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# Analysis of the Operating Energy Variables Involved in Mechanized *Khoa* Production

**Patel A. D [a++*], Patel S. I. [b++], Patel S. M [a#] and R. B. Modi [c]**

*[a] Dairy Engineering Department, SMC College of Dairy Science, Kamdhenu University, Anand, India.*
*[b] Dairy Chemistry Department, SMC College of Dairy Science, Kamdhenu University, Anand, India.*
*[c] Department of Food Processing Technology, College of FPT@BE, AAU, Anand, India.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Significant portion of the total milk production of India has been utilized for the manufacture of the Traditional Indian Dairy Products (TIDP). Khoa based products were traditionally produced in the Indian sub-continent since ancient times. Khoa produced by the mechanized methods can overcome the demerits of traditional manufacturing methods like insufficient use of energy, poor hygiene and sanitation, non-uniform product quality, etc. In the present study, steam jacketed open type hemispherical kettle equipped with spring loaded Teflon edged scraper blade assembly was utilized for the mechanized production of khoa. A standardized mixed milk having (6.0±0.1%) fat and (9.0±0.2%) SNF, was evaporated to the different level of concentration using a batch type vacuum pan. The performance of the mechanized manufacture of khoa was evaluated at different steam pressures ($P_1$= 98.06 kPa, $P_2$=147.1 kPa, $P_3$=171.61 kPa), scraper speed ($R_1$=0.67rps), and different level of milk concentration ($C_1$=35 %TS, $C_2$=40 %TS, $C_3$=45 %TS) for first stage. During the second stage, effect of operating variables on process mechanization were evaluated at

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[++] *Assistant Professor;*
[#] *Professor and Head;*
**Corresponding author: Email: drashishpatel@kamdhenuuni.edu.in;*

different steam pressures ($S_1$= 49.03 kPa and $S_2$= 78.45 kPa) and scraper speed ($R_2$=0.33rps). The primary objective of present study is to carry out thermal and electrical energy analysis associated with mechanized khoa production, which has a significant role in process optimization, scale-up of the operation and to design and fabricate the mechanized system. The overall heat transfer coefficients (U-values) of the mechanized system obtained at various processing parameters ranged from 156.87 to 234.16 W/m$^2$K during *khoa* manufacturing. The treatment $C_1 P_1 S_2$ gave the highest U-values for sensible and latent heating. The mean U-values of sensible heating and latent heating were increased with an increase in steam pressure during *khoa* making in the mechanized system. The mean value of specific steam consumption (kg steam/kg water evaporated) for the optimized operating conditions was 1.950 (kg steam/kg water evaporated) for manufacture of *khoa* in mechanized system. The total heat losses of mechanized system during manufacture of *khoa* was 17.15 to 28.02 % at different operating conditions studied. The mean values of electrical power consumption ranged from 141 to 203 Wh under different operating conditions. Considering the energy consumption data, we can narrate that existing system is energy efficient with lower electrical energy consumption and can reduce the labour cost due to mechanization.

*Keywords: Khoa production; energy and mass transfer; steam jacketed kettle; energy transfer equations; total milk solids.*

## 1. INTRODUCTION

India stands as a global powerhouse in dairy production. Being the world's largest milk producer, India has registered a 58% increase during the last nine years and crossed 230 Million Tonnes in the year 2022-23 with a CAGR of 5.85%. The milk utilization pattern revealed that about 50-55 % of the total milk produced in India is converted into traditional milk products, which is mainly confined to the cottage scale in the unorganized sector [1,2,3]. Since time immemorial, traditional milk products have been an indispensable part of the social and cultural life of India and have great economic importance.

*Khoa* occupies a pivotal position amongst traditional Indian dairy products as it forms the base material for various sweetmeats such as *peda, kalakand, burfi, gulabjamun,* etc. In India, about 600000 tons of *khoa* is being produced annually by utilizing 7 % of the total milk produced in the country [4,5] valued at ₹18, 000 million [6]. Thus, traditional Indian dairy products represent the most prolific segment of the Indian dairy industry. According to Tambekar et al. [7], the small-scale scattered production, poor quality of milk and unhygienic practices followed during production, handling and storage of *khoa* results in poor shelf life. To overcome these disadvantages, attempts have been made to automate the process to develop batch, semi-continuous, and continuous equipment for manufacturing Traditional Dairy products on large commercial scale [8]. Considering public health significance Yedatkar et al. [9] studied the microbiological quality of khoa produced by the local producers. Looking at the demand and profitability, many organized dairy plants have entered in the business of traditional dairy products adopting improved technology and mechanization in the manufacture of such products. Mechanization of the TIDP is a need of the day, but adaptation of such mechanised system is still limited due to some constrains like, lack of scientific data, unavailability of heat and mass transfer behaviour, inadequate thermal analysis data, etc.

Performance evaluation of the mechanised system is a very important aspect as it helps to scale up the existing operation, design of new equipment, fabrication of the equipment, energy requirements of the system, operating cost analysis of the set-up and profitability. Keeping all these points in mind, energy analysis of the developed mechanised production system was carried out in the present study.

## 2. MATERIALS AND METHODS

Raw fresh mix milk having 6% fat and 9% SNF was procured and collected in clean and dry aluminum cans and kept at refrigeration temperature. The milk samples for chemical analysis were prepared as per the method described in the BIS Handbook [10]. Various platform tests and compositional analysis were done by following the BIS Handbook.

### 2.1 Experimental Set Up for Mechanized Production of *Khoa*

Scraped Surface Heat Exchangers (SSHEs) are commonly used for the viscous, sticky and particulate matter containing products like khoa for better heat transfer, crystallization, freezing and other continuous processes. The steam jacketed open type hemi-spherical kettle, made from AISI 304 stainless steel, used for the mechanized production of khoa. Having a volumetric capacity of 50 liter, the kettle was provided with all accessories and mountings like steam pressure gauge, air release valve, safety valve, steam regulating valve, steam trap, warm and warm wheel mechanism for unloading of hot processed product and lid for covering the kettle. The unit also consisted of a specially designed scraper assembly to avoid burning of the product and to give the desired texture with a higher heat transfer rate. Scrapers assembly was also provided with a Variable Frequency Drive (VFD) to have variations of speed in the range of 1-50 rpm to get the desired rheological attributes of the product. Electricity connection for the operation of scraper assemblies was made through a three-phase energy meter and a direct-on-line starter. The design specifications of the steam kettle used are given in Table 1.

The jacketed kettle used for the manufacture of *khoa* for experimental trials required electrical energy for the operation of three phase induction motor which was driving scraper assembly. The steam generated from the IBR boiler was supplied to the installed mechanized system. Three-phase A.C. power supply was provided to the motor of the scraper drive through power analyzer. The photographs of the mechanized system are shown in Figs. 1 and 2.

## 2.2 Optimization of the process for Mechanized Production of *Khoa*

During *khoa* production, water from the milk was evaporated and the concentrated mass converted into semi solid paste like consistency due to heat induced changes. The milk was converted in dough like consistency known as the pat formation stage. After the pat formation stage, the heating and agitation were controlled by reducing steam pressure and increasing agitator speed. A semi solid mass having more than 60% TS was considered as final product.

The basic need for mechanized *khoa* production is to optimize the operating variable associated with *khoa* production. The *khoa* was prepared by various operating variables at different levels like the concentration of mixed milk (35%, 40%, and 45% TS), steam pressure (98.06, 147.1, and 171.61 kPa), scraper speed (0.67 rps), steam pressure after pat formation (49.03 and 78.45 kPa) and scraper speed (0.33 rps) after pat formation. Optimization of process variables for the mechanized system is essential for better control of khoa’s desired colour, flavour, body and texture at various production stages which were evaluated by the BIS scorecard for sensory

**Table 1. Specification of mechanized system**

| Sr. No. | Particulars | Specifications |
|---|---|---|
| 1. | Material of construction | Stainless Steel AISI 304 |
| 2. | Thermal conductivity of SS AISI 304 | 16.2 W/m K |
| 3. | Outer diameter of the inner shell | 0.500 m |
| 4. | Inner diameter of the outer shell | 0.505 m |
| 5. | Thickness of the inner shell | 0.005 m |
| 6. | Height of the inner shell (hemisphere + cylinder) | 0.450 m |
| 7. | Volume of kettle | 50 liter |
| 8. | Material of steam jacket | Stainless Steel AISI 304 |
| 9. | Thickness of steam jacket (middle shell) | 0.003 m |

**Fig. 1. Steam jacketed kettle**

**Fig. 2. Scraper assembly**

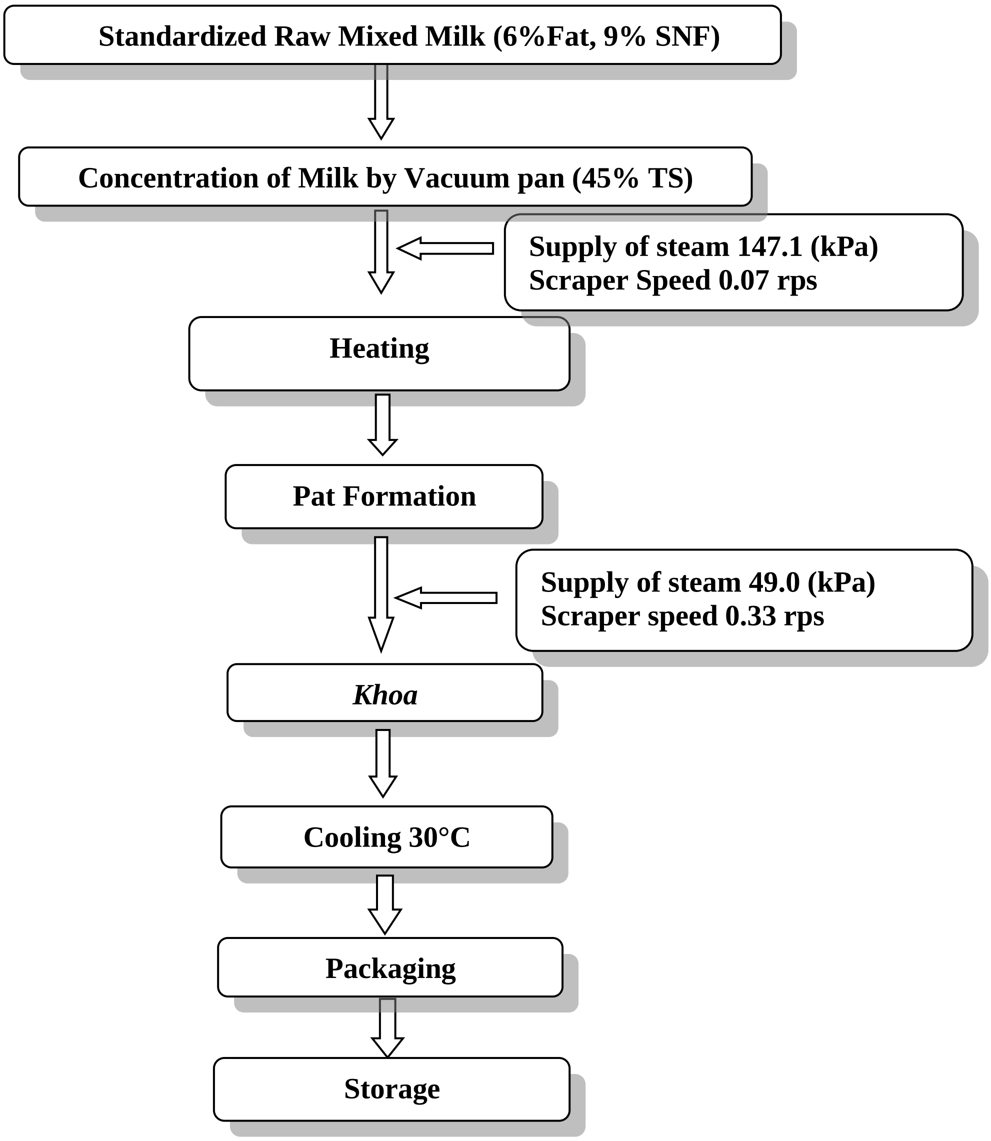

**Fig. 3. Standardized Process for the mechanized production of *khoa* [11]**

attributes. Results of the sensory attributes of *khoa* prepared from such operating variables were analyzed by statistical tools and considered for selecting the optimized parameters. The process flowchart for the manufacture of *khoa* by optimized parameters is shown in Fig. 3.

## 2.3 Measurement of Operating Variables

Performance evaluation of the mechanized system is a very complex procedure and it requires numerous data during various production stages. The temperature was measured with a digital temperature indicator (Model- 441E, Century make, Chandigarh) having RTD sensors (Pt100). The steam consumption of the developed system of *khoa* making was estimated by measuring the quantity of condensate coming out from the steam trap of the jacket. The electrical energy consumption (input voltage, current and power) of the SSHEs was measured by a power analyzer (MICO, 3 phase 4-wire power analyzer, 440 V) and an energy meter installed in the electrical circuit. The scraper speed was confirmed by digital tachometer (ASAHI, Nagasima Keiki, Japan) and for low speed, visual counting was carried out. The rate of evaporation was calculated by TS difference and mass balance. Thermal heat supplied and electrical power required to operate a mechanized system were measured using data collected during different experimental trials [12,13,14].

## 2.4 Heat Transfer Evaluation of Steam Jacketed Kettle

### 2.4.1 Sensible heat transfer

Sensible heat required for milk,

$$Q_{sm} = m_m \times C_m \times (t_2 - t_1) \qquad (1)$$

Where,

$Q_{sm}$= Sensible heat of milk, kJ
$m_m$= mass of the milk, kg
$C_m$= specific heat of milk, kJ/kg K
$t_1$= initial temperature of milk,°C
$t_2$ = final temperature of evaporation,°C

Therefore, total sensible heat required,

$$Q_s = Q_{sm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

### 2.4.2 Latent Heat Transfer

The latent heat transfer during the process was calculated using the following equation.

$$Q_l = E \times L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

Where,

$Q_l$= Latent heat, kJ
E = total evaporation of water, kg/batch
L = latent heat of evaporation, kJ/kg

As the evaporation takes place at atmospheric pressure, the latent heat of evaporation at atmospheric pressure was taken as latent heat of evaporation (L), which is 2257 kJ/kg.

### 2.4.3 Determination of overall heat transfer Co-efficient

According to Fourier's heat flow equation,

$$Q_s + Q_l = U \times A \times (T_s - T_p) \ldots\ldots\ldots\ldots \quad .(4)$$

Where,

U = Overall heat transfer co-efficient, W/m$^2$K
A = Effective heat transfer area of the SSHE, m$^2$
$T_s$ = Temperature of steam corresponding to steam pressure, °C
$T_p$ = Temperature of the product, °C

## 2.5 Energy Analysis of Steam Jacketed Kettle

Steam is supplied in the jacket through a steam valve and the condensate leaving the steam trap of the SSHE was measured. Fig.4 shows a block diagram of the SSHE indicating input heat energy as well as energy leaving the SSHE to carry out energy analysis.

## 2.6 Statistical Analysis of the Experimental Data

The rate of heat transfer, energy input, heat losses etc. were determined during the operation of the steam jacketed kettle by using heat transfer equations. The data obtained during the investigation were subjected to statistical analysis using a completely randomized design (CRD) and factorial completely randomized design (FCRD).

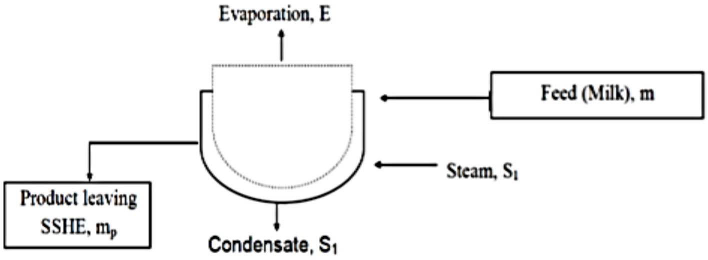

**Fig. 4. Block diagram of jacketed kettle with input and output energies**

The heat balance equation for the mechanized system is as under.

Rate of heat energy input = Rate of heat energy leaving the SSHE + Losses

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Heat energy with the feed materials | + | Heat energy of Steam | = | Heat energy of condensate | + | Heat energy of evaporated water | + | Energy going with the product | + | Energy losses |

$$(m \times C_p \times T_i) + S_1(h_s + X \times h_l) = \left(S_1 \times C_{pc} \times T_{s1}\right) + (E + H_v) + (m_p \times C_{pp} \times t_1) + E_l$$

Where, M = mass of each material, kg
$C_p$ = specific heat of each material, kJ/kg K
Ti = Initial temperature of each feed material,°C
$h_s$ = sensible heat of steam, kJ/kg K
x = dryness fraction of steam
$h_l$ = latent heat of steam, kJ/kg
$C_{pc}$ = specific heat of condensate, kJ/kg K
$S_1$ = quantity of steam used, kg/h
$T_{s1}$ = saturation temperature of condensate,°C
E = evaporation rate of water, kg/h
$E_l$ = energy loss, kJ/h
$H_v$ = enthalpy of evaporated water, kJ/kg
$m_p$ = mass of the product leaving the SSHE, kg
$C_{pp}$ = specific heat of the product, kJ/kg k
$t_1$ = temperature of the product leaving the SSHE,°C

## 3. RESULTS AND DISCUSSION

### 3.1 Optimization of Processing Parameters for Mechanized Production of *Khoa*

**Table 2. Optimization of operating parameters for mechanized production of *khoa* based on sensory attributes (batch size-10 kg)**

| % Concentration | Batch (kg) | Pressure (kPa) | Pressure After Pat formation (kPa) | Scraper speed before pat formation (rps) | Scraper speed after pat formation (rps) | Sensory Evaluation score | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Flavour (45) | Body & Texture (35) | Colour & Appearance (15) | Total score (100)* |
| 45%TS | 10 | 147.1 (kPa) | 49.03 (kPa) | 0.67 | 0.33 | 44.05±0.34 | 33.83±0.33 | 14.33±0.17 | 97.22±0.72 |

** Total score includes score of 5.0 for package (Patel et al, 2024)*

### 3.2 Heat Transfer Performance, Energy Analysis of Mechanized System

To design the equipment and to generate data for optimizing the operating conditions of the machine, the study of heat transfer is the most essential aspect. The heat transfer behaviour of the system is influenced by several factors such as operating parameters, characteristics of the product, type of metal of the kettle, the thickness of the kettle, etc. Generally, steam kettle having the hemispherical design, but with flat bottom and shallow design is recommended for typical traditional dairy products.

**Table 3. Rate of water evaporation during *khoa* manufacturing in mechanized system**

| Milk Concentration, %TS | Steam pressure, P (kPa) | Steam pressure after pat formation, S (kPa) | Rate of evaporation (kg/h) | Batch Time (min.) | Yield* of *khoa* (kg) |
|---|---|---|---|---|---|
| 35% | 98.06 | 49.03 | 4.48 | 65 | 5.15 |
| | | 78.45 | 5.02 | 58 | 5.15 |
| | 147.10 | 49.03 | 4.70 | 62 | 5.15 |
| | | 78.45 | 4.85 | 60 | 5.15 |
| | 171.61 | 49.03 | 4.85 | 60 | 5.15 |
| | | 78.45 | 5.29 | 55 | 5.15 |
| 40% | 98.060 | 49.03 | 3.92 | 63 | 5.88 |
| | | 78.45 | 4.49 | 55 | 5.88 |
| | 147.10 | 49.03 | 4.19 | 59 | 5.88 |
| | | 78.45 | 4.33 | 57 | 5.88 |
| | 171.61 | 49.03 | 4.49 | 55 | 5.88 |
| | | 78.45 | 4.94 | 50 | 5.88 |
| 45% | 98.060 | 49.03 | 3.38 | 60 | 6.62 |
| | | 78.45 | 3.83 | 53 | 6.62 |
| | 147.10 | 49.03 | 3.69 | 55 | 6.62 |
| | | 78.45 | 3.83 | 53 | 6.62 |
| | 171.61 | 49.03 | 4.06 | 50 | 6.62 |
| | | 78.45 | 4.51 | 45 | 6.62 |

*Each observation is mean of three replicate experiments (n=3) *For Batch Size: 10 kg*

## Table 4. Effect of processing parameters on the rate of evaporation through latent heat during pre-pat formation stage

| Milk Concentration %TS | Steam pressure P (*kPa*) | Batch Time (min.) | Rate of evaporation (kg/h) | Yield of *khoa* (kg) |
|---|---|---|---|---|
| 35% | 98.060 | 39 | 6.70 | 5.65 |
| | 147.1 | 37 | 7.06 | 5.65 |
| | 171.61 | 36 | 7.26 | 5.65 |
| 40% | 98.060 | 37 | 5.75 | 6.45 |
| | 147.10 | 35 | 6.08 | 6.45 |
| | 171.61 | 32 | 6.65 | 6.45 |
| 45% | 98.060 | 34 | 4.84 | 7.26 |
| | 147.10 | 31 | 5.31 | 7.26 |
| | 171.61 | 30 | 5.48 | 7.26 |

*Each observation is mean of three replicate experiments (n=3)*

## Table 5. Effect of operating parameters on the rate of evaporation during mechanized production of *khoa* at Post-pat formation stage

| Milk Concentration %TS | Steam pressure P (*kPa*) | Steam Pressure After Pat formation S (*kPa*) | Batch Time (min.) | Rate of evaporation (kg/h) | U value ($W/m^2K$) |
|---|---|---|---|---|---|
| 35% | 98.060 | 49.03 | 23 | 1.78 | 165.42 |
| | | 78.45 | 21 | 1.92 | 162.57 |
| | 147.1 | 49.03 | 20 | 2.00 | 161.72 |
| | | 78.45 | 19 | 2.10 | 161.01 |
| | 171.61 | 49.03 | 18 | 2.20 | 159.72 |
| | | 78.45 | 16 | 2.43 | 156.87 |
| 40% | 98.060 | 49.03 | 20 | 2.33 | 202.02 |
| | | 78.45 | 19 | 2.41 | 198.95 |
| | 147.10 | 49.03 | 18 | 2.53 | 197.47 |
| | | 78.45 | 16 | 2.82 | 195.89 |
| | 171.61 | 49.03 | 15 | 2.96 | 192.83 |
| | | 78.45 | 13 | 3.50 | 197.47 |
| 45% | 98.060 | 49.03 | 17 | 2.87 | 211.20 |
| | | 78.45 | 15 | 3.29 | 162.68 |
| | 147.10 | 49.03 | 14 | 3.58 | 165.00 |
| | | 78.45 | 13 | 3.94 | 234.15 |
| | 171.61 | 49.03 | 12 | 4.24 | 220.38 |
| | | 78.45 | 10 | 5.01 | 217.32 |

## Table 6. Effect of various processing conditions on steam consumption during mechanized manufacturing of *khoa*

| Milk Concentration %TS | Steam pressure P (kPa) | Steam Pressure After Pat formation S (kPa) | Rate of evaporation (kg/h) | Steam consumption, kg/h | Specific steam consumption, kg steam/kg water evaporated |
|---|---|---|---|---|---|
| 35% | 98.060 | 49.03 | 4.48 | 7.39 | 1.674 |
| | | 78.45 | 5.02 | 8.29 | 1.693 |
| | 147.10 | 49.03 | 4.70 | 7.75 | 1.661 |
| | | 78.45 | 4.85 | 8.01 | 1.669 |
| | 171.61 | 49.03 | 4.85 | 8.00 | 1.648 |
| | | 78.45 | 5.29 | 8.74 | 1.681 |
| 40% | 98.060 | 49.03 | 3.92 | 6.47 | 1.683 |
| | | 78.45 | 4.49 | 7.41 | 1.670 |
| | 147.10 | 49.03 | 4.19 | 6.91 | 1.672 |
| | | 78.45 | 4.33 | 7.15 | 1.684 |
| | 171.61 | 49.03 | 4.49 | 7.41 | 1.670 |
| | | 78.45 | 4.94 | 8.15 | 1.680 |
| 45% | 98.060 | 49.03 | 3.38 | 5.58 | 1.715 |
| | | 78.45 | 3.83 | 6.32 | 1.698 |
| | 147.10 | 49.03 | 3.69 | 6.09 | 1.653 |
| | | 78.45 | 3.83 | 6.32 | 1.671 |
| | 171.61 | 49.03 | 4.06 | 6.70 | 1.675 |
| | | 78.45 | 4.51 | 7.44 | 1.685 |

*Each observation is average of three replications*

## 3.3 Evaluation of Energy Requirement of the Mechanized System for *Khoa* Production

### 3.3.1 Thermal energy requirement

The study of steam consumption is one of the significant aspects affecting the economy of the product. The steam consumption was determined and it was correlated with the rate of evaporation in the mechanized kettle under various operating conditions.

### 3.3.2 Electrical power consumption of the mechanized system for preparation of *khoa* under different operating conditions

The electrical energy is required to operate the scraper assembly of the mechanized kettle. The power requirement is associated with several factors like properties of the material being handled, scraper speed, number of blades, the weight of the scraper assembly, the tension of the spring, etc. The values of electrical power consumption of the mechanized system during *khoa* making are given in Table 7.

**Table 7. Electrical power consumption of the mechanized system for preparation of *Khoa***

| Milk Concentration C (%TS) | Steam pressure, P (kPa) | Steam pressure after pat formation, S (kPa) | Rate of evaporation (kg/h) | Batch Time (min.) | Electrical power consumption (Wh) |
|---|---|---|---|---|---|
| 35% | 98.060 | 49.03 | 4.48 | 65 | 203 |
| | | 78.45 | 5.02 | 58 | 181 |
| | 147.10 | 49.03 | 4.70 | 62 | 194 |
| | | 78.45 | 4.85 | 60 | 188 |
| | 171.61 | 49.03 | 4.85 | 60 | 188 |
| | | 78.45 | 5.29 | 55 | 172 |
| 40% | 98.060 | 49.03 | 3.92 | 63 | 197 |
| | | 78.45 | 4.49 | 55 | 174 |
| | 147.10 | 49.03 | 4.19 | 59 | 184 |
| | | 78.45 | 4.33 | 57 | 178 |
| | 171.61 | 49.03 | 4.49 | 55 | 172 |
| | | 78.45 | 4.94 | 50 | 156 |
| 45% | 98.060 | 49.03 | 3.38 | 60 | 188 |
| | | 78.45 | 3.83 | 53 | 166 |
| | 147.10 | 49.03 | 3.69 | 55 | 172 |
| | | 78.45 | 3.83 | 53 | 166 |
| | 171.61 | 49.03 | 4.06 | 50 | 156 |
| | | 78.45 | 4.51 | 45 | 141 |

*Each observation is average of three replications*

## 3.4 Heat Utilization and Losses

**Table 8. Heat energy input, output and losses during manufacture of *Khoa* under optimized condition**

| Milk Concentration (%TS) | Steam pressure, P (kPa) | Steam pressure after pat formation, S (kPa) | Heat energy of feed (kJ/h) | Heat energy of steam (kJ/h) | Heat energy of condensate, (kJ/h) | Heat energy of evaporated water, (kJ/h) | Heat energy of product, (kJ/h) | Energy losses, (kJ) | Energy losses, (%) |
|---|---|---|---|---|---|---|---|---|---|
| 35% | 98.060 | 49.03 | 1831.5 | 18464.42 | 2417.42 | 11987.51 | 739.54 | 5151.5 | 27.90 |
| | | 78.45 | 1831.5 | 20926.34 | 2739.74 | 13434.28 | 828.79 | 5755.0 | 27.50 |
| | 147.10 | 49.03 | 1831.5 | 19060.84 | 2612.06 | 12567.55 | 805.53 | 4907.2 | 25.74 |
| | | 78.45 | 1831.5 | 19793.95 | 2712.53 | 12986.47 | 832.38 | 5094.0 | 25.74 |
| | 171.61 | 49.03 | 1831.5 | 19909.77 | 2780.34 | 12986.47 | 853.19 | 5121.3 | 25.72 |
| | | 78.45 | 1831.5 | 19663.97 | 2746.02 | 14167.06 | 853.19 | 3729.2 | 18.96 |
| 40% | 98.060 | 49.03 | 1765.5 | 16248.69 | 2127.33 | 10494.12 | 872.02 | 4520.7 | 27.82 |
| | | 78.45 | 1765.5 | 18464.42 | 2417.42 | 120249.03 | 998.86 | 4793.1 | 25.96 |
| | 147.10 | 49.03 | 1765.5 | 17105.89 | 2344.16 | 11205.58 | 967.42 | 4354.2 | 25.45 |
| | | 78.45 | 1765.5 | 17838.99 | 2444.62 | 11598.76 | 1001.36 | 4559.7 | 25.56 |
| | 171.61 | 49.03 | 1765.5 | 17943.37 | 2505.74 | 120249.03 | 1026.40 | 4156.2 | 23.16 |
| | | 78.45 | 1765.5 | 18434.97 | 2574.39 | 13222.59 | 1063.72 | 3339.7 | 18.12 |
| 45% | 98.060 | 49.03 | 1694.0 | 14279.15 | 1869.47 | 9051.176 | 1030.07 | 4022.4 | 28.17 |
| | | 78.45 | 1694.0 | 16002.50 | 2095.09 | 10246.61 | 1166.12 | 4188.7 | 26.18 |
| | 147.10 | 49.03 | 1694.0 | 14906.56 | 2042.77 | 9874.011 | 1167.50 | 3516.3 | 23.59 |
| | | 78.45 | 1694.0 | 15639.67 | 2143.23 | 10246.61 | 1211.55 | 3732.3 | 23.86 |
| | 171.61 | 49.03 | 1694.0 | 15731.17 | 2196.81 | 10861.41 | 1241.84 | 3125.1 | 19.87 |
| | | 78.45 | 1694.0 | 16714.37 | 2334.11 | 12068.24 | 1316.35 | 2689.7 | 16.09 |

*Each observation is average of three replications*

## 4. CONCLUSION

The performance of the mechanized system was evaluated during manufacture of *khoa* at different steam pressures, scraper speeds and different level of milk concentration for the first stage and second stage. The U-values obtained during the study ranged from 156.87 to 234.16 W/m$^2$K under various operating conditions. The treatment $C_1$ $P_1$ $S_2$ gave the highest U-values for sensible and latent heating. The heat utilization and heat losses were carried out using heat and mass balance equations. The mean values of specific steam consumption under different operating conditions of khoa manufacture was 1.67 (kg steam/kg water evaporated). The average value of specific steam consumption under optimized operating condition of khoa manufacture was 1.95 (kg steam/kg water evaporated). During manufacture of khoa, the total heat losses of the mechanized system were 16.09 to 28.17 % at different operating conditions. The electrical energy utilization analysis revealed that the mean values of electrical power consumption ranged from 141.0 to 203.0 Wh under different operating conditions. The electric consumption was reduced owing to the installation of the VFD. The overall performance of the mechanized system was found satisfactory and is useful in commercializing the manufacture of indigenous dairy products.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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