INTRODUCTION

The maintenance of potatoes at temperatures conducive to good tuber quality is one of the major considerations of potato storage. During most of the storage period heat must be removed from the structure to maintain proper temperatures. The heat removed is mainly from two sources, the field heat of the potatoes and the heat of respiration. Other minor sources of heat include that which is transferred through the walls and roof, outside air infiltration, and miscellaneous sources such as electric motors, tractors and trucks.

For satisfactory long-term storage, it is necessary that the storage environment be kept at critical levels of temperature and relative humidity (6, 7). However, when potatoes are first placed in storage it is well to stimulate wound healing of the tubers. This interval, 10-14 days, required for wound healing is known as the suberization period. Growth of the new skin or periderm is hastened when the potatoes are first placed in storage it is necessary that the storage environment be kept at critical levels of temperature and relative humidity. During most of the storage period heat must be removed from the structure to maintain proper temperatures. The heat removed is mainly from two sources, the field heat of the potatoes and the heat of respiration. Other minor sources of heat include that which is transferred through the walls and roof, outside air infiltration, and miscellaneous sources such as electric motors, tractors and trucks.

PUBLISHED WEIGHT LOSS ESTIMATES

Moisture loss from tubers during the storage period has been investigated by several researchers. Burton (1) found it possible to express the rate of evaporation from tubers during continuous ventilation, after the first few weeks when the wounds in the skin were healed, in the form

\[ \frac{dw}{dt} = (1.2 + 0.65) VPD 10^{-5} \]

where

\[ wt = \text{weight loss per unit of tuber (kg vapor/kg tuber)}; \]
\[ S = \text{percentage by weight of sprouts}; \]
\[ VPD = \text{water-vapor pressure deficit of the air surrounding the tubers (mm Hg)}; \]
\[ t = \text{time (h)} \]

For the 1st 2 wk after harvest, a coefficient of 4.2 should be used instead of 1.2.

Schippers (4) also suggested that the percentage weight loss due to moisture removed from the tubers is related to the product of vapor pressure deficit, expressed in millimeters mercury, and the duration of storage in weeks. Shortly after harvest, the regression coefficient was found to range from 0.7 to 0.9 which corresponds to a weight loss of approximately 0.05 mg/cm²/mm Hg/h. A regression coefficient of 0.125 was needed to estimate weight losses after several weeks of storage. The coefficient was found to be dependent on the maturity of the tuber.

More recently, Misenera determined that no linear relationship between vapor pressure or temperature and weight loss was apparent in his study. He also suggested that the relationship was at least partially time-dependent.

The cooling model

By using weather data as an input to computer programs developed to simulate heat and mass transfer during the ventilation of potatoes, the time for cooling, expected moisture loss and final potato temperatures can be determined. The simulation models can be used to determine the effects on the cooling phenomena of many variables including depth of potatoes, initial potato temperature.
temperature and relative humidity of the supplied air and ventilation rate.

The cooling model developed by Misener\(^a\) was utilized during the study to determine cooling time and moisture loss at various ventilation rates. Essentially the model consists of a set of heat and mass balances written for a single isothermal layer of potatoes to obtain equations describing the product temperature, the air temperature and specific humidity, and the moisture loss during the cooling process. The model utilizes a finite difference method to determine the cooling and drying performed on a deep bed of potatoes. A complete description of the model is available in the thesis\(^a\).

Modifications to the original program were necessary to accommodate the mixing of the fresh and storage air. When the outside air is too cold to use alone for cooling, the ventilating air is mixed with the recirculating air. A heat balance is necessary to determine the ratio, \(X\), of fresh air to the total supply air.

\[
M_dC_{pmix}T_{mix} - X(M_dC_{pi}T_i) - (1 - X)(M_dC_{ps}T_s) = 0 \quad \text{(3)}
\]

where

\[
M_d = \text{weight of air (kg)}; \\
C_{pmix} = \text{specific heat of mixed air (J/kg°C)}; \\
T_{mix} = \text{temperature of mixed air (°C)}; \\
C_{pi} = \text{specific heat of ambient air (J/kg°C)}; \\
T_i = \text{temperature of ambient air (°C)}; \\
C_{ps} = \text{specific heat of storage air (J/kg°C)}; \\
T_s = \text{temperature of storage air (°C)}.
\]

Once the fresh air to total air ratio is known, the new absolute humidity of the ventilation air can be determined.

**PROCEDURE**

**Model Validation**

To test the simulation model, experimental tests were carried out with laboratory equipment. The model describing the initial cooling of the potatoes was verified by Misener\(^a\) during the developmental stages. During the present study, it was of interest to determine the accuracy of the model for describing the cooling of potatoes that had been in storage for 2 mo. Equation (1) was used to describe the mass transfer during this portion of the study.

A 2.4-m deep bed of potatoes was subjected to an air flow with velocity of 1.3 m/min. Both the air and potato temperatures were measured using copper-constantan thermocouples connected to a Bristol multipoint recorder. The thermocouples were mounted in the bed in order that the temperatures of the air and tubers could be sensed every 0.15 m of depth. The temperature of the tubers was determined by inserting the thermocouple into the center of the tuber. The ventilation air was supplied by an Amino-Aire unit. The conditions under which the bed of potatoes was cooled were inputted to the computer model in order that temperature gradients in the bed of potatoes could be calculated. A comparison was then made between the experimental and calculated values.

**Simulations Using Weather Data**

Weather data were obtained from the Atmospheric Environment Services, Toronto, Ontario. The data describe a 5-yr period, 1967-1971, inclusive for Fredericton, New Brunswick. Hourly observations of the dry-bulb temperature and relative humidity were recorded on magnetic tape. The average hourly dry-bulb temperature and relative humidities...
RESULTS AND DISCUSSION

Model Validation

The temperature gradients within a bed of potatoes were measured during the cooling period with an air flow of 1.3 m/min. Temperature distributions were predicted by simulated cooling of potatoes under similar conditions. Figures 1 and 2 depict the degree of agreement between experimental and simulated values. It is apparent from Figures 1 and 2 that reasonable agreement exists between the two sets of values.

Simulations Using Weather Data

Figure 3 shows the predicted temperature distribution in a 4.8-m (16-ft) deep bed of potatoes as cooling progresses. Eighty-six hours are required to cool the mass of potatoes from 18.3°C to 7.2°C with an air flow of 1.56 m/min. It is of interest to note that although the minimum cooling air temperature is 6.7°C, the potatoes do cool to 5.8°C because of evaporative cooling.

Simulated cooling times during November 1-15 for the 4.8-m (16-ft) deep bed of potatoes are depicted in Figure 4. The values presented include the time when the cooling fan was not operating because of high ambient temperatures. The actual hours that the cooling fan operated are also presented. The warm ambient air conditions during this period caused the cooling time to be extended considerably when cooling the potatoes to 4.5°C.

The simulated moisture loss from the potatoes during this initial cooling period, November 1-15, ranged from 0.016 kg/kg of potatoes down to 0.009 kg/kg (Figure 5). The results indicate the importance of ventilation rate with regard to mass transfer. High moisture losses correspond to the low air flows as indicated in Figure 5.

A similar trend was apparent from the study using the weather data for December 1-15. Cooling time and moisture loss (Figures 6 and 7) both increased at the lower air flows. The results stress the point that in order to reduce the temperature of the entire bed of potatoes, the ventilation must continue over several hours. This should be taken into consideration when planning a time schedule for the ventilation of potatoes during the holding period.

SUMMARY

The ventilation of potatoes with ambient air was simulated using a computer model based on the finite difference method. Heat and mass transfer between the potatoes and cooling medium can be predicted for various ambient conditions.

Weather data for Fredericton, New Brunswick were supplied to the model in order that the effect of ventilation rate on cooling time and moisture loss could be studied. Low air flows resulted in increased cooling time and moisture loss during both the initial cooling period and the holding period. Cooling times and moisture loss are presented in the paper for the various air flows and cooling periods.

REFERENCES


