Abstract  
Khoa is an intermediate product widely used as a base material for various indigenous milk sweets. Long duration conventional natural cooling of khoa in open trays not only increases total production time but also results to various browning reactions and microbial contamination. Thermal performance of mechanized khoa cooling system was evaluated to enhance the quality of cooled khoa. The system consisted of an enclosed jacketed tubular screw conveyor. Experiments were conducted at various combinations of 3, 6, 9 screw rotations per minutes and 0°, 5°,10° inclination angle of cooling barrel. Cooling performance was evaluated in terms of overall heat transfer coefficient and cooling efficiency. The residual quantity of khoa left in the system after cooling was also determined. Optimum process parameters for maximum cooling were 9 rpm of screw speed and 10° angle of inclination. The sensory quality of mechanized cooled product was judged by an expert panel. The effect of system operational parameters on sensory attributes of khoa was insignificant.

Keywords: Continuous cooling system, Khoa, performance evaluation, viscous dairy product

Introduction

Indian dairy sweets are integral part of rich Indian cultures and its festivals. Khoa is an intermediate product and forms base for a large number of sweets such as burfi, peda, milk-cake, kalakand, gulabjamun etc. The annual production of khoa is estimated at more than one million tonnes, utilizing about 6 million tonnes of milk, equivalent to 7 per cent of total milk production. Khoa production is mainly confined to the non-organized sector. However, now some plants have undertaken mechanized production of high quality khoa on an industrial scale (Aneja et al., 2002; Aneja, 2007). Khoa is a product obtained from cow or buffalo milk or a combination thereof by rapid desiccation and having not less than 30% fat on dry matter basis of the finished product (FSSR, 2011). Traditional method consist of taking 4-6 litres of buffalo milk and a combination thereof by rapid desiccation and having not less than 30% fat on dry matter basis of the finished product (FSSR, 2011). Traditional method consist of taking 4-6 litres of buffalo milk, boiling it over direct fire in a shallow pan (mild steel) with vigorous stirring and scraping. A pan and scraper forms the essential parts of equipment required for traditional khoa making. Scraping is so vital that the operator's skill is the single most important factor governing the quality of product. With certain variations in the technique, three different type of product viz. Pindi, Dhap and Danedar can be obtained (De, 1980). Within 5-10 minutes a semi-solid mass having dough consistency is formed (Punjrath, 1991). Hot khoa is kept in large open type trays for normal atmospheric cooling to room temperature (25-30°C). Time required for cooling is around 3 to 5 h which increases the total production time. Long duration conventional khoa cooling may results several chemical changes like browning reactions and also leads to chances of physical and microbial contamination.

Increasing demand of khoa based indigenous dairy sweets has created the need for large scale production of khoa. A number of equipments have been developed for mechanized production of khoa like inclined scraped surface heat exchanger (Punjrath et al., 1990), two stage scraped surface heat exchanger (Dodeja et al., 1992), three stage scraped surface heat exchanger (Kumar et al., 2009; Dodeja and Deep, 2012), in-line system (Kumawat et al., 2012, Minz et al., 2013) etc. Large scale khoa production will require mechanized cooling of khoa. From the literature, it was revealed that none of previous investigators worked on development of system for cooling of khoa in industrial scale. Cooling system if integrated with the khoa making equipment will reduce the total processing time. In this research work thermal

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Thermal performance evaluation of continuous khoa cooling system

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performance of continuous khoa cooling system was studied.

Materials and Methods

Continuous khoa cooling system

Screw conveyors are generally used for conveying materials and can sustain positive pressure. It is widely used in food and agricultural processing operations for steady conveying. The performance of a screw conveyor is affected by the conveyor geometry and size, material properties and the conveyor operating parameters such as the screw rotational speed, screw clearance and conveying angle (Srivastava et al., 2006; Zareiforoush et al., 2010a). For cooling of highly viscous dairy product like khoa, rapid mixing of product with efficient heat transfer is essential. Screw type mechanism would be most suitable for continuous khoa.

Double jacketed screw conveyor system for cooling of khoa was designed and developed taking into consideration screw geometry, product throughput and heat transfer rate (Gurjar, 2009). Double jacketed tubular construction provides efficient heat transfer between cooling medium and hot khoa. Enclosed tubular construction prevents physical and environmental contamination. Screw mechanism aids in conveying as well as improves contact of product with the surface of heat exchanger. Rotating screw provides transverse motion to product being handled. Screw continuously scrapes the inner surface of barrel and therefore prevents fouling. Screw can be operated at different speeds by a variable frequency drive (VFD) motor (3 phase 1.5 hp).

The system has hinge and nut bolt provision to adjust the inclination angle of barrel upto 10°. Resistance temperature detector (RTD) sensors measure inlet/outlet temperature of product and chilled water. Outer jacket of barrel has two flanged ports for inlet/outlet of chilled water. Heat transfer takes place between hot khoa and chilled water (4°C). The water circulation line has a flow control valve and rotameter.

The volumetric throughput was adjusted to 60 kg/h to match the production capacity of the mechanized khoa manufacturing systems currently available. The screw system was operated at low rotational speed (3-9 rpm) to get high volumetric efficiency (Nicolai et al., 2004; Zareiforoush et al., 2010b). At low screw speed pressure buildup was avoided to retain the desirable texture of khoa during rapid cooling.

<table>
<thead>
<tr>
<th>Designed dimensions of developed cooling system</th>
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<tr>
<td>Length of conveyor for cooling</td>
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<tr>
<td>Barrel inside diameter</td>
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<tr>
<td>Thickness of barrel</td>
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<tr>
<td>Screw shaft diameter</td>
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<tr>
<td>Thickness of screw flight</td>
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<tr>
<td>Thickness of jacket</td>
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<tr>
<td>Pitch of screw</td>
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<tr>
<td>Average helix angle of screw</td>
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<td>No. of screw flights</td>
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Experimental procedure

Thermal performance in terms of overall heat transfer coefficient and cooling efficiency was determined for the system. The performance characteristics were investigated as a function of inclination angle and screw speed. After preliminary trials, levels of the operational parameters were decided. Effect of inclination angle (0°, 5°, 10°) on various responses was studied. Direction was such that with increase in inclination angle, the distance between output opening and the floor decreased. Effect of screw rotational speed on the thermal performance was evaluated by selecting three levels of screw speed (3, 6, 9 rpm). Inclination angle of the cooling barrel was adjusted by elevation nut fitted with two hinges. Screw speed was controlled by VFD motor with gear box. The system was operated on counter flow arrangement to maximize the heat transfer. Chilled water (4°C) was circulated through the barrel jacket at 500 l/h. The equipment was tested at the operational capacity of 60 kg khoa/h. Khoa was prepared using buffalo milk (5% fat & 9% SNF) in steam jacketed kettle and was cooled from 80±2°C to ambient temperature (30±2 °C) in the developed system. For analysing the reliability of experiment, univariate analysis of variance (ANOVA) was applied.

Thermal performance study of mechanized cooling system

a. Overall heat transfer coefficient (U)

Overall heat transfer coefficient (U) equals the quantity of heat passing through unit area of wall surface in unit time at a temperature difference of unit degree with dimension of W/ m² °C. This was calculated using following equation:
\[ U = \frac{Q}{A_c \cdot \text{LMTD}} \]

- **Q**: Rate of heat transfer (W)
- **A_c**: Effective total heat transfer area (m²)
- **LMTD**: Log mean temperature difference between hot khoa and chilled water (counter flow)

b. Cooling efficiency

Cooling efficiency is defined as the ratio of heat energy removed from product to the heat taken by cooling media which is expressed as a percentage of heat supplied.

\[
\text{Cooling Efficiency} = \left( \frac{\text{Heat energy removed from product}}{\text{Heat energy taken by cooling media}} \right) \times 100
\]

\[
= \left( \frac{M_p C_p (T_{ip} - T_{op})}{M_c C_c (T_{ic} - T_{oc})} \right) \times 100
\]

Where,

- **M_p, M_c**: Mass flow rate of product and chilled water respectively (kg/h)
- **C_p, C_c**: Specific heat of product and chilled water respectively (kJ/kg)
- **T_{ip}, T_{op}**: Product temperature at inlet and outlet respectively (°C)
- **T_{ic}, T_{oc}**: Chilled water temperature at inlet and outlet respectively (°C)

Residual quantity of khoa

During preliminary trials it was seen that a small quantity of khoa remained inside the cooling system and could not be recovered. Residual quantity of khoa left in the system was calculated by measuring the difference of weight between input and output quantity of khoa.

Sensory evaluation

The khoa samples were subjected to sensory evaluation by a judging panel. A 100-point descriptive scale was used for evaluation of sensory attributes like flavour (50), body & texture (35) and colour & appearance (15).

**Results and Discussion**

Effect of operating parameters on overall heat transfer coefficient

Overall heat transfer coefficient was maximum (338.68 W/m² °C) at 10° inclination angle and 9 rpm screw speed. Overall heat transfer coefficient of the mechanized system increased with inclination angle (Fig. 2). This may be explained by the fact that higher inclination angle creates drag. With increased inclination, there may be more tendency of viscous product to adhere to the screw blades. And this phenomena will increase the drag along the screw - barrel interface. And there is better contact between the product and heat transfer surface. But the effect of inclination angle on overall heat transfer coefficient was non-significant (p>0.05).

It was observed that there was 1.5 to 2 times increase in overall heat transfer coefficient when screw rotational speed was increased from 3 to 9 rpm (Fig. 3). This proportional relationship between overall heat transfer coefficient and screw speed may be due to number of reasons. Higher screw speed resulted in agitation and turning of khoa inside the barrel. At higher screw speed, the product film is quickly scraped which in turn improves the rate of heat transfer. The effect of screw speed on overall heat transfer coefficient was significant.
Better heat transfer rate can be achieved by operating the system at higher inclination angle and higher screw speed.

**Effect of operating parameters on cooling efficiency**

There was 3-12% increase in the cooling efficiency when inclination angle was increased from 0° to 10° (Fig. 4). In contrast, increase in cooling efficiency was about 28-35% when screw rotational speed was increased from 3 to 9 rpm (Fig. 5). Increasing inclination angle from 0° to 10° did not improve the cooling efficiency significantly (p>0.05). However the variance analysis of the data indicated that the effect of screw rotational speed on cooling efficiency was significant (p<0.05). Maximum cooling efficiency (84.3%) was achieved when system was operated at 10° inclination angle and screw speed of 9 rpm. At this optimum operational parameter hot khoa (80°C) was effectively cooled to ambient temperature (30°C). Inlet and outlet temperature difference (ΔT) of chilled water was 4-8°C.

**Quantity of khoa remaining the system was in the range of 460 to 970 g per batch. Residual quantity of khoa in system increased with increase in angle of inclination of the cooling system (Fig. 6). Whereas increasing screw rotational speed reduced the residual quantity of khoa (Fig. 7). Effect of inclination angle and screw speed on residual quantity of khoa was significant (p<0.05). Results indicate that the quantity of residue could be minimized by operating the system at higher screw speed and low inclination angle. Greater screw speed scrapes the internal surface and helps in reducing the quantity of residual khoa. Therefore, it is important that the clearance between the screw and barrel jacket is kept minimum.**

**Effect of operating parameters on sensory attributes**

The trends in sensory scores of mechanized cooled khoa were similar for all possible combinations of the selected
operational parameters (Fig. 8). Mechanized cooling of khoa had no adverse effect on the flavour and texture. Effect of inclination angle and screw speed on the sensory quality of khoa was insignificant (p>0.05).

Conclusions

It can be concluded that the optimum operating parameters for mechanized cooling system were 9 rpm screw speed and 10° angle of inclination. Maximum overall heat transfer coefficient and cooling efficiency were 338.68 W/m²°C and 84.3 % respectively. Such system can be integrated with continuous khoa manufacturing equipments for rapid cooling of khoa to ambient temperature. Continuous cooling system will not only reduce manufacturing time and also help in hygienic processing of khoa.

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