F R E E Z I N G   R A T E   S T U D I E S   I N   B L O C K S

O F   M E A T   O F   S I M P L E   S H A P E

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURE		AFTER PAGE

LIST OF TABLES

CHAPTER 1

INTRODUCTION

In view of the large quantities of foodstuff now being preserved in the frozen state, it is important to be able to predict the freezing time of a product under specified freezing conditions. An accurate knowledge of the freezing time of a product permits a precise termination to be made to the freezing process and the subsequent improvement possible in plant utilization is significant when large quantities of foodstuff have to be frozen in a given freezing plant. The freezing rate of a foodstuff must be high enough to prevent loss of quality as a result of microbiological and enzymic changes, but a loss of quality may still occur as a result of the nature of ice crystal formation during freezing. Mazur (27) proposed a quantitative relationship between the size and location of the ice crystals and the freezing rate and he considered that high freezing rates gave a high product quality. With these factors in mind the freezing rates obtained during the freezing of a product under different conditions were determined.

The freezing times and freezing rates of a product can be found by experiment. This involves making temperature measurements with suitably located thermocouples, and the product is frozen when a specified centre temperature is reached. To eliminate the necessity for making experimental studies it is desirable to develope a calculation method which will accurately predict the freezing rate and freezing time of a product.

The freezing of a product results in a change of the physical state of the foodstuff which is accompanied by the release of the latent heat of solidification of the large water component of the foodstuff. The latent heat of solidification is released over a temperature range and not at a specific temperature, the freezing point, as in the case of pure water because of the presence of salts in the tissue fluid, which cause a depression of the freezing point of the system. As freezing proceeds water separates out as ice which results in an increase in the concentration of these salts, and this causes a greater depression of the freezing point of that system. This results in the latent heat of solidification being released over a temperature range until finally a temperature is reached when the entire system is frozen. The change of physical state of the system during freezing also results in a change of the thermal property values of the foodstuff. The change in these values is associated with the higher thermal conductivity and lower specific heat of the ice formed during freezing.

The rate of heat transfer which occurs during the freezing of a product is governed by the Fourier heat conduction equation, which is a nonlinear partial differential equation. To determine the freezing rate, solutions of this equation have to be found which satisfy the heat transfer boundary conditions which prevail in the physical system being considered. Neumann (19) obtained an analytical solution for this equation for the case of slab ice formation on the surface of a liquid at its freezing point, with constant free surface temperature which corresponded to an infinite surface heat transfer coefficient. An analytical solution presented presented by Stefan (19) may be considered as a special case of Neumann's general solution. These solutions are of little technical use for the freezing of foodstuffs since generally the product is cooled from both sides and the heat transfer coefficient is far from infinite. Particular solutions are unknown when technically useful heat transfer boundary conditions are imposed. For a normal freezing process the heat transfer boundary conditions must account for the gradual release of the latent heat of solidification at the freezing boundary and for the variation of thermal property values with temperature. Variations in the initial product temperature, the surface heat transfer coefficient, the ambient temperature and the product thickness which occur must also be accounted for by the heat transfer equations.

The difficulties involved in obtaining an exact analytical solution to the freezing problem for technically useful heat transfer boundary conditions, resulted in the development of approximate solutions. These solutions were obtained by making assumptions which simplified the nature of the heat transfer boundary conditions existing in the experimental system. Analytical, graphical and numerical approximate solutions of the freezing problem were obtained when these assumptions were made, the different types of solutions requiring different degrees of assumptions to be made for their development. It was found that the numerical type of solution dealt most adequately with the heat transfer boundary conditions which existed in a normal freezing process. In this type of solution a nonlinear heat transfer equation is replaced by a series of approximately linear equations over restricted temperature ranges and the phase change which occurred in the physical system is taken into account by varying the thermal property values used in the calculations. Calculations in the numerical solutions are repetitive and they would be tedious if they are not made on a digital computer. The availability of a digital computer permitted the use of the numerical solution.

One dimensional freezing of a homogeneous body was studied because of the complexity of the numerical solutions for two and three dimensional freezing. Minced lean beef frozen in a plate freezer, closely approximated this system of a homogeneous product.

The aim of this study was to obtain freezing curves for minced lean beef under a variety of experimental conditions, temperature measurements being made with thermocouples, and to determine the accuracy with which these freezing curves could be estimated by the numerical solutions obtained with a digital computer. From these correlation studies the magnitude of the surface heat transfer coefficient which existed in a plate freezer was determined. Normally routine freezing time determinations are made with Plank's equation (32) which has the practical advantage of simplicity. Assumptions made during its derivation limit the accuracy of these results and thus Plank's equation was modified to give predictions which agreed closely with the experimental freezing times.