CFD MODELLING OF AIR FLOW AND HEAT TRANSFER IN A VENTILATED CARTON

QIAN ZOU

1998

CFD MODELLING OF AIR FLOW AND HEAT TRANSFER IN A VENTILATED CARTON

A thesis presented in partial fulfilment of the requirements for the Degree of
Master of Applied Science in Agricultural Engineering
at Massey University

Qian Zou

1998

ABSTRACT

Forced-air cooling is widely adopted for cooling fresh produce in ventilated packages. Air distribution inside the package is therefore an important factor for efficient cooling, since the heat transfer between product and air is largely affected by air motions. Computational fluid dynamics (CFD) provides a sophisticated but economic tool for modelling air flow.

A CFD-based mathematical model was developed to simulate air flow patterns in a ventilated apple carton during precooling. The model took account of both laminar and turbulent situations. In the model, air mass, momentum and energy conservation, as well as energy conservation of apples and packaging materials were described by a set of partial differential equations (PDEs) plus boundary conditions. For the turbulent flow a Lam and Bremhorst Low-Reynolds-number k-ε model was introduced to calculate local turbulent eddy viscosity.

Two modelling strategies were adopted. In the first approach, the air flow was assumed to be steady-state while the buoyancy force due to natural convection was neglected. Steady-state Navier-Stokes equations were solved first, and the outputs of fluid velocity were then used as input data to solve energy equations. For the second approach, all transport equations were solved simultaneously with consideration of the effect of natural convection on air flow patterns. All together, three air flow scenarios were considered: steady-state laminar flow, steady-state turbulent flow, and unsteady-state laminar flow.

The CFD package PHOENICS (CHAM, UK Ltd) was used to solve the set of PDEs. The curvilinear Body-Fitted Coordinates (BFC) grid system was used for mesh generation. The entire grid system had 19964 cells. Five sets of PHOENICS codes were written for the three different flow situations. An additional PHOENICS programme was also used to calculate the heat transfer coefficients on the carton external surfaces. It took much longer time to reach convergence for unsteady-state laminar flow (91 hours) than for steady-state laminar flow (9-14 hours).

The predicted flow patterns and temperature profiles were very similar for steady-state laminar and turbulent flows under 0.5 m/s inlet velocity. By comparing predictions for steady-state and unsteady-state laminar flows, effects of natural convection were considered negligible in unsteady-state laminar flow. Thus it was reasonable to adopt the programme for steady-state laminar flow instead of unsteady-state laminar flow because of much less computing time in solving steady-state flow.

A trial of apple precooling was conducted in which temperature in the centres of apples in various positions were measured. Good agreement between model predictions and experimental data was obtained in most locations, but fairly large errors were found in the apples near carton inlets and outlets. Further work is required to refine the model and to validate air temperature and velocity predictions.

ACKNOWLEDGEMENTS

I would like to thank my chief supervisor, Dr. Linus U. Opara (Institute of Technology and Engineering) and my co-supervisor, Professor Robert McKibbin (Institute of Fundamental Science), and Associate Professor Cliff Studman (Institute of Technology and Engineering) for their advice and assistance during the course of this project.

I would also like to express my appreciation to all the technical staff (former Agricultural Engineering Department), especially Mr Gerard Harrigan and Mr Leo Bolter who assisted with much of the experimental work.

I would like to acknowledge the following persons for their help and advice: Mr Yun Lu (graduate student, Institute of Technology and Engineering), Mr Phil Etheridge (Institute of Fundamental Science) and Mr David Tanner (PhD student, Department of Food Technology).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE