Heat and Mass transfer Study in the Spray Drying of Tomato Juice

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Abstract:

Spray drying is a procedure which is now used for a wide range of applications ranging from food products to chemicals. In this work, a co-current spray dryer is used and the tomato juice feed is initially heated to a temperature of 60 ºC. Also, pressurized nitrogen gas is used for atomizing the feed and thereby improving the performance of the spray dryer. Experiments have been performed at different inlet air temperatures while the other parameters like air flow rate, feed flow rate and feed temperature are maintained essentially constant. Through this study, it is found that immediately after the atomized feed are exposed to the drying medium, the relative humidity of the drying air reaches a maximum (99.99% RH), remains constant during the spray time and then decreases when the spray time is over. It is also found that, as the inlet air temperature is varied from 133 ºC to 161 ºC, there is an increase of 11.62% in heat transfer rate and a marginal increase of 0.51% in mass transfer rate.

Key-Words: Spray drying, Co-current dryer, Tomato juice, Heat transfer, Mass transfer, Feed heating

1 Introduction

Spray drying is a procedure which in many industries meets dried product specifications most desirable for subsequent processing or direct consumer usage. Intensive research and development during the last two decades has resulted in spray drying becoming a highly competitive means of drying a wide variety of products. Spray drying has moved into all major industries ranging from production in the most delicate of conditions laid down in food and pharmaceutical manufacturing right through the high tonnage outputs for processing of clays, mineral ores and chemicals. In this work, a spray dryer has been developed for fruit juice drying (tomato). Fruit juices in solid form have many advantages including ease of packaging, transportation and mixing.

The co-current dryer, used in the experiment is preferred for heat sensitive products because the inlet drying air contacts the atomized droplets when their moisture content is at a maximum. Here, the heat and mass balance for the system is evaluated to find out the quantity of drying air per hour to remove the water content in the juice.

2 Literature Review

Adamopoulous et al., [1] studied the spray drying of tomato pulp in dehumidified air and its effect on product recovery. It is found that dehumidified air which is used as the drying medium can increase product recovery compared to undehumidified air. The product recovery and residue accumulation which depends on inlet temperature, drying air flow rate and compressed air flow rate was found to be 36.63%- 65.82% higher and 20.17%- 45.83% higher as compared to spray system using undehumidified air. Adamopoulous et al.,[2] studied the effect of dehumidified type spray drying system on powder properties. On research it was found that powder moisture content decreases, solubility increases and bulk density increases with a decrease in drying air flow rate. Also, the powder moisture content decreases and solubility increases with an increase in compressed air flow rate. Kieviet et al.,[3] studied the temperature and humidity pattern in spray drying using a co- current dryer and the parameters were measured using a micro-separator. The pattern was modeled using a computational fluid dynamics program and the measured values matched well with the model.

Fernández-Péreza et al.,[4] investigated the effect of the inlet air temperature and feed flow rate on the dry product. Results showed that higher the temperature of inlet air, the faster the moisture evaporation. However, the powder is subjected to higher temperatures which may distort the chemical or physical properties of the product. A research made by T. Hino et al [5] investigated the diameters of spray droplets. It was concluded that the finest mists and dried products are obtained with the use of two fluid phase spraying nozzles as they were capable of blowing off fine droplets sized 10- 50 μm as compared to ordinary pressure nozzles which produce droplets having a diameter of 10^2- 10^3 μm. Goula A.M et al [6] discussed about the temperature profile of the product during each spray drying and the product temperature was found to be constant. And it was observed that in all experiments, drying was characterized by a short equilibrium period, during which the solid surface conditions are in equilibrium with the drying air.

From the study made on these literatures, it can be concluded that the inlet temperature, drying air flow rate and feed flow rate play a vital role in spray drying and the feed has not been heated initially. Therefore, an attempt is made to heat the feed (tomato juice) to 60 ºC.

3 Theoritical Considerations

3.1 General guidelines for spray dryer design

The basic design selects itself from the given powder specifications such as particle size distribution, particle form and the maximum temperature to which particles can be subjected to conduct the heat and mass transfer balance calculations. Sufficient residual time is essential to permit completion of the drying operation in order to meet the product specification. The required amount of air flow through the dryer may be determined by the heat and mass transfer balance calculations but the residual time determines the chamber size. As the drying chamber represents an item of large cost in any spray drying installation, correct sizing of the drying chamber is essential for minimizing installation costs.

Drying chambers are designed to handle an air volume containing sufficient heat for drying the spray droplets and to provide a residual time sufficient for the droplets to be dried. The optimum residual time is the time taken for completion of drying process with minimum increase in the temperature of the drying product.

3.2 Effect of operating variables on heat consumed in dryer

- Inlet temperature: Increase in inlet temperature decreases the amount of heat required by the dryer to produce a product of given specifications.

- Feed solid content: Spray drying is an expensive method for evaporating volatiles and thus to obtain optimum heat utilization conditions, the spray dryer should always be fed with the maximum solid feed stock possible.

- Drying temperature difference: The higher the temperature difference, the lower the heat required to produce a unit weight of product of constant residual moisture content from solid feed stock. This can be achieved by decreasing outlet temperature or increasing inlet temperature.

- Feed temperature: Increasing the feed temperature reduces the heat required to produce a unit weight of dried product. Also, pre-heating of feed is normally carried out to reduce the feed viscosity, thereby improving atomization performance and to prevent crystallization that can cause blockage in the atomizer.

4 Experimental Procedure

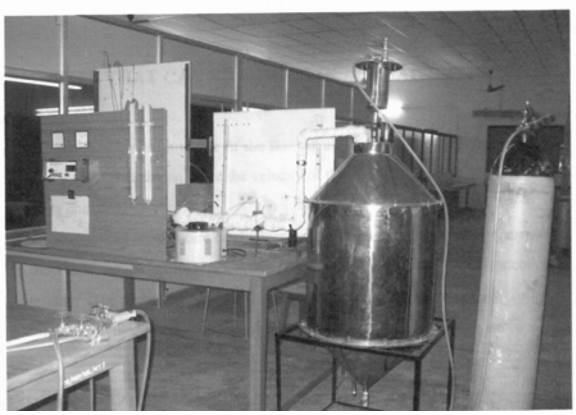

Fig. 1a: Overall setup of spray dryer

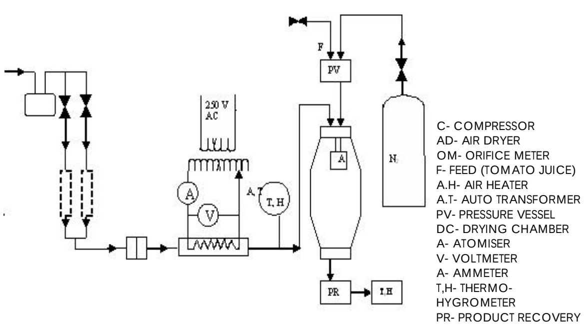

Fig. 1b: Schematic representation of spray dryer layout

Fig. 1 shows the schematic arrangement laboratory scale spray drying system designed and constructed to conduct the experimental part of the study. Air, supplied by a compressor is passed through an air dryer and a filter to remove the moisture and dust present in the air. It is then passed through a heater of maximum capacity 2.2 kW. The exit temperature of air from the heater is maintained constant for each experiment. The air flow rate is measured using a pre- calibrated orifice placed upstream from the heater. A U- tube manometer measures the pressure drop across the orifice plate. A Chromel- Alumel thermocouple is used to measure the dry bulb and wet bulb temperatures of the air at inlet. To measure the dry bulb temperature, wet bulb temperature and relative humidity of air, a thermo- hygrometer (KUSAM- MECO918) is installed at the outlet.

The feed (tomatoes) is crushed to form a puree after carefully removing the skin and seeds, and further refinement is done to reduce the particle size. And this juice is immediately heated to a temperature of 60ºC. However, the exact temperature depends upon the type of tomatoes used and finished powder specifications. The feed is then fed into the atomizer through the pressure vessel which uses inert nitrogen gas at high temperature. Atomization is done through a pressure nozzle. The inlet drying air, after passing through the electrical heater flows co-currently with the spray where it contacts the liquid feed droplets and thus evaporation takes place in the drying chamber. Spray evaporation is rapid and the temperature of the drying air is drastically reduced by the vaporization of water.

Readings are taken by varying the inlet temperature between 130ºC and 160ºC and keeping the other parameters such as feed flow rate, feed temperature and inlet air flow rate constant. 0.4kg of tomato juice sample was taken and heated at a specified temperature of 60 ºC and fed into the pressure vessel. Dried samples are collected from the base of the drying chamber. Some amount of the dried sample which is stuck on the circumference of the drier is removed by scraping. The dried sample is weighed and then dried in the oven. This final sample is again weighed to find out the mass transfer rate in the spray dryer. It is determined experimentally that the tomato juice specimen contains only 8% solid content as compared to the theoretically determined 10%. The air flow rate, determined by means of an orifice meter is found to be 0.275 kg/ min.

The total heat transfer may be calculated as per the following relation,

$$\frac{Q_T}{m_F} = C_P(T_P - T_C) + X_a C_L (T_V - T_F) + (X_a - X_a)\lambda + X_b C_L(T_P - T_V) + (X_a - X_b) C_V (T_O - T_V) \quad (1)$$

where,
C_P , Specific heat of ice = 2.1 kJ/kg K
C_L , Specific heat of water = 4.2 kJ/kg K
C_V , Specific heat of vapour [9] =2. 205 kJ/kg K
T_P , Tomato Powder Temperature (ºC)
T_F , Tomato pulp feed Temperature (ºC)
T_V , Vapourising Temperature (ºC)
T_O , Exit Temperature (ºC)
X_a , Initial moisture content (%)
X_b , Final moisture content (%)
λ- Latent heat of vapourization (kJ/kg)

The mass transfer rate in the actual spray drying process is calculated as

$$\text{Mass Transfer Rate} = m_s * (X_a - X_b) \quad (2)$$

where,
X_a , Initial moisture content (%)
X_b , Final moisture content (%)

5 Results and Discussion

An increase of 30 ºC in air inlet temperature results in an increase of 11.62% in heat transfer rate and a marginal increase of 0.51% in mass transfer rate.

T_i (^{0}C)	Heat Transfer Rate (kJ/ min)	Mass Transfer Rate (kg/ min)
133	652.501	0.3682
141	695.478	0.3693
149	706.557	0.3695
157	712.369	0.3697
162	728.397	0.3701

Table1: Comparison of heat and mass transfer rates at varying inlet air temperatures

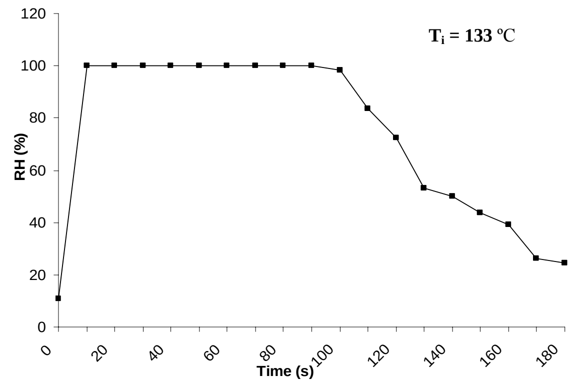

Fig. 2: Plot of Exit Relative Humidity w.r.t. Time (T_i = 133 ºC)

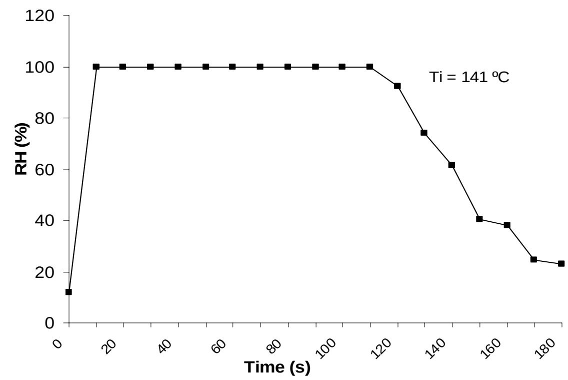

Fig. 3: Exit Relative Humidity of Air vs. Time (T_i = 141 ºC)

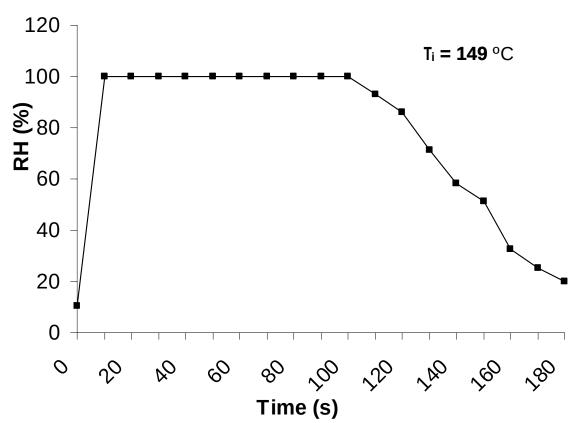

Fig. 4: Plot of Exit Relative Humidity of Air w.r.t. Time (T_i= 149 ºC)

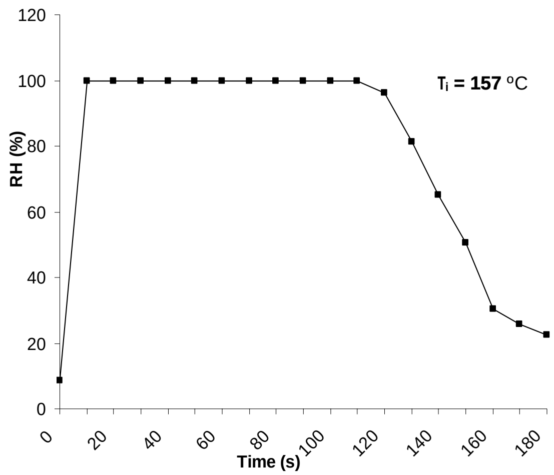

Fig. 5: Plot of Exit Relative Humidity of Air w.r.t. Time (T_i = 157 ºC)

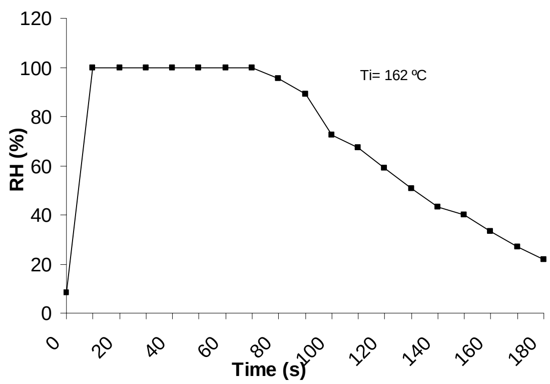

Fig. 6: Plot of Exit Relative Humidity of Air w.r.t. Time (T_i= 162 ºC)

In the above figures (2 to 6), the relative humidity of air at the exit increases as soon as the droplets come into contact with drying air. Immediately it reaches 100% RH and remains constant during spray time and finally it begins to decrease when the spray time is over.

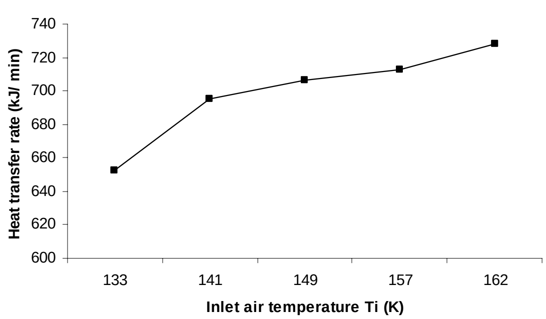

Fig. 7: Effect of Air Inlet Temperature(T_i) on Heat Transfer Rate

Fig 7. shows the plot between heat transfer rate and air inlet temperature and it can be inferred that heat transfer depends upon the temperature difference of the inlet and outlet drying air temperature. Also, increasing the drying air inlet temperature leads to increase in heat transfer rate. For an increase of 30 ºC in air inlet temperature, there is an 11.62% increase in heat transfer rate.

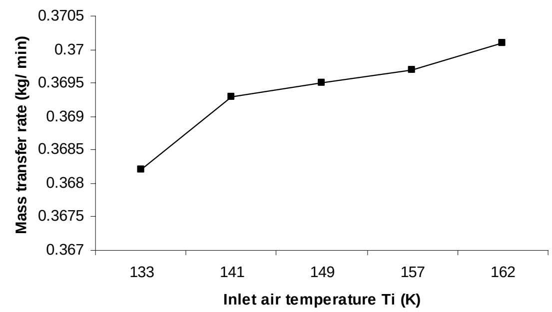

Fig. 8: Effect of Air Inlet Temperature (T_i) on Mass Transfer Rate

As seen from Fig. 8, the increase in drying air inlet temperature leads to increase in the mass transfer rate in the actual spray drying process. But in this case, there is only a marginal increase in mass transfer rate (0.51%) for an increase of 30 ºC in air inlet temperature.

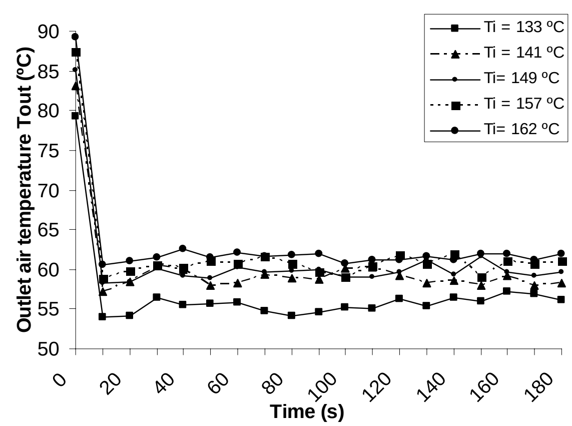

Fig. 9: Plot of Air Outlet Temperature (T_{out} K) w.r.t. Time

As is evident from Fig. 9, the air outlet temperature is higher for higher drying air inlet temperature. Also, the outlet air temperature initially reduces drastically when it contacts the liquid droplets and later becomes constant during the spray time. This plot is similar to that obtained by researchers Kieviet et al. [3]

6 Conclusion

- The quantity of air and heat required is lesser compared with the non feed heating spray drying system.
- The temperature and humidity profile of the actual spray drying process are drawn and compared. It can be seen that a dryer has almost constant temperature and humidity during spray time.
- The heat and mass transfer rate depends on the rate at which the drying medium contacts the liquid droplets i.e., the heat and mass transfer rate increases with increase in air inlet temperature and the moisture content in the final product is reduced when the air inlet temperature increases.
- For an increase of 30 ºC in air inlet temperature, there is an 11.62% increase in heat transfer rate and a marginal increase of 0.51% in mass transfer rate.

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