 - (W_s)_2] = G_a(H_2 - H_1)$$

The enthalpy or heat balance in the spray dryer

- Enthalpy of air entering dryer = $G_a(Q_a)_1$
- Enthalpy of feed entering dryer = $M_s(Q_s)_1$
- Enthalpy of exhaust drying air = $G_a(Q_a)_2$
- Enthalpy of product = $M_s(Q_s)_2$

HEAT INPUT = HEAT OUTLET + HEAT LOSS

$$G_a(Q_a)_1 + M_s(Q_s)_1 = G_a(Q_a)_2 + M_s(Q_s)_2 + Q_L$$

Q_L : heat loss from the dryer

Notice that the heat loss can be very small if one has a well-insulated chamber though there are some cases of defective insulation or special chamber design in which air is cooling the walls to allow handling of special products.

Specific enthalpy of feed $(Q_s)_1$ is the sum of the enthalpy of the dried solids and the moisture as a liquid (kJ/kg dry solids).

$$(Q_s)_1 = C_{DS}\,(T_{feed} - T_{ref}) + (W_s)_1\, C_W\,(T_{feed} - T_{ref})$$

Specific enthalpy of product $(Q_s)_2$ is the sum of the enthalpy of the dried solids and the moisture in product (kJ/kg dry solids).

$$(Q_s)_2 = C_{DS}\,(T_{product} - T_{ref}) + (W_s)_2\, C_W\,(T_{product} - T_{ref})$$

where,

C_{DS} : heat capacity of dry solids (kJ/kg dry solids.ºC)
C_w . heat capacity of moisture (in liquid form) (kJ/kg H_2O.ºC)

T_{ref} : a reference temperature (normally chosen as 0ºC).

Enthalpy of the drying air (Q_a) can be computed either at the inlet or outlet of the drying chamber by :

$$Q_a = C_s\,(\Delta T) + H \times \lambda$$

where,

Cs : humid heat = 1.005 + 1.88x(H) in SI units (kJ/kg dry air.ºC)

λ : latent heat of vaporization at references temperature (kJ/kg water)

H : absolute humidity (kg water vapor/kg dry air)

Specific enthalpy of air inlet (kJ/kg dry air) : $Q_{a1} = [(1.005 + 1.88x(H_1)]x(T_1 - T_{ref}) + H_1 \times \lambda$

Specific enthalpy of air outlet (kJ/kg dry air) : $Q_{a2} = [(1.005 + 1.88x(H_2)]x(T_2 - T_{ref}) + H_2 \times \lambda$

- The overall thermal efficiency $\eta_{overall}$ is defined as the fraction of the total heat supplied to the dryer used in the evaporation process. In the case of a truly adiabatic system, it can be approximated to the relation:

$$\eta_{overall} = \left[\frac{T1 - T2}{T1 - T0}\right] x100$$

where,

T_1 : temperature of air entering the spray dryer

T_2 : temperature of air leaving the spray dryer

T_0 : temperature of the atmospheric air.

- Evaporative efficiency is defined as the ratio of the actual evaporation capacity to the capacity obtained in the ideal case of air leaving the dryer at saturation conditions. It can be approximated to the relationship:

$$\eta_{evap} = \left[\frac{T1 - T2}{T1 - Tsat}\right] x100$$

where,

T_{sat} : adiabatic saturation temperature corresponding to T_1

- The thermal efficiency of a spray dryer depends upon the operation temperatures. As it is normal practice not to recover the heat content in the air exhausted from the drying chamber, the thermal efficiency is increased by increasing the temperature of the air entering the chamber and operating the dryer at an outlet temperature as low as the process allows. Maximum thermal efficiency (ideal case) is obtained by exhausting the drying air in a saturated state. It is defined as the ratio

$$\eta_{max} = \frac{\text{Heat used in evaporation}}{\text{Heat input}} = \left[\frac{T2 - Tsat}{T2 - T0}\right] x100$$

- The operational efficiency is the ratio of total dry solids in the product to the total dry solids initially fed to the dryer.

$$\eta_{oper} = \left[\frac{Mf}{Mi}\right] x100$$

where,

M_f : total mass of dry solids in the product

M_i : total mass of dry solids fed to the dryer

The residence time of the product is an important parameter in the design and selection of operating conditions for the dryer because it allows moisture to leave the product. The minimum residence time can be computed by dividing the volume of the chamber by the air volumetric flow. In the case of a cylindrical drying chamber with a conical base, the volume can be computed by the following assuming a 60º cone angle:

$$V = 0.7854 \times D^2 \times (h + 0.2886 \times D)$$

where,

V : volume of the drying chamber
h : cylindrical height of drying chamber
D : diameter of the drying chamber

Measurements

- Density of feed
- Feed temperature
- Dry bulb temperature and relative humidity of ambient air (or any other two properties of air)
- Spray dryer inlet and outlet air temperatures
- Total dry solids in feed
- Product temperature
- Moisture content of product
- Diameter and height of drying chamber

Data analysis and questions

1. Calculate water content of feed and product (kg water/kg dry solids)
2. How much water is removed at experimental drying conditions (kg water vapor/kg dry air)
3. How much water could be removed in the ideal case of air leaving the dryer at saturation conditions. Discuss why it is different from question 2.
4. Calculate the total amount of dry air (G_a) used (kg dry air)
5. Calculate the total amount of wet air used (kg wet air)
6. Perform a heat and mass balance
7. Compute heat loss and percent heat loss
8. Compute the overall thermal efficiency
9. Compute the evaporative efficiency
10. Compute the maximum thermal efficiency
11. Compute the operational efficiency of process
12. Compute volume of drying chamber
13. Compute the minimum residence time of a particle if linear air velocity of air passing through the pipe is 3 m/s and inner diameter of pipe is 5 cm.

References

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3. McCabe, W.L., Julian, C.S. and Harriot, P. Unit Operations of Chemical Engineering, 5th Edition, McGraw-Hill Inc., 1993.
4. Hui, Y.H. Encyclopedia of Food Science and Technology, V: 1, John Wiley & Sons Inc., New York, 1992.

Please learn more about the psychrometric chart and its applications !!!

DATA SHEET

- Concentration of feed solution % (w/v) :
- Density of feed (g/ml) :
- Feed temperature (°C) :
- Dry bulb temperature of ambient air (°C) :
- % Relative Humidity of ambient air :
- Spray dryer inlet temperature (°C) :
- Spray dryer outlet temperature (°C) :
- Moisture content of instant coffee (% wb) :
- Moisture content of product (% wb) :
- Diameter of drying chamber (cm) :
- Height of drying chamber (cm) :
- Weight of product (g) :

Date: First/Second Education :

Group Members: