CHAPTER 1
INTRODUCTION

Freezing of perishable products, in order to increase their storage life, has been one of the earliest and the most widely used technique. In practice a wide variety of food products, both of plant and animal origin, are frozen for preservation. In case of 'live' products like fruits and vegetables, the metabolic activity and spoilage due to post harvest chemical changes are retarded by freezing. For dead foods such as meat, fish, dairy products the deterioration caused by microorganisms and irreversible chemico-physical changes are considerably diminished by freezing.

For most of the perishable products, the rates of biological and chemical processes which are responsible for their spoilage have been observed to diminish exponentially with the reduction in temperature [1]. However, there is a wide disagreement amongst scientists regarding the lowest temperatures to which the product should be frozen [2]. It can safely be assumed that no bacterial spoilage can take place at temperatures below -10 °C [3-5]. The physical, chemical, micro-biological aspects of freezing of food products have been exhaustively studied by many investigators and their work have been reviewed in the literature [6-10]. It should be noted that while freezing can offer protection against spoilage it can also cause some undesirable changes in the products like damaging the live tissues, textural changes etc.

The rate of freezing determines the size and location of ice crystals formed in the tissues. Lind and skjoldebrand reported an experimental investigation of surface heat and mass transfer effect during freezing and thawing [11].
A brief review of commercial thawing practices are presented by Duvien [12]. Loss of juice from foods due to dripping and evaporation and the microbial growth on the surface due to the use of high temperatures and long exposure times are listed as primary deteriorative effects that should be minimized during thawing. Low temperature (15 °C) and high humidity (90%) air is generally recommended for thawing of frozen foods [13].

1.1 FREEZING AND TEXTURAL CHANGES

In the case of slow freezing, the ice crystals formed are large and distributed non-uniformly. In fibrous products like meat, the large crystals may cause dislocation and tearing of fibres. In cellular products, the ice gradually fills the intracellular space and may cause rupture. Gradual increase in concentration of fluids for a long time may also cause some textural changes. In the case of 'quick freezing', the above drawbacks are avoided since uniformly distributed sub-microscopic ice crystallites are formed. However, except in case of very low freezing rates, organoleptic quality of food products have been found to be independant of freezing rates.

1.2 TIME-TEMPERATURE HISTORIES OF PERISHABLES

Bacteriologically safe food processing and handling techniques require the prediction of time-temperature histories of perishables during various heating and cooling operations. Such a prediction cannot however be made without a knowledge of the thermal properties. For perishable products the thermal history depends on various factors like type of food, geometry and the process conditions. This is because most of the perishable products are heterogeneous in nature. Since the type of perishable products and the processing conditions are too numerous, it is not possible to measure the time-temperature data for all available systems. However, for products whose geometry and heat transfer boundary conditions are known, the time-temperature relation can be calculated if their thermal properties are known. Unfortunately thermal properties of perishable products are either not available or inaccurate if available.

Solid food products are moist porous bodies with complicated structures. The thermo-physical properties of these products vary over a
wide range. The variation of thermo physical properties with temperature must be taken into account during freezing and thawing of food stuffs. If the values of the thermophysical properties are known in the temperature range under consideration the resulting non linear heat conduction equations can be solved easily by numerical methods [14]. Also, the same variety of products may have different property values depending on the parameters like moisture, temperature, their gradients, fat content, protein content, density, place where it is grown, porosity, size, age etc. It can be seen from the above discussion that, for exercising a control over the quality of the food product and to achieve optimal and economical processing conditions a clear knowledge of heat and mass transfer in food product is essential. The major impendiment for this is the lack of data on the thermal properties. Various studies have been made, but to date there are still many foods whose thermal property values need to be evaluated. Sometimes reports available often fail to supply the complete details of the measurements made and the values reported also disagree. The disagreement could be due to the methods of evaluation, some of which are not suited for particular food products. A compilation of thermal conductivity and/or thermal diffusivity values of many food products have been made by Lentz [15] Hill et al [16], Woodams and Nowreg [17] Ansari and Iqbal [18] and Tressler et al [19]. The usefulness of these reports is limited since complete information regarding the composition of sample, moisture content, test conditions are often lacking. The most exhaustive data for thermal conductivity values for food products today is reported by Qashou et al [20]. They have compiled the conductivity values of about 160 products covering grains, seeds, vegetables and their juices, fruits and fruit juices, meat and meat derivatives, poultry, fowl, egg and their by-products, marine products, dairy products, additive, sugar, starch, bakery products, fats, oils, gums and extracts from animal and vegetable origin.

Exact analytical heat flow solutions can be obtained for homogeneous inorganic materials such as metals, ceramics, etc, whose physical and thermal properties are well known or can be measured precisely. However, exact mathematical formulation of heat and mass transfer in food products is difficult as they are heterogeneous in nature.
The simplest way of arranging the two phases of a heterogeneous system is to have them either in series or in parallel combination with respect to the heat flow. The series of combination which offers the maximum resistance to the heat flow predicts the minimum value for the conductivity. The parallel combination of the two phases offer the least impedance to the heat flow and hence predicts a maximum value for the conductivity. These two arrangements impose the limits for the conductivity value. The effective conductivity of materials should lie between these two limits. Figure 1.1 shows the comparison of the conductivity values obtained for different configurations and arrangement of the constituent materials of the composite body as assumed by different investigators.

The ordinate in the figure 1.1 represents the ratio of effective conductivity to the gas conductivity. The abscissa represents the ratio of solid to gas conductivity. The geometrical model proposed by Hughes [21] (reference number 1 in the Figure 1.1) reveal that conductivity value corresponding to intermediate weighted geometric mean is applicable for random distribution of the phases.

Maxwell [22] (reference number 2 in the Figure 1.1) proposed a random distribution of randomly sized spheres and cylinders in a continuous medium, and this model is applicable for large porosity values.

Eucken [23] (Reference number 3 in the Figure 1.1) generalized Maxwell's equation to the case of 'n' dispersed phase and one continuous phase.

Wyllie and Southwick [24] (Reference number 4 in the Figure 1.1.) have used an equivalent resistor model comprising of three elements. This is a combination of series and parallel distributions.

Krupiczka [25] (Reference number 5 in the Figure 1.1) simplified the equation for the evaluation of effective thermal conductivity for models madeup of spheres and cylinders.
FIGURE 1.1 COMPARISON OF EFFECTIVE THERMAL CONDUCTIVITY.
Brailsford and Major [26] (Reference number 6 in the Figure 1.1) proposed an expression equivalent to Maxwell's equation.

Deissler and Boegli [27] predicted a graphical solution for the evaluation of effective thermal conductivity which takes into account irregular arrangement and shape of the particle, using the statistical method.

It is seen from the Figure 1.1 that all the models proposed by different authors predict the value of thermal conductivity which lies between the two extreme values. However, the equations for thermal conductivity evaluation as given by these investigators are all derived for restricted cases wherein a regular arrangement of the component phases is assumed. This is not valid in practice.

Nekrasov [28] has given a simple empirical relation for determining the effective thermal conductivity of dispersed media. He considered a model made up of spheres arranged in cubic array. Some studies on the determination of thermal conductivity of heterogeneous material have been made by Gorring and Churchhill [29]. They have developed an expression for effective thermal conductivity for a cubic array of particles bounded by paraboloids of revolution. Chaudhary and Bhandari [30], Taso [31] and Cheng and Vachon [32] have proposed some geometrical models which take into account the irregularity of the shapes and random orientation of the constituents. However, the equations for evaluating the thermal conductivity as proposed by these authors include some constants which can be obtained only by experiments. Duinev and Zarichnyak [33] have made some studies on a generalized thermal conductivity in heterogeneous systems.

Most of the geometrical models available in literature are applicable only to dry products. (Example: Granular materials where the product constituents are in solid and gaseous phases only). As such the models available cannot be used with confidence for the evaluation of the thermal conductivity of moist materials.
1.3 EFFECT OF MOISTURE CONTENT

Since food products have a higher moisture content, heat transfer in them is invariably accompanied by moisture transfer. Moisture movement takes place within the product due to the combined effects of capillary diffusion, concentration difference and thermal gradient. At the surface, the moisture transfer is mainly due to evaporation, though in rare cases, mechanical entrainment of moisture particles with the heat transfer medium may take place (Ex. air Blast freezing) while in process like drying, the very objective is to achieve increased moisture loss, during operations like pre-cooling, freezing and storage, dehydration is considered to be detrimental to the product quality. During thermal processing of perishable products, rigorous consideration is to be given for the retention of quality, i.e., taste, flavour, colour, structure, vitamin content, nutritional value and natural appearance.

Thus the thermal processing of perishable products differs from that of other porous bodies like leather, timber, clays, textiles, etc., Hence a clear knowledge of heat and mass transfer in perishable products during various thermal processes is essential not only to exercise a control over the quality of the product but also to achieve optimal and economical processing conditions.

1.4 EFFECTIVE CONDUCTIVITY - GEOMETRICAL MODELS PROPOSED

Food products can be considered to be systems of two phases-solid and air (granular materials) or solid and water. Thermal conductivity of such a system can be predicted with the knowledge of the thermal conductivity of the constituents. Several investigators have determined the thermal conductivity of such multiphase materials by assuming that the constituents are in a regular pattern in the product. The overall conductivity of such a composite body is then evaluated using simple conduction equations. Such a conductivity value is referred to as apparent or effective conductivity. The different types of geometrical models proposed by several authors are given below.