FREEZE DRYING OF FRUITS AND VEGETABLES: A LABORATORY EXPERIMENT

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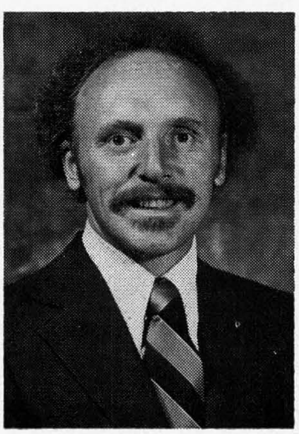
THERE ARE SEVERAL persistent problems with which an instructor must deal when developing a laboratory experiment. There is the matter of available space, cost of equipment, educational objectives and quality of the data produced. An experiment concerned with the freeze-drying of fruits and vegetables will be described which can address these problems.

Referring to Figure 1, the experimental apparatus covers a bench top with surface dimensions of 65 cm. by 200 cm. The apparatus is portable and can be stored when not in use.

The only piece of equipment considered expensive would be the vacuum pump. The other items are inexpensive and the vacuum pump represents by far the largest expenditure.

The educational objectives of this experiment are to expose the students to two subjects; the



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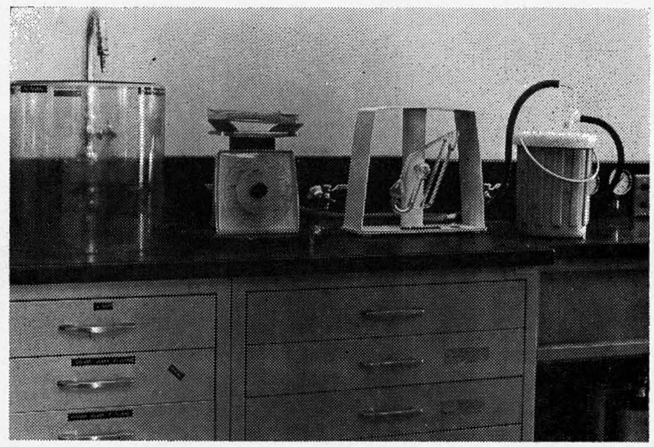

FIGURE 1. Experimental Apparatus

principles of drying and simultaneous heat and mass transfer. Sufficient time is also allocated so the students can write a group report which effectively communicates the knowledge and results obtained in the experiment.

Referring to Figure 2, a typical moisture content versus time graph for different materials is shown. As can be seen, the small degree of scatter makes analysis and interpretation of the data consistent with theory.

An additional benefit obtained is that the students can visually observe the progress of the experiment by observing the condition of the material being freeze-dried and the weight loss as time progresses. This gives students a feeling that the experiment is proceeding successfully and they are more inclined to be enthusiastic about it.

EXPERIMENTAL

A SCHEMATIC OF the experimental apparatus is shown in Figure 3. The material to be freeze-dried is first cut into slices of rectangular or circular cross-section approximately 0.3 cm. thick. The regular cross-section allows easy computation

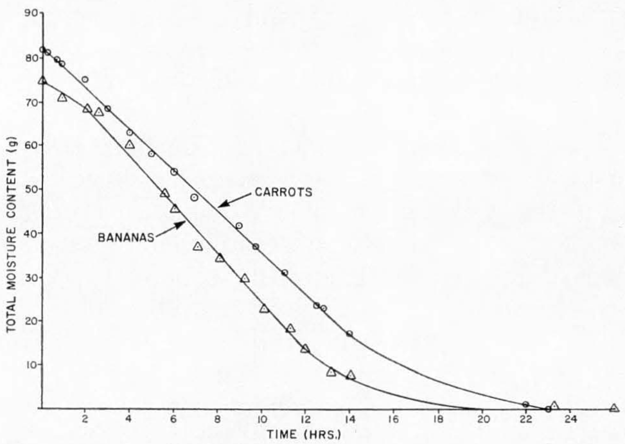

FIGURE 2. Total Moisture Content of Sample vs. Time For Various Materials Being Freeze-Dried

of exposed surface area. The material is then frozen. The previous steps can be accomplished the day before the start of the experiment.

The frozen material (approx. 100 grams) is loaded onto a coarse mesh screen. This is done so that both material surfaces are exposed. This combination is then placed on a simple weighing scale with visual readout. This can then be placed inside a transparent vacuum chamber. A thermometer is mounted on the scale to record the ambient temperature inside the chamber.

This vacuum chamber is combined in series with a McLeod gauge for observing system pressure, a condenser immersed in a dry-ice-isopropanol bath to remove evolved water, and vacuum pump.

Once the frozen material is placed in the vacuum chamber, the vacuum pump is turned on. The students record system pressure, system temperature, and remaining weight of material as a function of time. This data collection is done hourly for a 24 hour period.

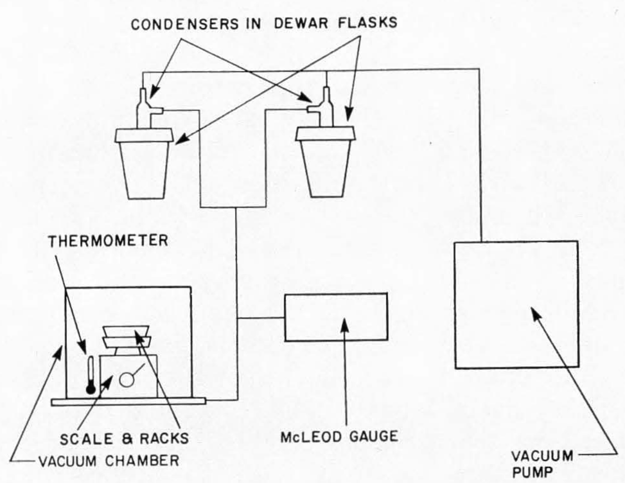

FIGURE 3. Experimental Apparatus

DATA ANALYSIS

A TYPICAL MOISTURE content vs. time graph is shown in Figure 2. These curves were obtained from data taken in this experiment and show three distinct regions of drying. It is assumed that the equilibrium moisture content is negligible. These are the initial (preliminary) period, constant drying rate period, and falling drying rate period. The students are asked to discuss the physical significance of each region.

For the constant drying rate period, the students calculate the drying rate and mas flux (N_w) from Figure 2. This information can then be used to calculate the heat flux (q)

$$q = \Delta H_s N_w \quad (1)$$

where ΔH_s is the heat of sublimation of water. An overall heat (U) and mass (K) transfer coefficient can now be calculated assuming an interior solid temperature (–30°C was used). The necessity of this assumption will be corrected in the future by placing a thermocouple in the frozen material and monitoring the temperature.

An additional benefit obtained is that the students can visually observe the progress of the experiment by observing the condition of the material being freeze-dried and the weight loss as time progresses.

The students then determine operating parameters for a large scale continuous process. This includes determining the amount of water that will be removed per hour per kg. of material charged, speed of conveyor system, and pumping capacity needed.

EXAMPLE CALCULATION OF U AND K

Data (carrots)

Chamber temperature, T_a = 21°C
Chamber pressure, P_a = 0.168 torr
Interior carrot temperature, T_i = –30°C (assumed)
Total surface area of carrots, A = 433 cm^2.

From Fig. 2, the slope is –5.2 g/hr during the constant drying rate period. Therefore, the drying rate (D) is 5.2 g/hr.

. . . this experiment is a good learning experience. This is . . . demonstrated by the fact that (it) is always chosen by one group for an oral presentation at the end of the semester.

$$N_w = \frac{D}{A} = \frac{5.2 \text{ g/hr}}{433 \text{ cm}^2} = 0.012 \frac{\text{g}}{\text{cm}^2 - \text{hr.}}$$

$\Delta H_s = 2838$ J/g (reference 2)

$$q = \Delta H_s N_w = (2838 \text{ J/g})(0.012 \frac{\text{g}}{\text{cm}^2 - \text{hr}}) = 34.1 \frac{\text{J}}{\text{cm}^2 - \text{hr}}$$

$$U = \frac{q}{(T_w - T_i)} = \frac{34.1 \text{ J/cm}^2 - \text{hr}}{[21°\text{C} - (-30°\text{C})]}$$

Saturated vapor pressure above ice @ −30°C: $P_s = 0.2859$ torr (reference 4)

$$K = \frac{N_w}{(P_s - P_a)} = \frac{0.012 \text{ g/cm}^2 - \text{hr}}{(0.2859 \text{ torr} - 0.168 \text{ torr})} = 0.102 \frac{\text{g}}{\text{cm}^2 - \text{hr} - \text{torr}}$$

DISCUSSION

THE LABORATORY IS scheduled for two 3-hour periods per week and the students are given 2 semester hours credit. The reason for the additional hours per week and credit is that emphasis is placed on communication skills, both written and oral, as well as technical competence in the laboratory procedure and data analysis.

For this particular experiment, the students are given four 3-hour laboratory periods to complete the experiment and the written report. The first laboratory period is spent in instructing the students in the use of the equipment and choosing a material to be freeze-dried. The following morning the students start the experiment and take hourly data for the next 24 hours. The remaining periods are used by the students to study the reference material and write a group report which effectively communicates the desired information.

The students indicate that this experiment is a good learning experience even though the time required for taking data is relatively long. This is further demonstrated by the fact that this experiment is always chosen by one group for an oral presentation at the end of the semester. One reason for good student response is the fact that the experiment "works". The data they obtain gives reasonable results and they can visually observe the success of the experiment. This eliminates the frustration associated with poor data.

One improvement in the experiment would be to place a thermocouple in a larger frozen slab with the vacuum chamber to obtain the core temperature. This would eliminate any assumption of this value. This will be done in future experiments.

In conclusion, a laboratory experiment for freeze-drying fruits and vegetables has been described. It utilizes a small amount of space, is relatively inexpensive, and gives reasonable results. The experiment is very useful for presenting the concepts associated with drying and combined heat and mass transfer. □

REFERENCES

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COMBINED PROGRAM

Continued from page 140.

not accredited by ECPD, persons obtaining only this degree find it impossible to become licensed professional engineers in a few states.

The starting salaries of M.Eng. graduates are not significantly lower than those of the M.S. graduates and it generally takes longer to complete the M.S. thesis. As a result, most students prefer the M.Eng. route. This, we believe, may have adversely affected the size of our M.S. and Ph.D. programs. We hasten to add that this effect must necessarily be a modest one since the number of American students enrolling in Ph.D. programs in most universities these days is small.

In summary, we believe that the M.Eng. concept is a beneficial one, in the current situation. It is not without problems but the severity of the problems can be dealt with to preserve the strengths of the program. □