MATHEMATICAL MODELLING OF HEAT TRANSFER AND WATER VAPOUR TRANSPORT IN APPLE COOLSTORES

A thesis presented in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Biotechnology and Bioprocess Engineering at Massey University.

Nevin David Amos

B.Hort.Sci. (Hons) (Massey)

1995

ABSTRACT

A study of heat transfer and water vapour transport in a large industrial apple coolstore was undertaken. A set of measurements was made including product cooling rates in both pre-cooling units and the bulk-storage area, evaporator and fan performance, floor and building shell temperatures, door opening frequency and air temperature, relative humidity (RH) and velocity variation with both position and time.

Measurements within pallet pre-coolers showed large variations in product cooling rate between apple cartons but this could not be attributed to any positional factor studied. The spread of data was probably due to widely differing airflows through and around each apple carton. A staggered pallet pre-cooler configuration had a 30% faster cooling rate on average than an in-line pallet arrangement. Measurements of cooling rates within single cartons showed large variation of cooling rate with position within a carton, probably resulting from non-uniform airflow within the carton.

Existing heat conduction-based models were unable to predict the level of variability of cooling rate within cartons. A multi-zoned conduction and convection model was developed which predicts apple temperature and weight loss, air temperature, enthalpy and humidity, and packaging temperature with position within the carton. Testing of the model against measured data showed good fit for air and apple temperatures, but insufficient data were available for comprehensive testing of the humidity and weight loss sub-models. Difficulties in developing methodology to accurately define the patterns of airflow within cartons were not adequately overcome, so measurements to determine airflow patterns would be required before predictions could be made for alternative packaging systems.

Within the coolstore measured there was significant positional variation in air temperature and humidity associated with local heat sources (such as pre-coolers, doors, uninsulated floor, and warm fruit batches), and the degree of air circulation as quantified by local air velocities. In addition, temperature and humidity showed a diurnal fluctuation associated with the operation of the coolstore. These results suggested the need for a multi-zone dynamic model to enable predictions of both the time and the positional variation to be made.

Such a model was developed which included component models for zone air, external surfaces, floors, heat generators, inert materials such as internal structural components, evaporators, fans, doors and product. Novel features of the model compared to existing models are that it estimates airflow between zones using fixed user defined pathways, rather than complex hydrodynamic models; it considers water vapour transport in detail as well as heat transfer; condensation on surfaces and water absorption by packaging are modelled; and the product sub-model both allows movement of product batches during the simulation and accounts for differences in cooling rate within a batch.

Single-zone, 5-zone, 8-zone and 34-zone versions of the model were tested. The 1-zone model predicted mean thermal conditions for the coolstore adequately. The 5-zone model which differentiated the pre-coolers and the bulk-storage area predicted measured data well for the pre-coolers, but more time-variability was predicted for the bulk-storage area than occurred in the measured data. Separate door zones and vertical subdivision of the bulk-storage area were allowed in the 8-zone model. The pre-cooler prediction was largely unchanged and predicted vertical temperature differences were consistent with measured data, but the predicted mean temperature in the bulk-storage area was offset from the measurements. Little accuracy improvement was achieved by further subdivision (up to 34 zones), probably because of imprecision in defining and predicting interzone airflow rates.

Irrespective of the number of zones, adequate air humidity predictions could only be achieved when water absorption by packaging was modelled as well as product weight loss, door infiltration and deposition of moisture on evaporators.

For the industrial coolstore studied use of 5 or 8 air zones appeared to be the best trade off between accuracy and complexity. The model allows study of the effect of design and operational features on coolstore air temperature, humidity, product temperature and weight loss with better accuracy than previous models.

ACKNOWLEDGEMENTS

The author would like to thank the following persons for advice and assistance during the course of this project:

Professor Donald Cleland, Department of Process and Environmental Technology, Massey University, Chief Supervisor.

Professor Andrew Cleland, Department of Food Technology, Massey University, Supervisor.

Professor Nigel Banks, Department of Plant Science, Massey University, Supervisor.

Assistance from the following during the experimental phase of the project helped make data collection possible:

Mr Hilton Talyor, Site Engineer, New Zealand Apple & Pear Marketing Board (NZAPMB) Whakatu depot.

Mr David Marden, Formerly, Forman NZAPMB Whakatu depot.

Mr Kevin Decon, Formerly, Assistant Regional Manager, NZAPMB, Hastings.

The author would like to acknowledge the NZAPMB and Steelfort Engineering Ltd for funding this project, and the NZAPMB for making available the industrial coolstore used in this work. In particular the author would like to acknowledge the support of:

Mr Mike Odey, Formerly, Engineering Manager, NZAPMB, Wellington.

TABLE OF CONTENTS

Appendix

LIST OF FIGURES

LIST OF TABLES