Original Research Article

Development and Assessment of a Batch Type Ohmic Heating System for Milk Processing

ABSTRACT

This study aims to develop and assess the performance of a batch type ohmic heating system for the thermal processing of cow and buffalo milk, focusing on heating efficiency and product quality. An experimental setup was fabricated with a 7-liter capacity, utilizing an agitator as one electrode and the vessel surface as the other. The system was tested for heating milk from 32°C to target temperatures of 75°C and 92°C. Key processing parameters, including agitator speed and applied voltage, were optimized for both milk types. The physicochemical and microbial properties of the ohmically heated milk were evaluated, along with performance metrics such as heating rates, power consumption, and system efficiency. The developed ohmic heating system achieved heating rates of 4.29°C/min for cow milk and 2.85°C/min for buffalo milk. Cow milk demonstrated lower energy consumption, requiring less time and voltage compared to buffalo milk, with system performance coefficients of 58% for cow milk and 50% for buffalo milk. However, fouling on the agitator surface was identified as a challenge for industrial applications. In conclusion, the batch type ohmic heating system exhibited high efficiency and rapid heating capabilities for both cow and buffalo milk, indicating its potential for dairy processing. Future research should focus on addressing fouling issues and further optimizing the system for commercial use, enhancing the overall viability of ohmic heating technology in the dairy industry.

Keywords: Ohmic heating, milk processing, thermal efficiency, cow milk, buffalo milk, fouling, energy consumption, product quality

1. INTRODUCTION

In the food industry, ensuring safety and quality is crucial, especially for perishable products like milk. Traditional thermal treatments, while effective in eliminating pathogens, often lead to uneven heating and degradation of nutritional and sensory qualities. The challenge lies in preserving the integrity of complex food matrices, particularly those containing proteins and minerals, which are prominent in dairy products.

The problem is exacerbated by the limitations of conventional heating methods, which may not uniformly distribute heat throughout the product, resulting in hot and cold spots. This uneven heating can compromise the safety and quality of milk, prompting the need for more effective thermal processing techniques.

Ohmic heating has emerged as a promising alternative. This technology uses electrical currents to generate heat within the food product itself, ensuring rapid and uniform heating. However, its application in dairy processing remains underexplored, particularly in addressing localized heating challenges that arise due to the heterogeneous composition of milk. Notably, Ariç Sürme et al. (2021) investigated the evaporation process of cow's milk under atmospheric conditions with varying voltage gradients, revealing that as the voltage gradient increased, so did the energy and energy efficiency of the ohmic heating-assisted evaporation method. Their study found that this method reduced the initial dry matter content of milk more efficiently than traditional methods. Similarly, Norouzi et al. (2021) compared the performance of ohmic and conventional heating methods for concentrating sour cherry juice, highlighting the significantly higher heating rate of the ohmic method and its advantages in preserving color integrity. Furthermore, Rocha et al. (2022) explored the effects of different electric field strengths of ohmic heating on high-protein flavored milk, demonstrating benefits over conventional pasteurization, including reduced energy expenditure and improved microbial inactivation.

To tackle these issues, this study proposes the design and development of a batch-type ohmic heating system specifically customized for milk. By incorporating an agitator as one of the electrodes, the system aims to enhance heat distribution and minimize localized heating effects. This innovative approach seeks to optimize operational parameters, thereby improving the quality and safety of processed milk.

A brief literature survey reveals several relevant studies. Kumar et al. (2014) utilized response surface methodology to optimize ohmic heating parameters, demonstrating significant effects of processing time and voltage on quality metrics. Pataro et al. (2014) explored the influence of electric field strength and frequency on metal release in ohmic heating, highlighting the importance of electrical parameters. Priyanka et al. (2018) noted the efficiency of ohmic heating in achieving rapid and uniform heating of milk. However, these studies primarily focus on solid foods or specific aspects of ohmic heating, leaving a gap in the exploration of its application in dairy products.

The scope of this work encompasses the development of the ohmic heating system, optimization of its operational parameters, and assessment of its impact on milk quality. This research aims to bridge the knowledge gap regarding the application of ohmic heating in the dairy industry. By enhancing heat distribution and efficiency, the study seeks to contribute to improved food safety and quality.

Justification for this work stems from the pressing need for innovative thermal processing techniques that can effectively preserve the quality of dairy products while ensuring safety. The findings of this study are anticipated to advance the application of ohmic heating in the dairy sector, offering insights that could inform future research and practical implementations.

2. MATERIAL AND METHODS

This section outlines the materials and methods employed in the development and evaluation of a batch-type ohmic heating system for milk processing. The information provided herein aims to facilitate the reproducibility of the experiments conducted.

2.1 Experimental Setup

The conceptual design of the batch-type ohmic heater is illustrated in Figure 1. The setup consists of several integral components, including a milk vessel, an agitator, a motor, and a slip ring assembly, all mounted on a stainless-steel frame for stability. The agitator and milk vessel were used as electrodes to minimize fouling during the heating process.

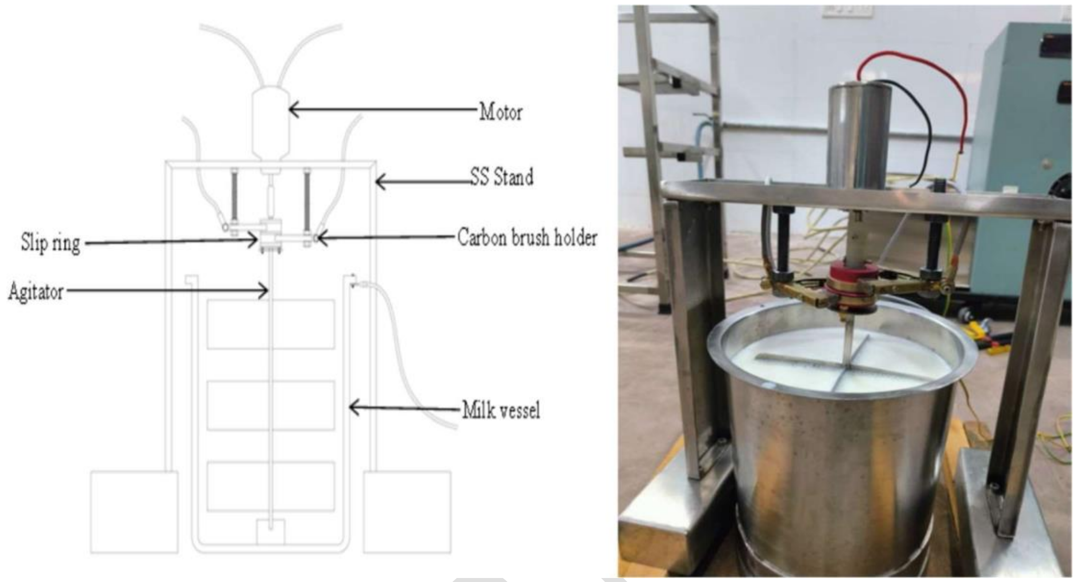

Figure 1: The conceptual diagram of an ohmic heater

2.2 Design and Fabrication of a Batch-Type Ohmic Heating System

The design of the small capacity ohmic heating vessel was based on a thorough review of existing literature. The final system includes Milk Vessel, Agitator & Motor assembly, and Slip Ring & Carbon Brush Assembly.

These components collectively facilitate efficient and controlled ohmic heating of milk

2.2.1 Design of Milk Vessel

The milk tank was fabricated from stainless steel, with a thickness of 2 mm and dimensions of 225 mm in diameter and 230 mm in height. The nominal capacity of the vessel was 7 liters, with a headspace of 50 mm to accommodate heating without overflow. Compliance with Bureau of Indian Standards (IS 2689) was ensured in its design.

2.2.2 Design of Agitator and Motor Assembly

The agitator featured a stainless-steel blade design with 12 blades positioned at three levels on the shaft, as shown in Figure 2. It was powered by a 12 V DC motor, capable of rotating at speeds between 10 and 100 RPM, with a torque of 5.7 kg-cm. A Teflon coupling was employed to electrically isolate the motor from the agitator while maximizing contact area for effective heat transfer.

Figure 2: Agitator, motor and slip ring assembly

2.2.3 Slip Ring and Carbon Brush Assembly

The slip ring and carbon brush assembly was crucial for current transmission to the rotating agitator, allowing it to serve as an electrode. A copper slip ring and carbon brushes were selected for their efficiency in transferring high amperage, as depicted in Figures 2. The entire assembly was secured to a stainless-steel frame, ensuring hygienic maintenance and ease of cleaning.

2.2.4 Electrical Panel

An electrical panel was used to manage all electrical components of the ohmic heating system, as shown in Figure 3.. It included a miniature circuit breaker (MCB) for safety, as well as key components like a voltmeter, ammeter, variac, kilowatt-hour meter, and transformer.

Figure 3: An electrical panel

2.2.5 Raw Milk

Two types of milk were utilized: raw cow milk, sourced from the Livestock Research Station (LRS) at Kamdhenu University, Anand, and raw buffalo milk, procured from a local vendor in Hadgud village of Anand District.

2.3 Experimental Design

The ohmic heating system underwent preliminary trials to establish operational parameters, specifically voltage settings for cow and buffalo milk. The parameters monitored included temperature profile, heating rate, and thermal efficiency.

2.4 Performance Evaluation of the Ohmic Heating System

To evaluate the performance, a series of experiments were conducted aiming for target temperatures of 75˚C and 92˚C. Response Surface Methodology (RSM) was employed for optimization, with various parameters assessed as outlined in Table 1.

Table 1: Experimental Parameters of ohmic heating system

Process Parameters		**Levels**
Variable Parameters	Voltage	Cow milk :18-35 V (90-180 V)
		Buffalo milk: 22-40V (110-200 V)
	Agitator speed	10 to 100 RPM
Fixed Parameters	Type of milk	Cow and Buffalo
	Initial Temperature	32˚C
	Final Temperature	75˚C & 92˚C

Performance Parameters (Responses)
• Temperature profile • Current profile • Heating time • Heating rate • Energy consumption • Sensory score • System performance coefficient

2.4.1 Performance Evaluation Parameters

Temperature Profile: Monitored using average temperature over time.
Current Profile: Recorded average current variations during heating.
Sensory Score: Evaluated using a 9-point Hedonic scale by a panel from the Dairy Engineering and Technology Department at Sheth M. C. College of Dairy Science, Anand
Heating Time: Total time to increase temperature from 32˚C to target temperatures.
Heating Rate: Calculated as $HR=\frac{\Delta T}{t}$. Where, ΔT =Temperature difference(°C) and t = time(min)
Energy Consumption: Calculated using $E = VIt$. Where, E = Energy (Wh), V = voltage (V), I= current (A), t = time (min)
System Performance Coefficient (SPC): Defined as $SPC = \frac{mC_p\Delta T}{\sum VIt}$ Where, m = Mass of the sample (kg), C_p = Specific heat capacity (J/kg˚C), ΔT = Temperature difference (˚C), V = applied voltage (V), I = Ampere (A), t = Time of heating (Minutes)

2.5 Chemical Analysis

The composition of milk like Fat, Protein and SNF content was analyzed using a Milkoscan instrument, recognized for its accuracy in dairy analysis. Acidity measurements followed the procedure outlined in the BIS Handbook (IS 1479-1961). Alkaline phosphatase levels were determined using the method specified in ISO 11816:2013.

2.6 Microbial Analysis

Dilutions were prepared aseptically by transferring 1 ml of the milk sample into a test tube containing 9 ml of diluent, creating a 1:10 dilution, with further dilutions prepared sequentially.

Viable bacteria were enumerated following Houghtby et al. (1992), using Plate Count Agar and incubating at 37°C for 48 hours. For Yeast and Mold Count methodology from Marshall (1992) was used, employing Potato Dextrose Agar and incubating at 30°C for 5 days. Coliform enumeration utilized the pour plate method described by Houghtby et al. (1992), employing Violet Red Bile Agar and incubating at 37˚C for 48 hours.

2.7 Statistical Analysis

Response Surface Methodology (RSM) was utilized to optimize variables, specifically voltage and agitator speed. The experimental design was evaluated using Design Expert 13.0.5.0 software, which facilitated statistical analysis of response variables. A total of 52 runs were conducted, with 13 runs for each treatment at varying temperatures. Observed data were analyzed to derive polynomial regression equations, and their significance was assessed through ANOVA. Response surface diagrams were generated to visualize the interactions between independent and dependent variables.

3. RESULTS AND DISCUSSION

This section presents the results and discussion from a four-phase study investigating an ohmic heating setup for milk processing. Key phases included system design, optimization of heating parameters, quality assessment of treated milk, and performance evaluation. Statistical analysis was conducted using Design Expert software to interpret the findings comprehensively.

3.1 Design and Fabrication of Batch Type Ohmic Heating System

The development of the batch-type ohmic heater involved creating a 7-liter stainless steel vessel, designed to optimize heating efficiency. The effective electrode surface area was determined to be 1670 cm², aligning with recommendations from Priyanka et al. (2018) to minimize fouling. The agitator, equipped with 12 blades arranged at three levels, had an effective surface area of 1427.55 cm², serving as a secondary electrode.

The effective rotation speed of the agitator was crucial for optimal performance, with literature suggesting a range of 10 to 100 rpm to avoid fat separation. A 12 V DC metal geared motor was selected, achieving a torque of 5.7 kg-cm, enabling effective mixing within the specified speed range.

Two methods for electrical current transfer to the rotating agitator were assessed. The first method, using an 8 mm bearing connected to a hook, resulted in sparking at elevated voltages and was discarded. The second method, employing a 2-copper ring slip ring and carbon brush assembly, was effective and reliable, enhancing the system's overall functionality.

Using stainless steel for all components was intentional, given its favorable properties in food processing. The complete assembly was mounted on a robust frame to ensure operational stability. The results indicate that the fabricated ohmic heating system is suitable for milk processing, confirming the effectiveness of the slip ring assembly in addressing electrical transfer challenges.

3.2 Response Surface Analysis of Heating Parameters

3.2.1 Heating time, energy consumption, and overall sensory score of cow Milk (at 75˚C)

The heating time for ohmically processed cow milk at 75˚C varied between 9.2 to 38 minutes. The shortest heating time of 9.2 minutes was recorded at a voltage of 35 V and agitator speed of 55 rpm. Analysis revealed significant effects of voltage ($P = .001$) and agitator speed ($P = .060$) on heating time, although no significant interaction effects were observed. The model's coefficient of determination (R^2) was 0.9923, indicating a strong fit.

Energy consumption ranged from 0.0551 to 0.1182 kWh. The lowest consumption was at 35 V and 55 rpm, while the highest was at 18 V and 55 rpm. Both voltage ($P = .001$) and agitator speed ($P = .004$) significantly influenced energy consumption. The model yielded an R^2 value of 0.9491, further establishing the significance of these factors.

The overall sensory score ranged from 6 to 8.5, with the highest score at 26.5 V and 55 rpm. Voltage significantly affected the sensory score ($P = .001$), while the effect of agitator speed was marginally significant ($P = .066$). The model's R^2 for sensory score was 0.8968, indicating reasonable fit.

Optimization identified settings of 32.5 V and 67 rpm, achieving a desirability of 0.847. Replication of the optimized process as per table 3 showed no significant differences for heating time ($P = .632$), energy consumption ($P = .609$), or overall sensory score ($P = .106$), confirming the reliability of the optimization.

Table 2: Validation of the optimized solution for heating Cow milk (at 75˚C)

Response	Predicted Value*	Actual Value@	Cal. t-Value#	P Value	Significance
Time of heating (minute)	10.126	10.071 ± 0.287	0.503	0.632	NS
Energy consumption (kWh)	0.072	0.071± 0.006	0.538	0.609	NS
Overall Sensory score	8.129	7.857 ± 0.378	1.903	0.106	NS

* Predicted values of Design Expert 13.0.1.0 package
@ Actual values are average of seven trials for optimized product
# t-values found non-significant at 5 per cent level of significance
NS = non-significant
Tabulated t-value = 2.447 (cal. t-value less than tabulated value)

3.2.2 Heating time, energy consumption, and overall sensory score of cow Milk (at 92˚C)

At 92˚C, heating time varied from 12 to 55.4 minutes, with the minimum at 35 V and 55 rpm and the maximum at 18 V and 55 rpm. Both voltage ($P < .05$) and agitator speed ($P < .05$) significantly affected heating time, with an R^2 of 0.9923 and an F-value of 181.27 ($P < .001$).

Energy consumption at this temperature ranged from 0.1148 to 0.1928 kWh. Voltage and agitator speed both significantly influenced energy consumption ($P < .05$), yielding an R^2 of 0.9959.

The overall sensory score ranged from 5 to 8.5, with significant positive effects from voltage ($P < .05$). The optimization led to settings of 32.5 V and 63 rpm, with validation in table 3 confirming no significant differences (P = .680 for heating time, P = .196 for energy consumption, P = .163 for sensory score).

Table 3: Validation of the optimized solution for heating Cow milk (at 92˚C)

Response	Predicted Value*	Actual Value@	Cal. t-Value#	P Value	Significance
Time of heating (min)	13.711	13.657 ± 0.336	0.432	0.680	NS
Energy consumption (kWh)	0.12	0.118 ± 0.006	0.921	0.196	NS
Overall Sensory score	8.450	8.214 ± 0.393	1.585	0.163	NS

* Predicted values of Design Expert 13.0.1.0 package
@ Actual values are average of seven trials for optimized product
# t-values found non-significant at 5 per cent level of significance
NS = non-significant
Tabulated t-value = 2.447 (cal. t-value less than tabulated value)

3.2.3 Heating time, energy consumption, and overall sensory score of Buffalo Milk (at 75˚C)

For buffalo milk at 75˚C, heating time ranged from 12 to 38.4 minutes. The shortest time was at 40 V and 55 rpm, while the longest was at 20 V and 55 rpm. Voltage significantly influenced heating time (P = .01), with an R^2 of 0.990.

Energy consumption ranged from 0.0802 to 0.1458 kWh, significantly affected by voltage (P = .01) and agitator speed (P = .05). The model showed an excellent fit (R^2 = 0.998).

Sensory scores varied from 6 to 8.5, with voltage significantly influencing the scores (P = .02). The optimal conditions identified were 37 V and 43 rpm, achieving a desirability of 0.884. validation in table 4 confirming no significant differences

Table 4: Validation of the optimized solution for heating Buffalo milk (at 75˚C)

Response	Predicted Value*	Actual Value@	Cal. t-Value#	P Value	Significance
Time of heating (minute)	16.755	16.529 ± 0.359	1.668	0.146	NS
Energy consumption (kWh)	0.087	0.085± 0.005	1.109	0.309	NS
Overall Sensory score	8.337	8.071± 0.345	2.036	0.087	NS

* Predicted values of Design Expert 13.0.1.0 package
@ Actual values are average of seven trials for optimized product
# t-values found non-significant at 5 per cent level of significance
NS = non-significant
Tabulated t-value = 2.447 (cal. t-value less than tabulated value)

3.2.3 Heating time, energy consumption, and overall sensory score of Buffalo Milk (at 92˚C)

Heating time at 92˚C ranged from 15 to 58 minutes (Table 4.), with both voltage (P = .01) and agitator speed (P = .01) significantly affecting the duration. The model had an R^2 of 0.9948 and an F-value of 266.64.

Energy consumption ranged from 0.1108 to 0.2018 kWh (Table 4), with significant effects from both voltage (P = .01) and agitator speed (P = .01). The model fit was strong (R^2 = 0.9877).

The overall sensory scores varied from 5 to 8, influenced by both voltage (P = .01) and agitator speed (P = .01). The optimization process led to conditions of 37 V and 69 rpm, yielding a desirability of 0.894. Validation in table 5 confirmed no significant differences (P = .875 for heating time, P = .857 for energy consumption, P = .457 for sensory score)

Table 5: Validation of the optimized solution for heating Buffalo milk (at 92˚C)

Response	**Predicted Value***	**Actual Value@**	**Cal. t-Value#**	**P Value**	**Significance**
Time of heating (minute)	21.025	21.00 ± 0.404	0.164	0.875	NS
Energy consumption (kWh)	0.126	0.126 ± 0.004	0.188	0.857	NS
Overall Sensory score	8.0	7.857 ± 0.476	0.795	0.457	NS

* Predicted values of Design Expert 13.0.1.0 package
@ Actual values are average of seven trials for optimized product
# t-values found non-significant at 5 per cent level of significance
NS = non-significant
Tabulated t-value = 2.447 (cal. t-value less than tabulated value)

3.3 Quality Evaluation of Ohmically Heated Milk

3.3.1 Physico-Chemical Properties

Analysis of the physico-chemical properties of ohmically heated milk indicated slight variations compared to raw milk (Table 6). Cow milk's protein content decreased from 3.1% to 2.84% after heating, while buffalo milk showed a reduction from 3.81% to 3.72%. Fat content also decreased slightly, attributed to the lack of immediate cooling. Acidity increased from 0.133% in raw cow milk to 0.142% at 92˚C. Alkaline phosphatase tests confirmed effective pasteurization, indicating that the observed changes were primarily due to processing conditions.

Table 6: Comparison of the physico-chemical properties between raw and ohmically heated Cow and Buffalo milk

Particulars	**Raw Cow milk**	**Ohmic heated Cow milk (at 75˚C)**	**Ohmic heated Cow milk (at 92˚C)**	**Raw Buffalo milk**	**Ohmic heated Buffalo milk (at 75˚C)**	**Ohmic heated Buffalo milk (at 92˚C)**
Fat %	4.32 ± 0.187	4.30 ± 0.0173	4.29 ± 0.023	6.17 ± 0.015	6.15 ± 0.023	6.14 ± 0.021
Protein %	3.1 ± 0.034	2.91 ± 0.029	2.84 ± 0.36	3.81 ± 0.028	3.77 ± 0.029	3.72 ± 0.025

SNF %	8.55 ± 0.030	8.24 ± 0.023	8.1 ± 0.031	9.15 ± 0.040	9.12 ± 0.021	9.09 ± 0.037
Acidity %LA	0.133 ± 0.002	0.143 ± 0.001	0.142 ± 0.003	0.149 ± 0.003	0.152 ± 0.001	0.154 ± 0.002
Alkaline phosphatase test	Positive	Negative	Negative	Positive	Negative	Positive

3.3.2 Microbial Analysis

Microbial evaluations demonstrated significant reductions in microbial load. Aerobic Plate Counts for cow milk were recorded at 4.43 log CFU/ml at 75˚C, reducing to 4.31 log CFU/ml at 92˚C. Buffalo milk showed similar results, indicating effective microbial control. Coliform and yeast & mold counts were undetectable in heated samples, attributed to the electroporation effects during ohmic heating. Processing times for cow and buffalo milk ranged between 10 to 13 minutes and 16 to 21 minutes, respectively.

3.4 Performance Evaluation of The Developed Ohmic Heating System

3.4.1 Heating Times

The total heating time required for cow and buffalo milk at two different temperatures was systematically evaluated (Figure 4). The results indicated that buffalo milk necessitated a longer heating time compared to cow milk, primarily due to its higher fat content, which functions as an insulator during ohmic heating. Higher applied voltages correlated with the increased heating times for buffalo milk, underscoring the influence of milk composition on heating efficiency. In contrast, cow milk heated more rapidly owing to its lower fat content.

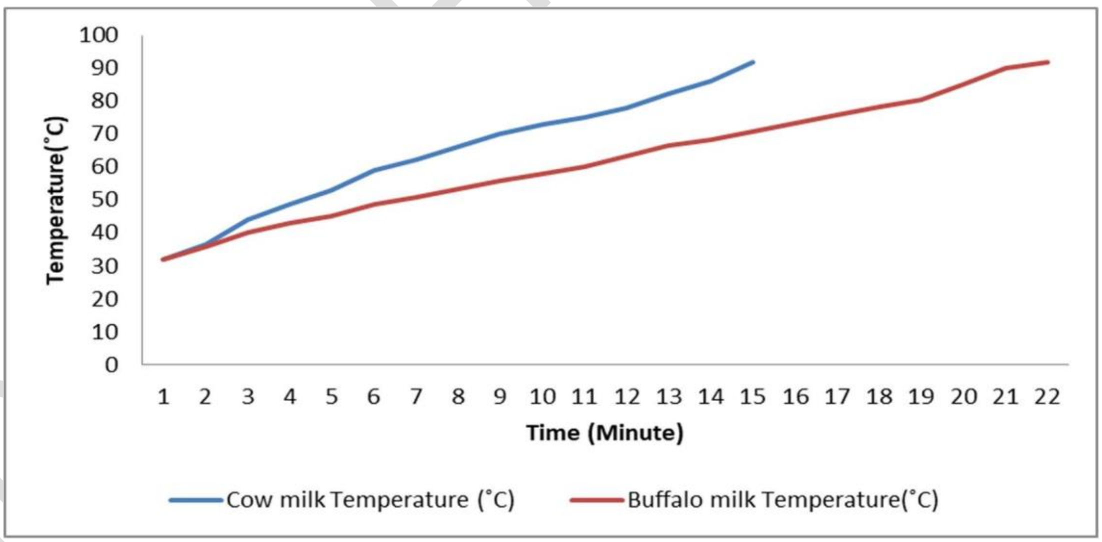

Figure 4: Temperature profile during ohmic heating

3.4.2 Temperature Profile

The temperature profiles of cow and buffalo milk during ohmic heating illustrated distinct behaviors (Figure 4). Cow milk demonstrated a faster initial temperature rise compared to buffalo milk, attributable to its lower fat and total solids content. As heating progressed, the rate of temperature increase for both types of milk gradually declined. This phenomenon can be explained by the transition of fat content into a liquid state, affecting the thermal conductivity of the milk. Additionally, higher applied voltages facilitated increased currents, enhancing the heating rates observed for both milk types.

3.4.3 Current Profile

The current profiles during the heating process exhibited notable differences between cow and buffalo milk (Figure 5). Cow milk showed a continuous increase in current with both time and temperature, reflecting a steady increase in electrical conductivity. In contrast, buffalo milk's current profile revealed an initial decrease within the temperature range of 32 to 60˚C. This reduction can be linked to the liquefaction of fat and the initial fouling of the agitator's surface. Both milk types of experienced fluctuations in current over time, indicating variations in electrical conductivity throughout the heating process.

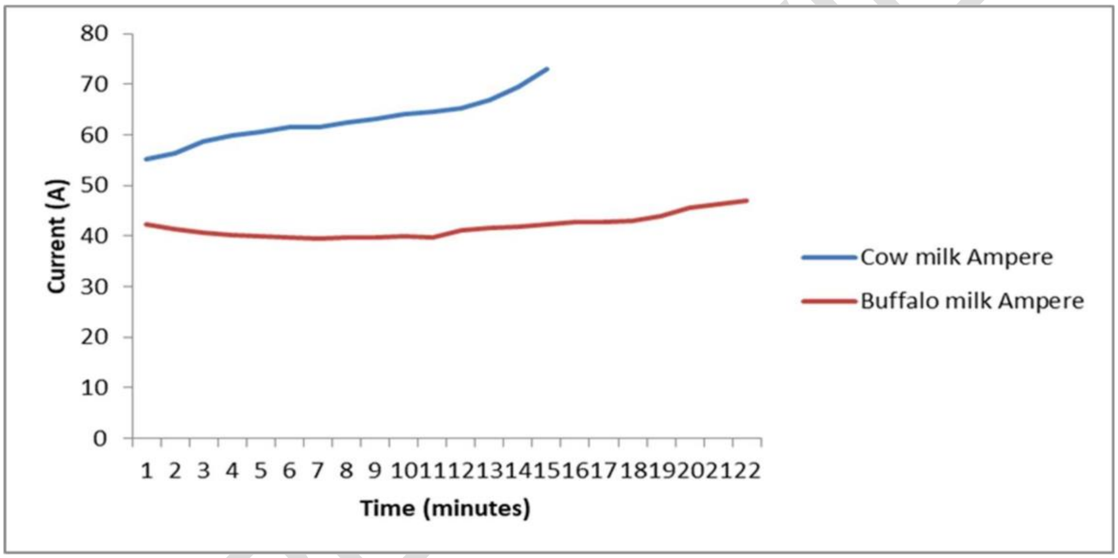

Figure 5: Current profile during ohmic heating

3.4.4 Heating Rate

The heating rate was significantly influenced by the interplay of current and resistance within the system. Electrical heating efficiency is proportional to both current and the square of resistance. Throughout the trials, it was evident that electrical resistance increased due to the effects of the agitator, leading to a reduction in current and a subsequently lower heating rate. The average heating rate was calculated at 4.29˚C/min for cow milk, while buffalo milk exhibited a reduced average heating rate of 2.85˚C/min. These findings highlight the critical role of current and resistance in determining the heating dynamics of the milk samples.

3.4.5 System Performance Coefficient

The system performance coefficient (SPC), representing the ratio of energy required for heating to the energy supplied, was calculated to evaluate system efficiency. Cow milk exhibited a higher SPC compared to buffalo milk, with values of 58.79 and 58.44 at temperatures of 75˚C and 92˚C, respectively. In contrast, buffalo milk showed lower SPC values of 46.71 at 75˚C and 50.10 at 92˚C. The disparity in SPC can be attributed to the insulating effects of the higher fat content in buffalo milk, which hampers efficient heat transfer during the ohmic heating process.

3.4.6 Fouling on the Agitator

Fouling on the agitator surface was a recurring observation during the heating process. The fouling primarily consisted of proteins and minerals from the milk, leading to a decrease in current supply and consequently affecting the heating rate. This reduction in current impaired the efficiency of the heating process and posed potential risks to the nutritional quality of the milk. The impact of fouling was significant, indicating the need for effective cleaning protocols to maintain optimal system performance.

3.4.7 Effect on the Surface of Agitator

Post-trial inspections consistently revealed the formation of fouling on the agitator surface (Figure 6). Cleaning procedures involving water and soap were employed to remove these deposits after each trial. Visual assessments of the agitator surface illustrated the extent of fouling resulting from the ohmic heating process. Furthermore, the presence of such fouling raises concerns regarding the potential transfer of stainless-steel material from the agitator into the processed milk, thus impacting product safety and quality.

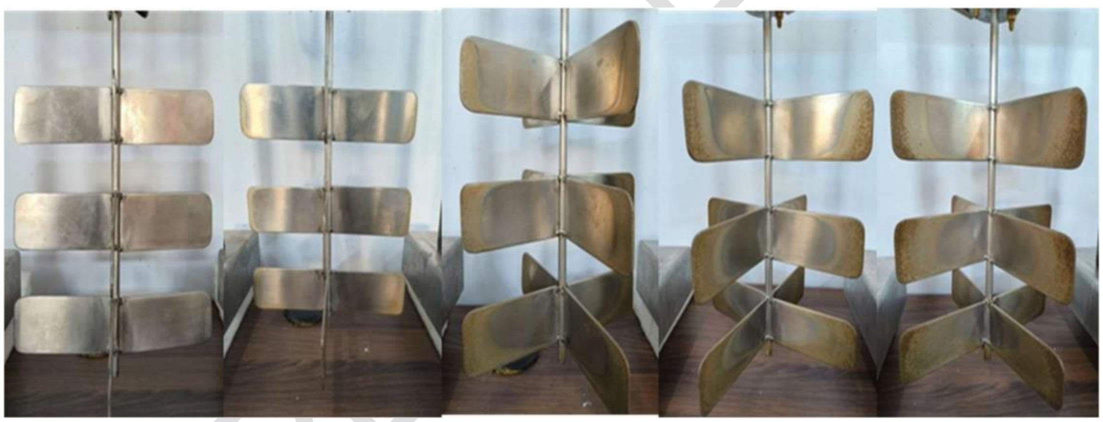

Figure 6: Effect on the surface of the agitator after ohmic heating of milk

4. CONCLUSION

The study successfully developed and assessed a batch-type ohmic heating system for the thermal processing of cow and buffalo milk, focusing on heating efficiency and product quality. The system achieved heating rates of 4.29°C/min for cow milk and 2.85°C/min for buffalo milk, demonstrating its capability for rapid heating. Notably, cow milk exhibited lower energy consumption and higher system performance coefficients (58% at 75°C and 50% at 92°C) compared to buffalo milk, indicating greater overall efficiency. In terms of quality, ohmic heating resulted in slight reductions in protein and fat content, with effective pasteurization confirmed by alkaline phosphatase tests. Significant reductions in microbial load were observed, with undetectable coliform and yeast counts in heated samples. However, the study identified fouling on the agitator as a significant challenge, impacting current supply and heating efficiency, primarily due to the deposition of proteins and minerals. This necessitates effective cleaning protocols to maintain optimal system performance and ensure product safety. Overall, the developed ohmic heating system exhibited high efficiency and rapid heating capabilities, indicating its potential for application in dairy processing. Future research should focus on addressing fouling issues and further optimizing the system for commercial viability.

REFERENCES

Ariç Sürme, S., & Sabancı, S. (2021). The usage of Ohmic heating in milk evaporation and evaluation of electrical conductivity and performance analysis. Journal of Food Processing and Preservation, 45(9), e15522. https://doi.org/10.1111/jfpp.15522

BIS|IS 2689 (1964): Batch pasteurizer (Stainless steel) IS 1479-1 (1960): Methods of test for dairy industry, Part 1: Rapid examination of milk IS 1479-2 (1961): Method of test for dairy industry, Part 2: Chemical analysis of milk (archieve.org)

Houghtby, G. A., Maturin, L. J., & Koenig, E. K. (1992). Microbiological count methods. Standard methods for the examination of dairy products, 16, 213-246.

Kumar, V., Rajak, D., Jha, A. K., & Sharma, P. D. (2014). Optimization of ohmic heating of fish using response surface methodology. International Journal of Food Engineering, 10(3), 481-491. https://doi.org/10.1515/ijfe-2014-0131

Marshall, R. T. (1992). Standard methods for the examination of dairy products. American Public Health Association, Washington D.C

Norouzi, S., Fadavi, A., & Darvishi, H. (2021). The ohmic and conventional heating methods in concentration of sour cherry juice: Quality and engineering factors. Journal of Food Engineering, 291, 110242. https://doi.org/10.1016/j.jfoodeng.2020.110242

Pataro, G., Barca, G. M., Pereira, R. N., Vicente, A. A., Teixeira, J. A., & Ferrari, G. (2014). Quantification of metal release from stainless steel electrodes during conventional and pulsed ohmic heating. Innovative Food Science & Emerging Technologies, 21, 66-73. https://doi.org/10.1016/j.ifset.2013.11.009

Priyanka, M. P., & Subramani, P. (2018). Study of heating pattern during heat treatment of milk by ohmic heating. J Pharmacogn Phytochem, 7(2), 3033-3036.

Rocha, R. S., Silva, R., Ramos, G. L., Cabral, L. A., Pimentel, T. C., Campelo, P. H.,& Cruz, A. G. (2022). Ohmic heating treatment in high-protein vanilla flavored milk: Quality, processing factors, and biological activity. Food Research International, 161, 111827. https://doi.org/10.1016/j.foodres.2022.111827.