Chapter I

INTRODUCTION

India ranks fourth in the world in milk production with annual production in 1983-84 estimated at 36.3 million tonnes. Milk and milk products are the second largest contributor to the gross agricultural output. It is estimated that about 50 per cent of all milk produced is utilized for making indigenous dairy products and about 7 per cent of total milk produced is used for khoa. Khoa is a highly concentrated milk (about 70 per cent solids) which is a protein denatured product prepared in an evaporator. Evaporation offers the advantages of lowering the packaging, storage, transportation and preservation costs due to the large reduction in weight and volume. The operation of evaporation may be used for products having wide variation in characteristics which in many cases influence the evaporator design considerably.

Several factors may influence the selection of an evaporation system. The highly concentrated milk is viscous and heat-sensitive product and needs special attention in order to have minimum contact time between the product and the heated surface. The characteristics of concentrated milk tend to promote scaling or fouling of the heat transfer surfaces in the evaporator, resulting in a degradation of the product and significant decrease of the evaporation rate. The amount of degradation is a function of the temperature and the length of time. Foaming characteristics of milk also affect the design of an evaporator.

There are several types of evaporators available for concentration of milk. Generally, khoa is prepared in open kettles either put directly over the flame or heated by steam. They have insufficient heating area to rapidly boil off large volumes of water. In addition, thickning and burn-on of product to the kettle wall gradually lowers the efficiency of heat transfer and slows the concentration process. High temperatures, long concentration times and inefficient manual agitation lower the quality of khoa. A scraped-surface evaporator seems to be a better choice for highly concentrated milk due to its unique features such as suitability to handle viscous, heat-sensitive and foaming materials; having a short residence time and high evaporation rate. In an evaporator of this type, product is agitated by an internal rotor or a scraper which may have a fixed clearance, or blades with adjustable clearance or spring loaded blades which actually scrape the heat exchange surface. The rotating scraper blades continuously clean the surface of the heat exchanger preventing localized overheating and giving rapid heat transfer. A rotor not only induces turbulence but also uniformly spreads the product on heat transfer surface. The shearing action of the rotor blades decreases the apparent viscosity of the product and improves heat transfer. In a batch process, this type of evaporator is more convenient for incorporating the product ingradients at the final stage of preparation and maintaining the required quality of the product.

A key design consideration in an evaporator is the amount of heat transferred from the heating medium to the product. The required heat transfer surface area cannot be computed without estimating the overall heat transfer coefficient of the heating surface. The overall heat transfer coefficient includes the resistance offered by the heating medium, heat exchange wall, and the product. The convective heat transfer coefficient on the heating medium side can be predicted with acceptable accuracy (61). However, very little is known about the product side film coefficient. Some work has been reported for water, glycerol under conditions similar to that of scraped-surface heat exchangers (8, 10, 16, 104). Non-Newtonian nature of highly concentrated milk (2, 50, 87) makes it difficult to use Nusselt theory for predicting the product side film coefficient due to variation in its apparent viscosity depending on the shear rate. The only theory available for calculating the film heat transfer coefficient in a scraped-surface heat exchanger is the penetration theory. For predicting film coefficient with this theory, it is necessary to know the required properties of the product and the right temperature of the boiling liquid as it is elevated during concentration. But very little is known about these properties especially for highly concentrated milk. The theory although gives a good approximation in many cases, it is somewhat an oversimplification. It has been found that the theory either overestimates or underestimates the film heat transfer coefficient (9, 16, 41, 55, 71).

Hitherto no generally valid theoretical or emperical relationship for the prediction of heat transfer in a batch type scraped-surface evaporator has been published. Information upon which to base the design of large scale installation is therefore obtained in laboratory and pilot plant units.

In general, the factors affecting the rate of heat transfer in a batch type scraped-surface evaporator are :

i) Thermal and physical properties of the milk;

ii) Temperature difference between the condensing steam and the milk;

iii) Volume of milk;

iv) Scraper speed;

v) Number of blades on the scraper;

vi) Clearance of the scraper;

vii) Initial temperature of the milk;

viii) Length of the cylinder;

ix) Diameter of the cylinder;

x) Cylinder characteristics :

(a) cylinder material

(b) cylinder thickness

(c) type of treatment on cylinder; and

xi) Degree of concentration of the product.

However, some of the variables such as the effect on the rate of heat transfer due to length, diameter and other characteristics of the cylinder; the number of scraper blades and its clearance were not included in the study.

A research project was undertaken with the following broad objectives :

1. To develop experimental data on the following thermal and physical properties of whole milk as a function of concentration and temperature, for use in predicting heat transfer coefficient by penetration theory :

   i) Specific heat;

   ii) Thermal conductivity;

   iii) Specific gravity; and

   iv) Viscosity.

2. To study the parameters affecting the overall heat transfer coefficient and the physical quality of khoa with a view to optimise the design of batch type scraped- surface evaporator. The parameters investigated were :

   i) Scraper speed;

   ii) Temperature drop across heat transfer wall;

   iii) Batch size;

   iv) Degree of concentration of milk; and

   v) Heating temperature.

In the first phase of the project, the thermal and physical properties, such as thermal conductivity, specific heat, viscosity, specific gravity were determined. These are required to predict the heat transfer coefficient with penetration theory. The properties of concentrated milk having total solids varying from 35 to 70 per cent in temperature range of 30 to 90 ^{o}C were studied. The samples were prepared in open kettle by the traditional method (22). Experimental set-ups were designed and fabricated to determine the specific heat and thermal conductivity of the concentrated milk. In the second phase, the effect of process conditions of the scraped-surface evaporator on the coefficient of heat transfer and quality of the final product (khoa) was determined. The experimental set-up consisting of a single cylinder, batch process, scraped-surface evaporator with all the components was designed and fabricated at the Agricultural Engineering Department, Indian Institute of Technology, Kharagpur. The experiments were carried out with the developed batch type scraped-surface evaporator using whole milk.

The details of the experimental techniques and procedure as well as the results and discussion are presented in Chapters IV and V respectively.