FV190

CARROTS: REDUCTION OF DISEASE IN LONG AND TEMPORARY STORAGE BY MICROCLIMATE MANIPULATION

ANNUAL REPORT

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Grower's Summary - Year 1

The aim of this project is to investigate ways of storing carrots after harvest without dehydration, re-growth or disease. Carrots are currently stored in high humidity cold stores for a period of 3 - 4 weeks but thereafter mould often starts to grow on the tops. We think this is because the carrot skin's are often wet. In this project we aim to keep the skins dry, whilst keeping the air in store at high humidity and low temperature. This means that there must be no variation of temperature in the store as this often leads to condensation on the skin of the carrots. Also a system of a humification is required.
To test whether this is possible some sealed containers, each containing 4 carrots and some wetted paper towels (to maintain the humidity at a high level), were immersed in barrels of water - to ensure that there was no variation in temperature. The surrounding air was then cooled to around 1.5°C. In these conditions the carrots were stored for 9 weeks. At the end of this period the carrots were assessed by a commercial grower for quality. The results were surprisingly good, weight loss was very low but by the end of the test the carrots were beginning to dry out. This test will be repeated in the Jan 1998 to try to ascertain to what point the quality remains acceptable.

The next stage is to see whether the same conditions and results can be achieved in a one tonne box. To do this we have had to design a new refrigeration system that cools continuously thus minimising the temperature differential between the temperature of the carrots and that of the air from the refrigerator. This is almost ready for installation.

Finally, this project intends to produce a computer simulation of conditions in a carrot store. This is being done by converting an existing model of conditions in potato stores to carrots. To do this some laboratory tests have been carried out to find out thermal properties of carrots so they can replace the values related to potatoes. A test run showing the cooling of a single carrot from 20°C using cold air reveals that it takes around 10 hours. This result has still to be confirmed but once this has been done conditions within a one tonne box will be simulated, then a whole store.

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26 September 1997

Carrots: Reduction of disease in long and temporary storage by micro-climate manipulation

Annual Report - Year 1

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The aim of this work is to provide more information on carrot storage and to develop a system that allows carrots to be stored at acceptable quality for a period of up to two months. Carrots are currently stored in humid systems at low temperature but suffer from mould growth after around three weeks of storage. This work aims to investigate the effect of storing carrots in air of high humidity but ensuring that the carrot skins stay dry. To evaluate whether it is possible to create these conditions and to assess the effect of storing carrots in this environment a small scale storage experiment was planned and conducted. Following this a design specification for a new refrigeration unit was compiled and tests on a larger quantity of carrots are planned for early 1998. Also there has been work done on the development of a computer simulation of the environment in a carrot store. Ideas and methods are mainly derived from recent work on potato storage(Appendix 1). To gain further information on the current standards of carrot storage Kettle Produce Ltd of Cupar, Fife were visited on 9 July 1997.

Small Scale Storage Experiment

First trial conducted 24/2/97 -- 7/5/97

The carrots for this trial and for the laboratory experiments were provided by Moray Coast Growers. The storage conditions planned for the carrots were optimal: low temperature (0 to 1 C) and high humidity (> 98%)[4]. The carrots were assessed before storage and all those that were used in the experiment were in good condition.

The carrots were placed into storage at 3pm on 18/2/97. Data logging commenced at 9:50 am on 25/2/97. Data was recorded every ten minutes until 8:40 am on 7/5/97 when the sensors were disconnected and the carrots removed for final evaluation after 78 days in store. The carrots were originally placed in the store as follows:

Box	Lid	wet/dry	sandy/loamy	Carrots	Weight
1	Green	wet	sandy	4	612g
2	Green	wet	loamy	4	475.6g
3	Yellow	dry	sandy	4	580g
4	Yellow	dry	loamy	4	504.4g
5	Blue	wet	-	-	-
6		ambient	loamy	8	725.3g
7		ambient	sandy	7	780.8g

Boxes 1 to 5 had a perforated grille elevated above the bottom of the box on which the carrots were placed. This allowed condensation which might form on the inside walls of the box to drain away from the carrots. The under-surfaces of the lids of boxes 1 to 5 were covered in paper towelling to absorb condensation that might drip onto the carrots.

Boxes 1 to 5 had close fitting lids and were stored partially submerged in water tanks to minimise temperature variations. Boxes 1, 2 and 5 had wet paper towels under the grille in the base of the box to provide extra humidity. Boxes 3 and 4 did not have extra humidification. Boxes 6 and 7 were loosely covered and exposed to the ambient conditions in the store. The boxes were fitted with sensors as follows:

Box	Temperature	Skin Resistance	Relative Humidity	Dew Point
1	T1	SR1	RH1	DP
2	T2	SR2	-	-
3	T3	SR3	-	-
4	T4	SR4	-	-
5	T5	-	RH2	-

Relative humidity sensors do not give precise readings at such high humidity levels as present in the experimental chambers. Nonetheless they did give consistently high and stable readings throughout the storage period. The dew point sensor combined with the corresponding temperature was used to work out relative humidity. This settled to a high and stable value throughout the storage period.

The skin resistance sensors gave readings which normally would be associated with wet skins in potatoes throughout the test period. This is likely to be due to the carrots thinner skins. Laboratory tests are planned to gain more information on the relationship between electrical resistance across the skin of a carrot and the amount of skin moisture.

Due to a problem with the refrigeration system the temperature in the boxes sometimes rose above 2°C for periods, affecting about ten days of the storage.

Following the storage period the carrots were re-weighed and assessed with the following results:

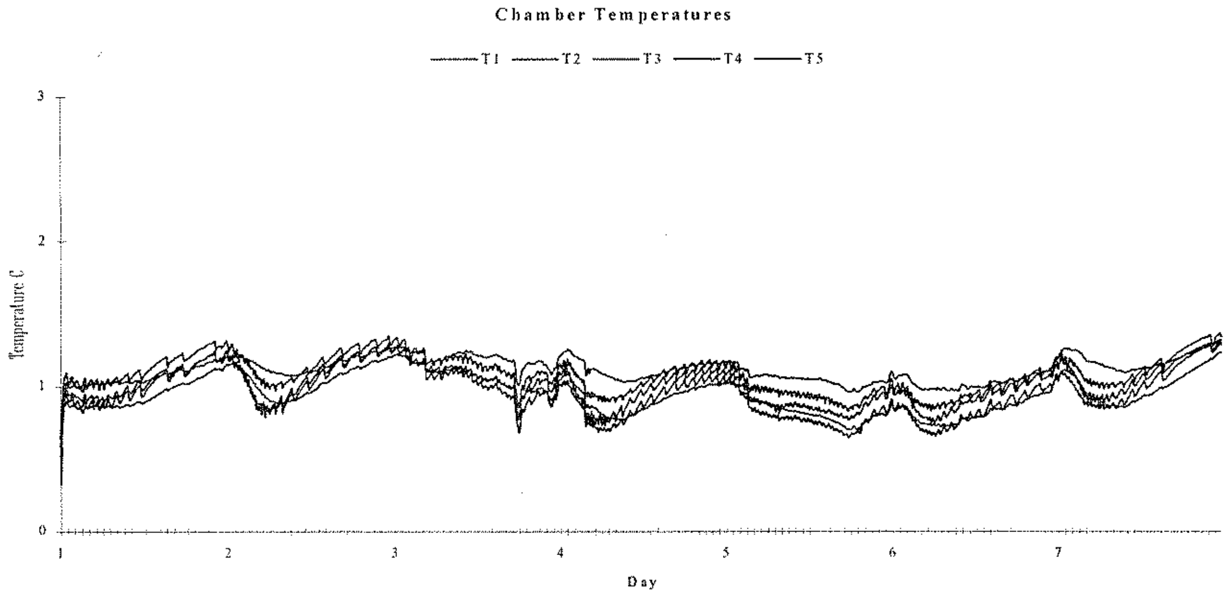
Box	Lid	wet/dry	sandy/loamy	Carrots	Weight	% Change
1	Green	wet	sandy	4	603.7g	-1.3562
2	Green	wet	loamy	4	463.5g	-2.5442
3	Yellow	dry	sandy	4	567.8g	-2.1034
4	Yellow	dry	loamy	4	495.6g	-1.7446
6		ambient	loamy	8	557.1g	-23.1904
7		ambient	sandy	7	602.6g	-22.8227

The average weight loss of the carrots stored in boxes 1 to 4 was 1.91% (0.735%/month) whereas the average weight loss of the carrots exposed to the ambient store conditions was 23% (8.85%/month). The weight loss of carrots stored with ice-bank cooling systems is 0.9 - 1% per month [3]. The samples were assessed by a commercial producer (Moray Coast Growers) as follows:

Box	Assessment
1	Tips beginning to dry out.
2	Tips breaking down. Dry.
3	Some re-growth. Tips breaking down. Dry.
4	Re-growth. Dry.
6	Appalling. Rotting and un-washable.
7	Beginning to break down. Won't wash.

The clear difference between samples 6 and 7 and the samples 1- 4 in weight loss is continued in the assessment. Boxes 1 and 2, which had extra humidification, were assessed as not having re-growth whilst boxes 3 and 4 which did not have extra humidification both showed some re-growth.

Example temperature data:

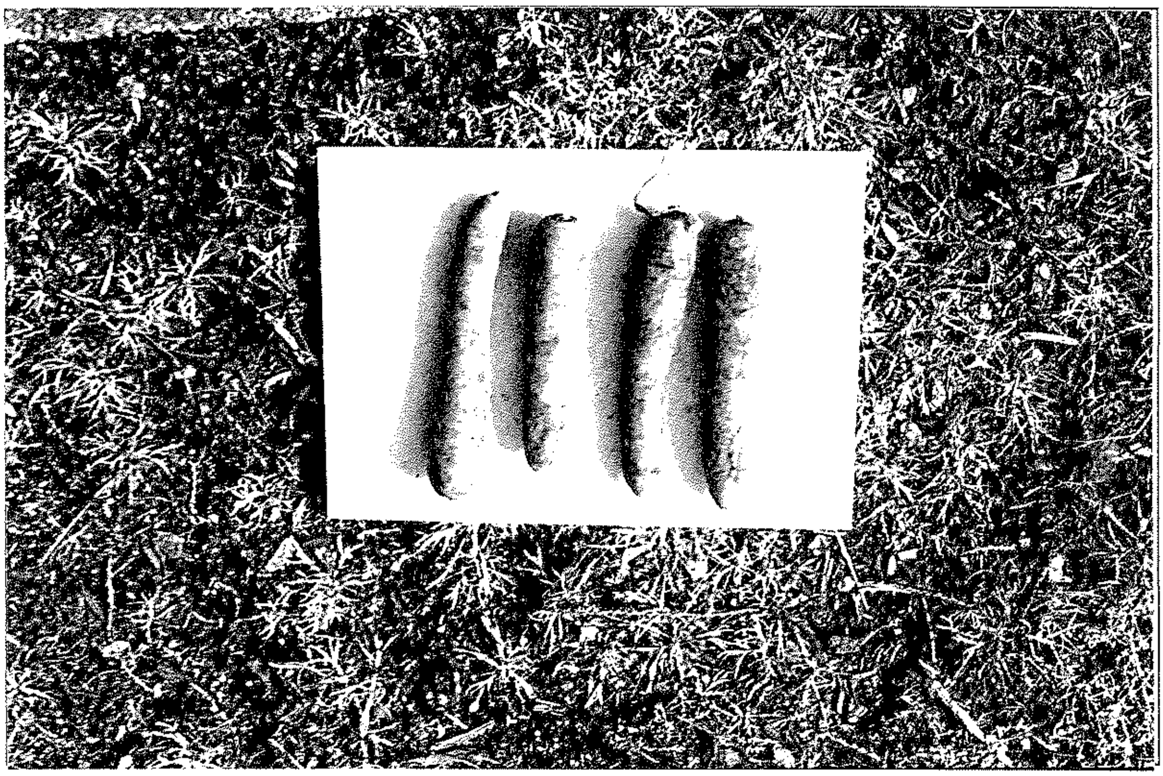


This data is taken from the first week of data logging and shows the temperatures in the storage containers at the target levels.

Conclusion to the small scale tests

The results of the small scale tests show that in a high humidity, cold environment it is possible to store carrots for a period up to eight weeks without serious quality loss. The weight loss experienced during the test was lower than would normally be expected, even in the best stores.

It was not possible to determine the affect of condensation on the storage of the carrots. For this reason it was decided to repeat the trial. Scheduling of the use of the storage facility and the difficulty of removing field heat from the carrots during the summer led to the repeat trial being scheduled for January 1998.

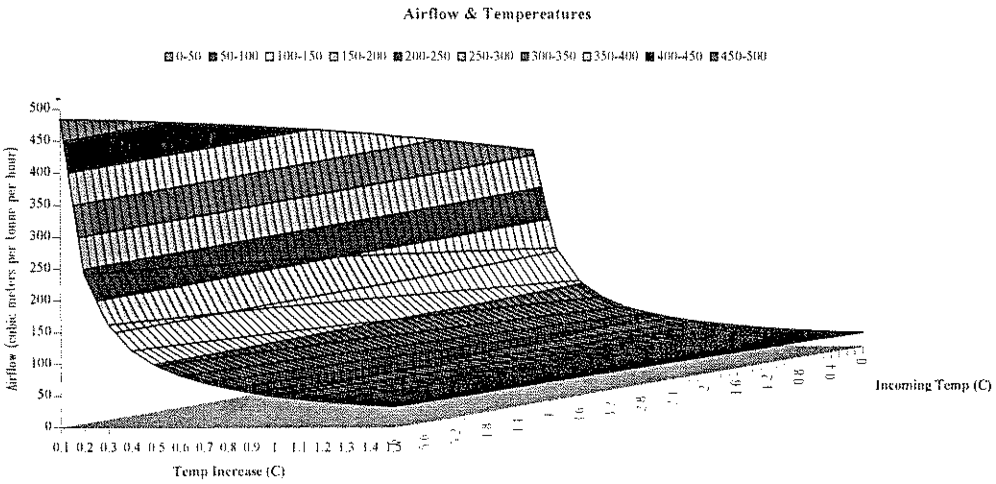


Carrots from Box 1 at the end of the storage period.

Refrigeration Design

Analysis of requirements completed.

Detailed computer modelling of the heat and mass transfer of carrots to air enabled the calculation of the airflow rates required to limit the temperature increase of the air as it passes through the produce.



The graph shows that as the airflow rate is decreased the temperature rise within the crop increases. If cooler ventilating air is used the airflow can be reduced slightly for the same temperature gain in the crop. The minimum ventilation rate is approximately 25 m^3/h/tonne as this is generated by natural convection through the crop.

This information was used in conjunction with the design of the store and the quantity of carrots to be stored to give the required capacity of the cooling system during storage which was calculated to be 6 kW [6].

The specification that resulted was:

1. Ventilation air to be cooled continuously
2. Ventilating air to be cooled to 1°C
3. System to be able to provide 70 to 150 m^3/h/tonne of cooled air during normal storage
4. The system should be able to provide 200 m^3/h/tonne during cool down.
5. Variable cooling capacity of 3 - 6 kW to meet demand in the store (varying with seasonal weather variation, different quantities of product and changing heat output of produce)
6. System to be able to cool 1 - 15 tonnes of carrots
7. The cooler must dehumidify the air as little as possible.
8. If necessary the cooled air should be re-humidified. Air circulated through the crop should have a humidity exceeding 97%.

The refrigeration equipment is to be supplied by Proctors Ltd. The unit is to be checked out as part of a BSc(Hons) engineering project.(Appendix 1)

Computer Software

Adapting the potato computer model for use with carrots primarily involved identifying and then modifying those parts of the potato model which rely on explicit or implicit assumptions which are valid for the potato model but which need to be changed for carrots.

The lowest level of these changes involved basic physical parameters such as density which differ between potatoes and carrots. These values can be set interactively before running the program and default values are stored in a database. A new table in the database was created to hold default carrot values where these were different from corresponding potato values.

The next set of changes involved functions used frequently in the model to calculate values related to the dimensions and properties of a single carrot. The potato model represents a potato as a sphere with volume and surface area being calculated using the standard geometrical formulae. Because the carrot has a different shape and physiology than a potato these functions had to be completely redesigned and rewritten. These changes included functions to calculate the shell radius, node volume, node radius, interface area, node difference, area of radius, volume, dimensions, respiration rate and surface area.

The shape of a carrot lies between that of a cone and a cylinder. A shape factor, C, which has a value of 1 for a cylinder and of 1/3 for a cone may be estimated by the equation $C = \frac{W}{\pi \cdot r^2 h}$ where r is the radius of the greatest diameter of the root (cm), W is the weight of the root (grams) and h is the length of the root (cm). [1].

Having obtained the shape factor it is then possible to derive equations for the volume and surface area of the carrot and to express these in forms suitable for use in the computer program.

The equation for the volume of a carrot can be expressed as $C\pi \cdot r^2 h$. However for the purposes of the model it is more convenient to record the ratio of h to r which we shall call k.

The equation for the approximate volume of a carrot is then given by $cV = C\pi r^3 k$ where cV is carrot volume, C is shape factor and k is the ratio of carrot length to radius.

The equation for the approximate surface area of a carrot is given by $cA = C\pi \cdot r^2 \cdot \frac{4}{1+C} \cdot (1+k)$ where cA is carrot area, C is shape factor and k is the ratio of carrot length to radius. This includes the area of the rounded end of the carrot as well as the curved conical surface.

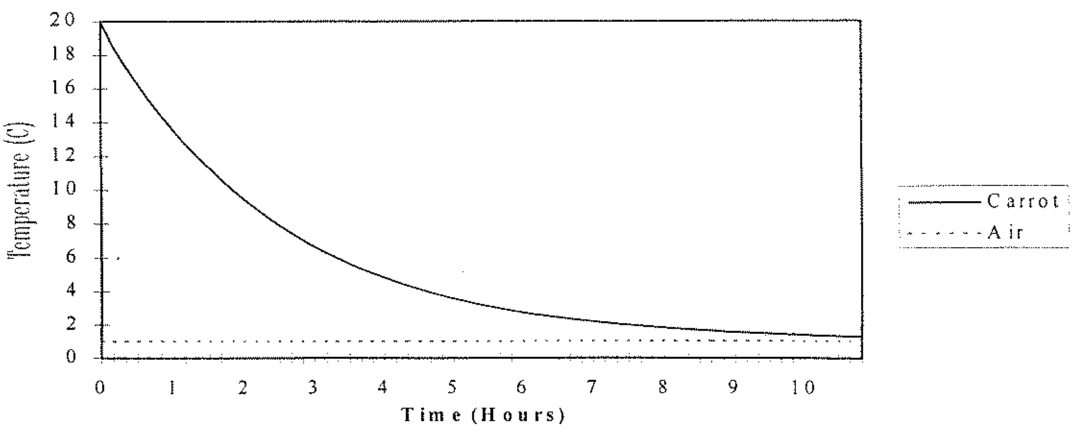
The changes in the design of these subsystems required in turn that requirements to change the systems that depend on or support them be identified and appropriate changes be designed and implemented.

The carrot shape is described using more parameters than the potato shape and so the database format needed to be revised and the extra parameters provided when required by these functions.

The final level of changes required the identification of functions with implicit assumptions inappropriate to the carrot model. An example of this is the airflow calculations which had been mathematically simplified using standard results relating to airflow over spheres. These had to be re-derived using results relating to airflow over cylinders.

A final preliminary version of the carrot model program awaits the delivery of the final potato model program so that the changes identified can be integrated into it. This will allow simulation of heat and mass transfer from one carrot, one tonne of carrots and many tonnes of carrots in store depending on the external conditions and the ventilation regime. Once received the program can then be validated.

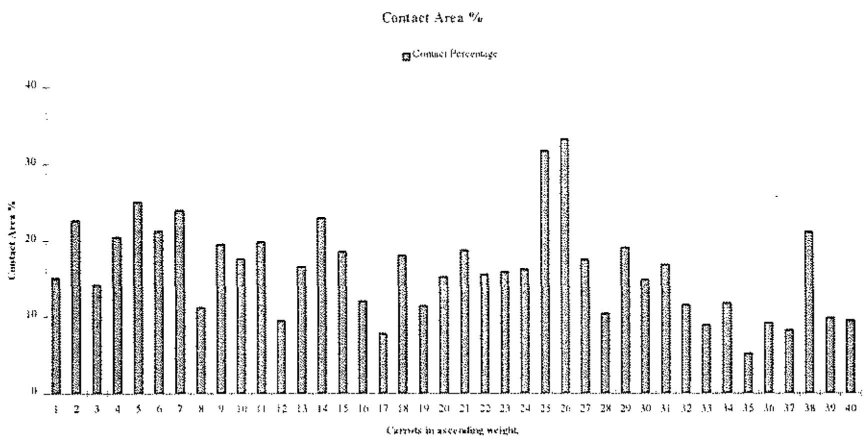
Results of the simulation of the cooling of a single carrot in an airstream of $0.015 m^3/s$ at a temperature of 1°C are shown below. This has still to be compared to actual data but it is reasonably similar to the cooling curve for a potato in a similar airstream.



Laboratory Experiments

Contact Area: 2 trials

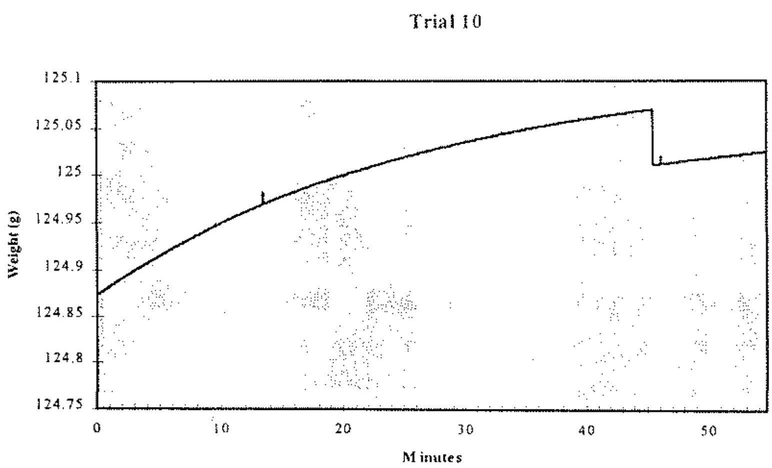
This experiment is designed to determine the percentage of the carrot surface that is exposed to the airflow through the container and how much is blocked from the airflow by contact with other carrots. This value is used in the computer model. A sample of carrots is placed in a suitable container with drainage holes in the base and quick-drying opaque paint is poured over the top so that all the exposed surfaces of the sample are coated with paint. The areas where the carrots are in contact are protected from exposure to the paint. When the paint has dried the sample is separated and the unexposed areas measured. The chart below represents the results of the second trial.



Forty carrots were measured. Their surface area was calculated from their length, diameter and weight. The areas unmarked by paint were measured using a transparent grid. The chart shows the percentage of the surface area of each carrot that was in contact with others. The results are ranked in ascending order of carrot size.

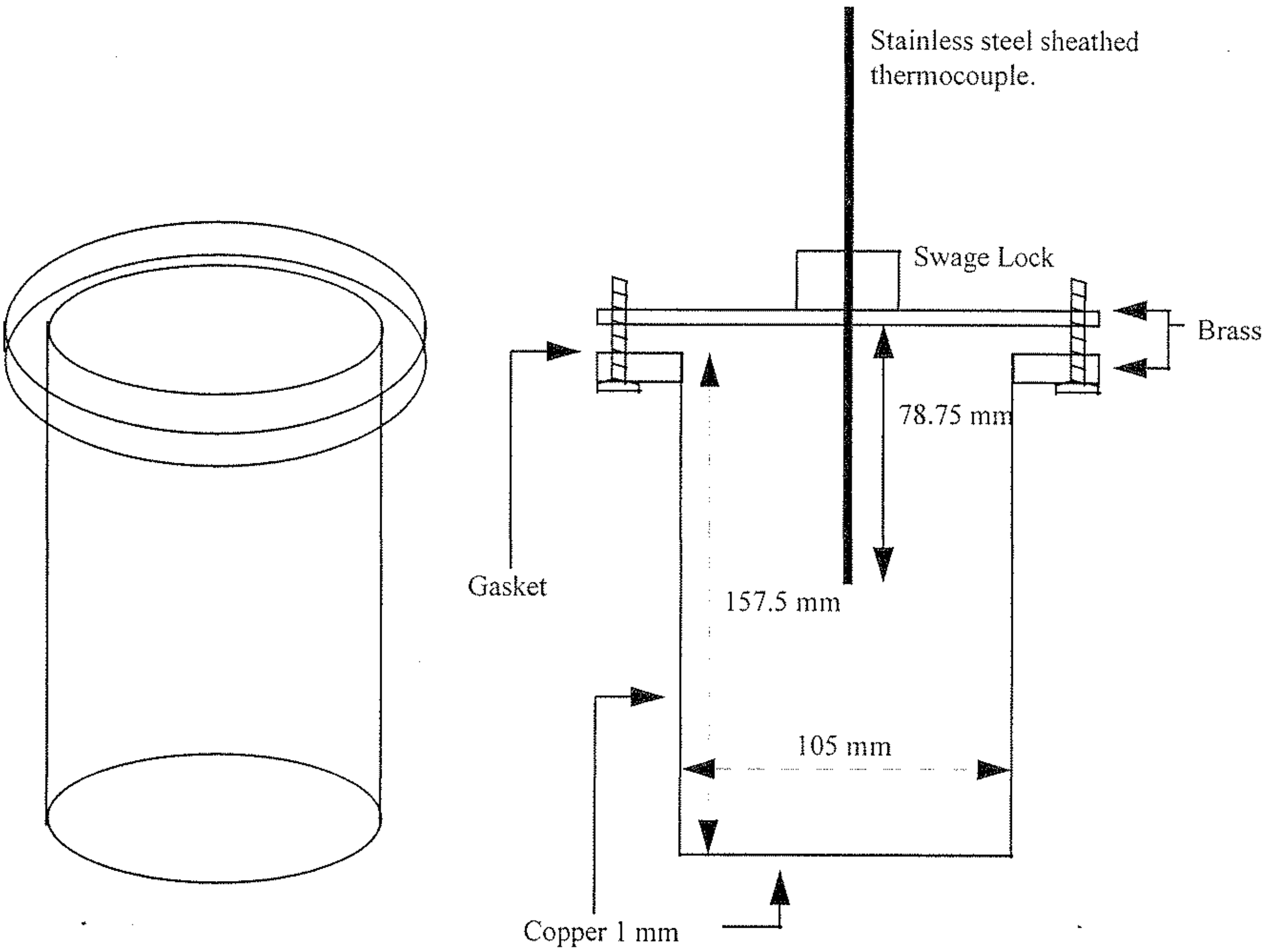
Maximum skin moisture: 14 trials

This experiment is designed to determine the maximum amount of water from condensation that can adhere to the surface of a carrot before dripping off. A carrot which has been chilled in a refrigerator is placed within a high-humidity chamber while suspended from a sensitive balance and the changing weights recorded by computer until the weight gain has peaked and gone into decline. The graph below shows part of the results for trial 10. Water dripping from the carrot is shown by the dramatic loss of weight at 44 mins after the start. This indicates that the maximum amount of water that was held on the surface of the carrot was in the region of 0.19g. The data from the other tests is still to be statistically analysed.



Thermal diffusivity: Apparatus designed and constructed, 1 trial.

The purpose of this experiment is to determine the thermal diffusivity of carrot tissue, one of several important properties used in the computer model. The sample tissue is pulped and placed in a sealed copper cylinder with a temperature probe centrally mounted on the axis. [2] The density of packing of the tissue in the apparatus has a significant impact on the results obtained. The heating and cooling curves obtained by immersing the cylinder in a thermostatically controlled heated water-bath and in an icebath are recorded and from them the thermal diffusivity may be calculated. By calculating the thermal diffusivity of the carrot tissue at several different packing densities it will be possible to interpolate the value for carrot tissue at normal density.



With a packing density of 0.8649 g/cc the value obtained for thermal diffusivity was 1.1433 +- 0.0523 E-7 m^2/s. The value calculated from published values is 1.5455E-7 m^2/s. which relates to the normal density of carrot tissue which is 1.04 g/cc.[5]. This work continues and it is hoped that it will result in a paper entitled "Factors and constants related to carrot storage" - or similar which should be ready for submission by the end of the year.

Progress Report/Timetabling

During the first year of the project some adjustments to the originally proposed program became necessary. Most of the laboratory experimental programme originally scheduled for completion by the end of project year two has been moved forward to be completed by the end of 1997. Installation of the refrigeration system has been deferred from October 1997 to December 1997.

Testing of 15 tonnes of carrots in store will be delayed until early 1999. Completion of the computer software awaits the delivery of the complete potato model.

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[5] Mohsenin Nuri N. Thermal Properties of Foods and Agricultural Materials. Gordon and Breach Science Publishers, New York. 1980. ISBN 0 677 05450 5

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Appendix 1: Potato storage results

Results of storage of 45 t of potatoes continuously ventilated with humidified air.

Experimental work over the last two years on potatoes being undertaken for MAFF studentship "An assessment of a continuous, low-rate ventilation of humidified air for ambient air cooling of potatoes in the UK climate" indicates the direction in which we should proceed for carrot storage. The results are encouraging and indicate that at least tuber skins can be kept dry even in the most humid of conditions. The main results were as below.

Cooling using high humidity ventilation air on potatoes.

Cooling air flowed in a vertical upwards direction. The temperature of the potatoes therefore increased with both height up the box and height up the stack. It appeared from airflow measurement and analysis of temperature differences that the two lower layers of boxes were under pressure ventilation, while ventilation in the upper layer of boxes was primarily due to convection. The surface of the top layer was cooler than the potatoes below by 0.15°C, but this did not appear to cause condensation.

The concept of the Hylmo, Sparks system of continuous low volume ventilation of humidified air (Hylmo *et al.*, 1975) is that the ventilating air never meets potatoes colder than the air. In bulk storage systems there is nowhere for the air to go but up, so the stack will always be warmer the higher the air goes. In box systems, the air can leak out through between the boxes so a forced upward airstream for all layers may not always occur. If forced air is required in all layers of boxes up the stack, airflows may have to be increased in magnitude to improve distribution and to ensure that all layers are being positively ventilated. Alternatively, air may be fed into the pallet apertures all the way up the stack to ensure an upward forced airflow in every layer. This may best be done using a redesigned box. With such a system, airflow over the top of the potatoes should be kept low or this may over cool the top potatoes. While the return air flowing over the top of a pile of bulk potatoes is likely be warmer than the potatoes, this may not be the case with box stores. Since a proportion of the air leaks out between gaps in the boxes, the combined airflow of "escape" air plus "potato exhaust air" may be cooler than the top potatoes.

During the whole period of ventilation of the boxes with air approaching 100% RH there was never any indication of condensation on the crop. Its heat output ensured that its skins were kept dry. This confirms why the system appears to work well in practice, and perhaps confirms that it is the presence of skin moisture rather than high humidity that allows disease to infect tubers and to multiply.

Implications from disease assessments.

In the second year of experiments, the crop in store was positively ventilated after harvest, naturally ventilated for two months, positively ventilated for two months, subject to approaching 100% RH air for one month and was not refrigerated till the beginning of March, yet the crop which was infected in the field with skin spot did not develop the disease to any extent. Throughout this period condensation was kept off the crop. It would appear therefore that high RH in the crop, or low skin resistance is not a problem regarding disease development. Rather it is a change in resistance indicating moisture forming on the crop that is allows disease to develop.

Moisture on store fabric

The only problems that did occur was moisture formation on the roof and walls of the store in cold weather and some white mould growth formation on both store fabric and potato boxes. The installed roof heating system control failed to work properly, but this was caused by control problems and can be rectified. Roof space heating will however be essential if dripping is to be avoided. Keeping boxes free from mould will be more difficult to achieve.

Further details of these experiments are available on request from ourselves in the MAFF final report "Control of heat and mass transfer processes in crop stores", by RT Pringle, K Potter, RE McGovern and C Hardy, Engineering and Mechanisation Unit, SAC Aberdeen, June 1997.

Appendix 2: Student Project

Design and testing of a refrigeration system for continuously cooling carrots with high humidity air

Background: Carrots require to be stored at 1°C and 98% RH, yet still keep their skins dry to ensure that disease does not develop. Since condensation at such high humidities is very likely if temperature differences occur in store, temperature control within the crop has to be precise. A system of cooling whereby humidified air is continuously circulated through the crop ensures that the cooling air always meets carrots that are warmer than the air. This ensures condensation on the crop cannot occur.

Wet cooling systems are available that provide humidified air, but these systems require an antifreeze to be included in the cooling water to prevent freezing. The antifreeze has to be compatible with the food stored. These system are expensive. If a dry system of cooling can be used, that does not freeze up too quickly, this would solve many of the existing problems with such units.

Project: The project will be in a number of parts.

1) To check the design a two stage glycol refrigeration system for the constant cooling of 15 tonnes of carrots. The carrots will be held within the SAC store. (A humidifier is already available for placement before the glycol heat exchanger. Details of cooling loads required are available from Bill Goodall, PhD Student, SAC.)

2) To carry out a detailed simulation of the glycol heat exchanger, perhaps using CFD, to check if cooling can be achieved with minimum icing up of the heat exchanger.

3) To discuss the design of heat exchanger with the manufacturer of the refrigeration system.

4) To monitor the performance of the refrigeration system in practice to ensure it operates to specification.

Associated work

A fridge has to be in position by late December. We are at present giving a specification for the fridge to a company for their engineers to design. They envisage using a scroll compressor so that performance can be related to load. The supply of glycol to the heat exchanger would also be proportional to load. Shaun Brett would hopefully liaise with these engineers to check out in theory that their design will work in practice.

RT Pringle
25/09/97