ABSTRACT

Ice cream is a frozen aerated mixture with milk, cream, sugar, milk solid-not-fat (MSNF), stabilizer, and emulsifier as its basic ingredients. Scraped Surface Freezer (SSF), which is augmented with Liquid Nitrogen (LN_2) freezing technique was deployed for the production of ice cream. The design considerations were followed by assuming that the ice cream mixture enters at 4 ºC inside the freezer and comes out in the form of a frozen dessert at a temperature of -6 °C. The overall heat transfer coefficient and area of heat transfer were analysed based on the results obtained after various trials and errors during calculation. The dimensional parameters were decided based on the analysis and trials carried out. The individual parts were fabricated as per the decided dimensional parameters and were then assembled. The statistical modal analysis was done using ANSYS *Workbench* to decide the arrangement of blades that promotes heat transfer and better mixing. The performance evaluation of the fabricated SSF was done initially with ethylene glycol and water mixture, mixed in the ratio of 60:40; after which the performance evaluation was carried out by passing the ice cream mixture inside the freezer barrel at different process parameter conditions and observing the drawing temperature. The ice cream obtained from the developed freezer was then compared with the commercially available ice cream.

The study suggests that the heat transfer coefficient, area of heat transfer, and volumetric flow rate play an important role in deciding the various design parameters of the freezer. The larger the coefficient, the easier heat is transferred from its source to the product. Also, it reduces the time of operation. Length and diameter are decided such that the equipment is cost-effective along with the highest possible overall heat transfer coefficient. After various trials and analysing the results, a heat transfer area of 0.26 m^2 was selected for a good overall heat transfer coefficient approximately equal to 600 $W/m^{2\circ}C$. For the heat transfer area of 0.26 m^2, a length of 0.7 m and a diameter of 0.12 m of the heat transfer tube were considered. The SSF has been simulated and the flow properties distribution was obtained through numerical simulation. The Computational Fluid Dynamics (CFD) results show that flow is confined between blades and the inner heat transfer tube surface, and as a consequence change in the velocity direction was found at that area. Due to this recirculation, a faster decrease in temperature was observed in this area. The results of the experimental investigation of the SSF were rigorously compared with the CFD results. The highest temperature occurs at the inlet, and the lowest temperature occurs at the outlet which makes the temperature gradient larger and the heat transfer effect more satisfactory. Liquid nitrogen along with refrigeration was also used to create the desired overrun in the ice cream mix. This technique provides net primary energy savings and economic benefits to the users.

Keywords: Ice cream, Scraped surface freezer, Liquid nitrogen, Heat transfer, Computational fluid dynamics.