Resistance of Marigold Flowers to Airflow

S. D. Reed, P. R. Armstrong, G. H. Brusewitz, M. L. Stone

Abstract. *Airflow resistance of marigold flowers dried in an experimental rotary dryer was determined by measuring pressure drop versus airflow through a bed of flowers for depths ranging from 0.15 to 1.0 m and flower moisture contents ranging from 10% to 85% (wet basis). A single power relationship adequately described pressure drop for a broad range of flower moisture conditions and airflow. Bulk density varied from 118 to 276 kg/m^3 for bed depths and flower moisture contents ranging from 0.15 to 1.0 m and 10% to 85%, respectively. Moisture content had the most effect on bulk density.*

Keywords. *Airflow, Pressure drop, Bulk density, Marigold flowers.*

Marigold flower petals are a significant source of the carotenoid pigment xanthophyll and have a much higher concentration of this pigment compared to other plant materials (Verghese, 1997). The largest user of marigold–derived xanthophyll is the poultry industry, where it is used as a feed supplement for the coloration of egg yolks and chicken skin. The intensification of yellow color produced in the skin and yolk is highly desired by consumers, and several studies have examined the effects of diets containing xanthophyll on skin and yolk color development (Fletcher et al., 1978, 1986; Hencken, 1992; Piccaglia et al., 1998).

Research at Oklahoma State University is currently investigating the production, harvesting, and processing of marigold flowers to obtain a dried petal material for direct feed use or for the extraction of xanthophyll. Post–harvest processing research efforts have studied drying and petal removal techniques. One concept being tested is a combined rotary dryer and thresher (Armstrong et al., 2000). This system provides more uniform drying than other methods, and the simultaneous removal of petals is possible because of agitation during rotation. An additional advantage is that a significant portion of the petals can be threshed and removed from the system as they dry, to minimize exposure of the xanthophyll to the high–temperature, oxidative environ–ment.

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Data on the resistance to airflow of marigold flowers are needed but not available for commercial dryer design. Bulk density properties, also considered an important part of dryer design, are also needed.

Objectives

The objective of this research was to measure pressure drop vs. bed depth and bulk density vs. bed depth characteristics for marigold flowers at different flower moisture contents. The data obtained would be used to develop model equations to predict pressure drop for a range of drying conditions.

Literature Review

Various biological products ranging from milkweed pods (Jones and Von Bargen, 1992) to wood chips (Cooper and Sumner, 1985) have been studied to determine airflow resistance. Pressure drop data for more common products like grains have been well documented (ASAE Standards, 1995). Airflow resistance through a bed of material is fundamental to the design of air–drying systems and is commonly defined as the pressure drop per unit depth of material (Pa/m) versus the volumetric airflow rate per unit area (m^3/m^{2}s). To determine airflow relationships for a biological material, it is common to include some physical characteristics of the material. Biomass materials have pressure drop characteristics often affected by bulk density and particle size (Cooper and Sumner, 1985). As examples, bulk density and moisture content were shown to affect the slope and intercept of the pressure drop–airflow curves for bluestem grass seed (Farmer et al., 1981) and wet bulk density and airflow were determining parameters for pressure drop in herbage alfalfa cubes (Sokhansanj et al., 1990). For whole potatoes, Irvine et al. (1993) reported that air resistance was affected by potato size and airflow direction for different potato types. Orientation of tobacco leaves was also determined to affect air resistance (Anderson et al., 1998). For marigold flowers, the shape, moisture content, and bulk density during drying were considered to potentially affect air resistance properties.

MATERIALS AND PROCEDURES

TEST FLOWERS

Two marigold flower varieties (I822 and EI236, Resource Seeds, Gilroy, Calif.) were used for this study. Flowers were cultivated on research plots located on a commercial farm near Hydro, Oklahoma. Whole flowers that had mature, well–developed blooms were handpicked into polyethylene bags and brought to the Oklahoma State University Biosystems and Agricultural Engineering Research Lab, where they were stored at 7° C until used for tests. Samples of 25–30 flowers were used to determine initial moisture content by oven drying at 102° C for 24 hours (ASAE Standards, 1998).

AIR RESISTANCE TEST EQUIPMENT

The apparatus used to determine air resistance is shown in figure 1. The material test chamber was constructed from a 1.2–m length of PVC pipe (294 mm inside diameter). The PVC pipe was mounted over an equally sized hole in the top of a plywood box, which functioned as a plenum chamber. A single–inlet, forward–curved blower (Dayton 75 W, 115 V) was mounted to one end of the plenum chamber. Wire screen was used between the test chamber and the plywood box to support the flowers. Foam weather–stripping provided a seal between the plenum and test chamber. A 100–mm inside diameter, 3.05–m long, PVC pipe was connected to the fan inlet to provide airflow straightening to obtain accurate flow velocities. An air gate valve, attached to the inlet of the flow–straightening pipe, provided airflow volume control.

An anemometer probe (VelociCalc TSI model 8350) was inserted through a port located midway along the length of the flow–straightening tube to measure the air velocity profile. Volumetric airflow was computed from the measured velocity and the cross–sectional area of the tube. Static pressure was measured at a port located on the plywood plenum chamber (same face side as the fan) using a Dwyer Magnehelic differential pressure gauge (0–20 mm H_2O full scale). The box port was connected to the high–pressure port of the gauge; the low–pressure gauge port measured atmospheric pressure.

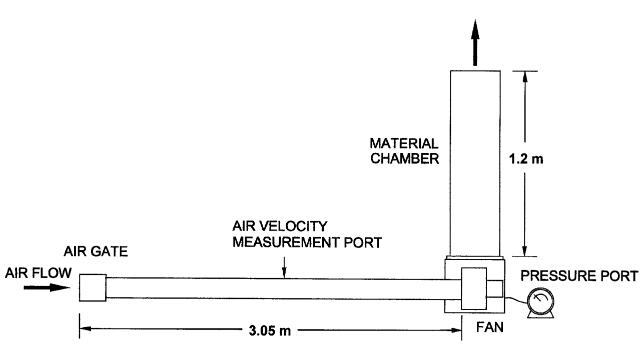

Figure 1. Test chamber to measure pressure drop.

ROTARY DRYER DESIGN CONSIDERATIONS

Marigold airflow resistance testing required some consideration of the rotary drying system that would use the relationships derived from this research. Moisture content, flower shape, and bulk density were expected to affect airflow resistance. During rotary drying, the flower volume decreases significantly due to moisture loss and wilting and can be characterized by bulk density measurements. Changes in flower shape caused by wilting, moisture loss, and tumbling could also affect airflow resistance. Although flower shape was not quantified in this research, the data that were collected pertain to the characteristics of flowers dried by a rotary system.

ROTARY DRYER

The rotary dryer used to condition flowers to different flower moisture contents was 1.2 m in diameter and 0.3 m in width. The dryer was divided into nine equal pie–shaped sectors to provide better air distribution through the flowers. Heated air was supplied to the drum via a 152–mm diameter plenum at the center of the drum. Armstrong et al. (2000) provide a detailed description of the rotary dryer. Drying air temperature during flower drying was 72° C. The average cross–sectional airflow across each drum sector was 0.33 m^3/m^2s, and the drum angular velocity was 1 rpm.

PRESSURE DROP TESTS

Pressure drop measurements were obtained for flowers at various moisture contents and depths. Moisture content conditions were obtained by drying flowers in the rotary dryer for a couple of hours, removing the flowers, and measuring pressure drops as described below. Flowers were placed back in the rotary dryer for additional drying and the same pressure drop procedure was repeated.

Pressure drop measurements for each moisture condition were conducted as follows. The test chamber was filled with non–compacted flowers to a measured depth. Pressure drops were recorded for incremental changes of airflow, which ranged from 0.04 to 0.9 m^3/m^2s. Approximately eight airflow–pressure drop readings were performed for each depth. Additional flowers were added to incremental depths and the measurements were repeated. The total mass of flowers required for each fill depth was computed to determine bulk density. A sample of 30 flowers was taken after each drying period to determine moisture contents of the petals and receptacles. The drying periods, flower moisture contents, and bed depths are shown in table 1. Due to

Table 1. Flower component moisture contents and test depths for pressure drop measurements for drying at 72° C.

Drying Time (h)	Petal MC (% wb)	Receptacle MC (% wb)	Test Depths (m)
0[a]	84.8	86.2	0.25, 0.50, 0.75, 1.0
3	79.7	83.4	0.25, 0.50, 0.75, 1.0
5.5	71.0	82.6	0.25, 0.50, 0.69
8.5	58.5	79.6	0.15, 0.30, 0.45
20	10.3	13.4	0.25, 0.5

[a] Fresh flowers.

shrinkage, the maximum bed depth that could be tested decreased as the flowers dried. Flowers used at the 10.3% petal MC were combined with previously dried flowers to create enough volume for testing.

RESULTS

A power equation, generally referred to as Shedd's airflow equation, was used to describe the relationship between airflow and pressure drop per unit depth (Shedd, 1953).

$$\frac{\Delta P}{L} = aQ^b \tag{1}$$

where

ΔP = pressure drop (Pa)
L = bed depth (m)
Q = airflow (m^3/m^2s)
a and b = material constants.

Initial data analysis was performed by determining the relationship between log–transformed airflow and log–transformed pressure drop using linear regression for each moisture content condition and depth. Two additional models included linear regression models using non–transformed data and airflow and the square root of pressure drop. In all cases, the models fit the data very well. Coefficients of determination ranged from 0.88 to 0.99 for log–transformed data (table 2), from 0.89 to 0.99 for linear airflow and the square root of pressure drop, and from 0.92 to 0.99 for non–transformed data. Because Shedd's equation is used to represent a wide range of materials, further analysis was centered on this model.

Statistical analysis was performed to determine if the regression coefficients were different for each moisture content and depth compared to regression results obtained by combining the data for all moisture contents and depths. Regression coefficients from the combined data (table 2) were used to predict pressure drop values from the airflows for each data set of fixed moisture content and depth. Predicted values were compared with measured pressure drop values from each data set to determine if the mean difference was zero ($\alpha = 0.05$). Table 2 indicates cases where measured pressure drops were significantly different from those predicted by the combined regression model results. Although some cases were different, the combined data are well represented as a single variable model (fig. 2). This relationship adequately describes pressure and airflow drop for a wide range of flower moisture conditions.

Bulk density, in varying from 118 to 276 kg/m^3, was found to increase with increasing bed depth (fig. 3). At moisture contents of 58.5% to 79.7%, the change in bulk density with bed depth was more pronounced, as indicated by the larger slope of the regression lines. At highest moisture, the slope was the lowest, indicating reduced influence on bulk density. For a fixed bed depth, as flowers dry, their bulk density increases to a maximum value of more than double the density of fresh flowers, until the moisture content declines to about 60%. Bulk density then decreases with further drying. This relationship is related to the large shrinkage that occurs as a result of significant changes in the flower's structure. This trend is similar to the behavior found for a fibrous material like garlic (Lozano et al., 1983) but opposite to that found for grains at lower moistures (Brusewitz, 1975).

Table 2. Regression coefficients and r^2 values obtained from regression of log–transformed airflow and pressure drop for moisture contents and depths.

Depth		Moisture Content (% wb)				
(m)		10.3	58.5	71.0	79.7	84.8
0.15	*a*		1166			
	b		0.779			
	r^2		0.98			
0.25	*a*	1221		938	970	1230
	b	0.730		0.702	0.699	0.956
	r^2	0.94[a]		0.98	0.97	0.96
0.30	*a*		925			
	b		0.666			
	r^2		0.98			
0.45	*a*		819			
	b		0.619			
	r^2		0.99			
0.50	*a*	1119		800	724	1063
	b	0.726		0.610	0.560	0.735
	r^2	0.97[a]		0.99	0.97	0.94
0.69	*a*			675		
	b			0.546		
	r^2			0.99		
0.75	*a*				446	973
	b				0.447	0.671
	r^2				0.89[a]	0.97
1.00	*a*				609	840
	b				0.554	0.621
	r^2				0.96[a]	0.97

[a] Regression coefficients are significantly different ($\alpha = 0.05$) from data coefficients (a = 922, b = 0.694, $r^2 = 0.93$) for all moistures and depths.

CONCLUSIONS

This research indicated that pressure drop characteristics of marigold flowers can be adequately described by Shedd's log–log equation, using airflow alone, for a wide range of

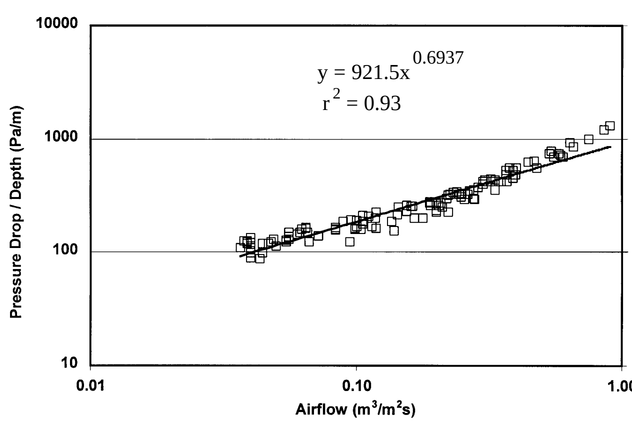

Figure 2. Combined data of pressure drop vs. airflow for all moisture contents and bed depths.

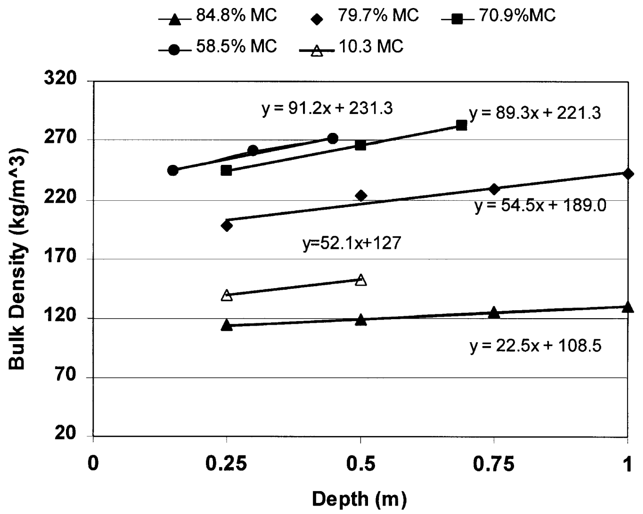

Figure 3. Flower bulk density versus bed depth at different moisture contents. With two replicates at each data point, r^2 was at least 0.92 for the five regression equations.

flower moisture conditions (10% to 85% wet basis) and bed depths (0.15 to 1.0 m). Bulk density is significantly affected by flower moisture content and ranged from 118 to 276 kg/m^3.

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