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MATHEMATICAL MODELLING FOR DESIGN OF HORTICULTURAL PACKAGING

A thesis presented in partial fulfilment of the requirements for the degree
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'The roots of education are bitter, but the fruit is sweet'
- Aristotle

ABSTRACT.

A simulation system for design and optimisation of horticultural packaging systems was developed. This computer-based system is applicable to a range of horticultural products and package designs and predicts product cooling rate, product weight loss, local in-package relative humidity, and package material moisture properties.

A zone definition methodology was developed which related geometric characteristics of a wide range of packaging systems to specific model input data. The methodology also allowed the important intra- and inter-zonal heat and mass transfer pathways to be delineated and characterised. The model component hierarchy treated the fluid, packaging and product as equally important. This decision, differing from some previous models, was instrumental in achieving both greater flexibility and improved alignment between the modelled system and reality.

The dynamic simulation system was developed, with two model components. The pre-cooling (heat transfer) model within the 'Packaging Simulation for Design' software included ten major convective or conductive heat transfer pathways between air, packaging and product. Whilst these were the most significant modes of heat transfer envisaged, not all are necessarily significant for any particular package design. The dynamic bulk storage (mass transfer) model, also within the 'Packaging Simulation for Design' software, included six major mass transfer pathways associated with: packaging material moisture uptake, water vapour transport across packaging and ventilation boundaries, and product mass transfer.

In addition, a quasi-steady-state simulation system 'Weight Loss Simulator' was developed. The associated software incorporates a database of packaging configurations, and product specific data. The user inputs only a sub-set of the data needed by the dynamic model.

With the exception of in-package fluid velocity, most data needed for using the models could be adequately estimated using previously available methods. An experimental technique was developed for characterisation of airflow distribution within horticultural product packages. This technique used CO₂ as a tracer gas, measuring

arrival times at different locations following injection of CO₂ into the air stream entering the package. Several package designs for apples were characterised and in-pack air velocities estimated.

The heat transfer model was successfully applied to a range of both small and large packaging units (from single cardboard packs to apple pallets and bins). Both time-temperature data collected as part of this research and data from three external sources were predicted as well as could be expected, taking into account model input data uncertainties.

The dynamic and quasi-steady-state mass transfer models were tested for apple and tomato packaging systems (including both commercially used and prototype configurations). Where good quality input data were available, both models accurately predicted the mass loss from product/package systems.

Overall, the generalised simulation systems developed in this research were shown to be of sufficient accuracy for confidence to be placed in their application to design, optimisation and comparison of packaging system performance across a range of typical horticultural food cooling and storage operations. Nevertheless, areas for possible improvement are identified. The models may be applicable beyond horticultural commodities, but require testing for other products to substantiate this.

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