April – June, 2024
Original Article
DOI: http://dx.doi.org/10.30867/action.v9i2.1382
Pages: 259 – 269
AcTion:
Aceh Nutrition Journal
p-issn 2527-3310; e-issn 2548-5741

Study of physical and chemical characteristics of cow's milk evaporated by climbing film evaporator method

Kajian karakteristik fisik dan kimia susu sapi evaporasi metode climbing film evaporator

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Article History:
Received: October 03, 2023; Revised: January 31, 2024; Accepted: March 07, 2024; Published: June 13, 2024.

Publisher:

Politeknik Kesehatan Aceh
Kementerian Kesehatan RI

Abstract

Cow milk is a livestock commodity that is in demand among the public as a complement to nutritional needs. Milk has various macro and micro components that support daily nutritional needs. One method to increase the nutrients contained in milk is through evaporation. The purpose of this study was to analyze the physical and chemical characteristics of milk that underwent evaporation using a climbing film evaporator. This study used an experimental method with a descriptive approach, which described the physical and chemical characteristics of cow milk before (control) and after evaporation. The physical and chemical properties were analyzed using a paired sample t-test at the 5% level (0,05) to determine the difference in milk quality before and after the evaporation process. The temperature of the steam passing through the evaporator ranged from 132 to 176^{0}C with an evaporation process of 25 min. The results showed that there were significant differences ($p<0,05$) in freezing point, moisture content, fat, protein, lactose, minerals, and solid non-fat between fresh and evaporated milk. Density and pH showed no significant differences. Evaporation of cow's milk can enhance its nutritional content (protein, fat, lactose, and minerals).

Keywords: Climbing film evaporator, physical and chemical characteristics, nutrients, evaporated cow's milk

Abstrak

Susu sapi merupakan salah satu komoditas peternakan yang diminati di kalangan masyarakat sebagai salah satu pelengkap kebutuhan gizi. Susu memiliki berbagai komponen baik makro maupun mikro yang dapat menunjang kebutuhan nutrisi harian yang dibutuhkan. Salah satu upaya yang dilakukan untuk meningkatkan kadar nutrisi yang terdapat pada susu yakni melalui metode evaporasi. Evaporasi susu merupakan proses pengurangan kadar air di dalam susu melalui proses pemanasan. Tujuan dari penelitian ini adalah untuk menganalisa karakteristik fisik dan kimia dari susu yang mengalami proses evaporasi menggunakan *climbing film evaporator.* Penelitian ini menggunakan metode eksperimen dengan pendekatan deskriptif, yaitu mendeskripsikan karakteristik fisik dan kimia susu sapi sebelum (kontrol) dan sesudah dievaporasi. Analisis data uji fisik dan kimia menggunakan paired sample t-test pada taraf 5% (0,05) untuk mengetahui adanya perbedaan kualitas susu sebelum dan sesudah proses evaporasi. Hasil analisis menunjukkan bahwa terdapat perbedaan yang signifikan ($p<0,05$) pada parameter titik beku, kadar air, lemak, protein, laktosa, mineral, dan solid non-fat antara

susu segar dan susu evaporasi. Sedangkan densitas dan pH tidak menunjukkan perbedaan yang signifikan. Evaporasi susu sapi dapat meningkatkan kandungan nutrisi yang terdapat pada susu (protein, lemak, laktosa dan mineral).
Kata Kunci: Climbing film evaporator, karakteristik fisik dan kimia, nutrisi, susu sapi evaporasi

Introduction

Dairy milk is a livestock commodity in Indonesia, with an increasing amount of consumption among the public. Data from the Directorate General of Animal Husbandry and Animal Health show that the participation rate in milk consumption in 2021 was 44,23%, which increased to 45,12% by 2022 (Direktorat Jendral Peternakan dan Kesehatan Hewan, 2023). However, this figure is still quite low compared with other countries in the world.

In 2022, the total milk consumption in Indonesia is only 989,154 tons, while India, which is the country with the largest milk consumption in the world, has a total milk consumption of 85,000,000 tons in 2022, followed by the United States and China (Pusat Data dan Sistem Informasi Pertanian, 2022). In Indonesia, the increasing public consumption of cow's milk is in line with economic progress, as shown by an increase in the per capita income of Indonesian people (Hidayat & Anggraeni, 2021). In addition, the emergence of public awareness of milk consumption as a complement to nutritional needs also contributes to the level of milk consumption (Hendriyanto et al., 2021).

Milk has various components, both macro and micro, that can support the daily nutritional needs of the body. Macro components include water, fat, protein, and lactose. Microcomponents include vitamins, enzymes, minerals, lipids, and dissolved gases, which also determine the physical, chemical, and biological characteristics of milk (Lambrini et al., 2020).

The composition of macro and micro components contained in milk is influenced by several factors including cow age, reproduction, milking stage and conditions, temperature, and health conditions of cows (Sigit et al., 2021). Water content is the macro component for milk, which had the highest composition. Based on data on the composition of food ingredients Indonesian Ministry of Health (2021), the value of water content in milk is 88,3 grams per 100 grams of milk. One of the attempts to increase the level of nutrients in milk is through a concentrating process using the evaporation method. Evaporated milk is produced by reducing the water content in the milk by approximately 60% to achieve a certain level of concentration to increase the viscosity of the milk and enhance its nutritional value (Silveira et al., 2017; Silveira et al., 2013).

The evaporation process is a thermal process where the solvent separates from the solution owing to the applied heat. The amount of heat applied during the process will affect The quality of the evaporated product. Several studies reported that the conventional evaporation process on food affects the nutritional and sensory characteristics (Julai et al., 2023). Nutrient content such as protein will denature at high temperature of heating. In addition, the taste, smell, and color of milk can also change upon heating (Hariono et al., 2021). Therefore, to maintain the nutritional content of milk, evaporation was carried out under vacuum conditions using a pressure below atmospheric pressure (1 atm). Thus, the temperature applied can also be reduced and does not harm the components contained in milk (Ismiyati & Sari, 2020; Susilo et al., 2021). Research conducted by Julai et al. (2023) and Syakdani et al. (2019) showed that evaporation at low temperatures through a vacuum process produces products with better nutritional content.

Currently, the consumer demand for evaporated milk is increasing. In Sabah, Malaysia, the average consumption of evaporated milk per household during Covid-19 was 1018 g, and that of fresh milk was 1425 mL (Seriger et al., 2022). On the other hand, evaporated milk is the most preferred milk by Peruvians (Mónago & Tavera, 2018). During the second half of the twentieth century, Chile began to increase the import of evaporated milk to meet consumer demands (Llorca-Jaña et al., 2020). In Indonesia, evaporated milk has been used as an alternative to coconut milk in making typical Makassar desserts, considering the nutritional content of evaporated milk. The research conducted by Sara et al. (2022) showed that products with evaporated milk substitutes were preferred by consumers compared to products with coconut milk ingredients.

One type of vacuum evaporator that can be applied for milk evaporation is the climbing-film evaporator. The climbing film evaporator was chosen as a tool in the vacuum evaporation process because of the short contact time with the liquid and the use of low temperatures during heating to avoid damage to the material (Hasan & Ali, 2011). A short contact time on the material occurs because of the rapid heat transfer rate in the evaporator (Ahmad et al., 2018; Yang et al., 2010). The selection of the evaporator is an important variable for improving the quality of the product produced.

We find it crucial to conduct further research on evaporated milk to improve the quality of evaporated milk in terms of both physical and chemical characteristics. A large amount of cow milk production in Indonesia in 2023, namely 837,22 thousand tons (Direktorat Jendral Peternakan dan Kesehatan Hewan, 2023), can be a supporting factor in producing dairy products in the form of evaporated milk. However, there is no information regarding the production of evaporated milk using a climbing film evaporator. Therefore, in this study, we aimed to prepare evaporated milk using a climbing film evaporator, as well as its physical and chemical characteristics.

Methods

The research was conducted in the Food Engineering Laboratory and Livestock Production Laboratory of Politeknik Negeri Jember on July 12-14, 2023. Cow milk was obtained from the PFH (Peranakan Friesian Holstein) dairy farm managed by the Department of Animal Husbandry of Politeknik Negeri Jember. Cow milk was obtained from one cow aged three years. The process of feeding the cow was done once with three times distribution processes at 08.30 AM, 09.00 AM, and 09.30 AM for each cage and drinking adlibitum. Sampling was performed during milking in the morning at 07.00 AM and the cow was in good health. A climbing film evaporator (Armfield, UK) was used for the evaporation process, and LactoStar (Funke Gerber, Germany) was used for the milk analysis process. Lacto Star has advantages over other milk analysis methods, as it is more efficient in terms of time and cost (Hariono et al., 2021). pH was determined using a digital pH meter (Schott).

This study used an experimental method with a descriptive approach to describe the physical and chemical characteristics of cow's milk before and after evaporation. Milk samples used in the control and treatment groups were the same milk samples, which were obtained from PFH cattle farms managed by the Department of Animal Husbandry, Politeknik Negeri Jember. Milk samples were divided into two groups: control (without treatment) and milk samples evaporated using a climbing-film evaporator. A certificate of ethical feasibility was issued by the Research Ethics Commission Politeknik Negeri Jember with number: 1096/PL17.4/PG/2023

Evaporated Milk Production

Milk evaporation was performed by placing 1000 mL of milk in the chamber. The steam source (steamer) was set at a pressure of 2 bar with an adjusted steam flow rate. Hot vapor from the steamer flowed through the faucet and was integrated into the evaporator.

The temperature of the steam used in the evaporation process ranged from 132 to 176^{0}C. The time required for the evaporation process refers to the research conducted by Ahmad et al. (2018) with a total evaporation process time of 25 min, with details of 5 min being the time when the appliance was switched on until the boiler steam temperature reached 132^{0}C, 15 min of heat exposure time, and 5 min for cooling the device. Providing heat for 15 min to the milk sample was the best time needed for the heat transfer process using a climbing-film evaporator. The pressure used during the evaporation process was controlled in the range of 0,5 - 1 bar. Milk concentrate (250 mL) was automatically collected in the evaporator vessel for the analysis of its physical and chemical properties. Physical analysis included density and freezing point, whereas chemical analysis included moisture, protein, fat, lactose, solid non-fat (SNF), pH, and mineral content.

Physical (density, freezing point,) and Chemical (protein, fat, lactose, mineral content, solid non-fat) Properties Testing

Protein, fat, lactose, total non-fat solids (SNF), freezing point, density, and milk mineral content were analyzed using a LactoStar milk analyzer. Before the test, the milk analyzer was cleaned using acid and alkaline solutions and rinsed with distilled water. Samples (25 ml) were placed in sample tubes and in the sample holder. The device was switched on by pressing a power button. Next, the enter button was pressed and the cow's milk sample was selected on the screen.

The scanning process lasted for ±4 min, and the results of milk quality readings, including density, freezing point, solid non-fat, fat, protein, lactose, and mineral content, were displayed on the screen (Shaker et al., 2015).

pH Testing

The pH was tested according to AOAC 1998 using a digital pH meter that had previously been calibrated using pH 4 and 7 buffer solutions. The electrodes on the pH meter were washed before being immersed in milk. The pH of the milk was recorded on the screen.

Moisture Content Analysis

Determination of milk moisture content used oven method (SNI 01-2891-1992). A total of 1-2 ml of milk was placed in a cup with known initial weight. The cup that had been filled with the sample was then placed in an oven at 105^0 C for 24 h. After 24 h, the cup was placed in a desiccator and weighed again to determine the weight of the sample after evaporation. The calculation of water content can be seen in the equation below:

$$\text{Moisture content} = \frac{W}{W_1} x\ 100\%$$

Where:
W = weight of sample before drying (g)
W_1 = weight of sample after drying (g)

The physical and chemical characteristics obtained were then subjected to statistical analysis using a paired sample t-test at the 5% level (0,05) to determine the difference in milk quality before and after the evaporation process. If the p-value was <0,05, there was a significant difference between the physical and chemical characteristics of the milk before and after evaporation. The data were analyzed using IBM SPSS Statistics 20.

Result and Discussion

Evaporation is the process of reducing the amount of solvent contained in the solution. The evaporation process is different from the drying process because, in evaporation, the final result of the process is a thick liquid, not a solid, as in drying (Wijaya et al., 2019). Evaporated milk is milk in which the moisture content is reduced to as much as 60% (Nouh et al., 2017). This causes changes in the nutritional content of milk. This change is due to the loss of one milk component in a sufficiently large amount to affect the levels of other components. In this study, the milk evaporation process used a climbing-film evaporator.

A climbing film evaporator is a type of evaporator that is easy to maintain compared to other evaporators. In addition, the high heat-transfer rate at low evaporation temperatures causes the contact time with the material to be faster. The heat transfer coefficient in a vertical tube can reach 6000 W/m^{2}K (Yang et al., 2010). The higher the heat transfer coefficient, the more effective the evaporation process in the evaporator and condensation in the condenser, and the more optimal the quality of the evaporated product (Kusumadewi et al., 2018). The rapid contact time with the material preserves nutrients in heat-sensitive milk and improves the evaporation process can take place better (Yang et al., 2010). Therefore, climbing film evaporators can be an option for the milk evaporation process to obtain a more optimal nutritional value with a more efficient process.

Physical characteristics of evaporated milk

Evaporated milk is a liquid food product with a higher viscosity than fresh milk because of its reduced water content (Nieuwenhuijse, 2021). Some of the physical characteristics analyzed in this study are density and freezing points, as listed in Table 1. The test results of the physical characteristics of the evaporated milk were also compared with those of fresh milk to determine the effect of the evaporation process on the physical characteristics of milk.

Table 1. Test results of physical parameters of evaporated milk and fresh milk

Parameter	Fresh milk*	Evaporated milk*	p-value
Density (g/ml)	1,028 ± 0,113	1,051 ± 0,199	0,202[a]
Freezing point (^{0}C)	(-) 0,511 ± 0,019	(-) 0,829 ± 0,031	0,004[a]

**Data presented as mean ± deviation*
[a] Paired sample t-test (significant p<0,05)

As shown in Table 1, the value of each physical parameter of evaporated milk was higher than that of fresh milk. Density is the measurement of the mass per unit volume of a substance (Abdurrojaq et al., 2021). The higher density value indicates that the number of components (carbohydrates, fats, proteins, vitamins, and minerals) was greater (Christi et al., 2022); therefore, the nutrient content in evaporated milk was also higher. The statistical test results showed that the p-value was 0.202; therefore, there was no significant difference in the densities of fresh milk and evaporated milk (p>0,05). However, evaporation process was able increased the density of milk by 2%. Evaporation causes water loss in milk, resulting in reduced milk volume (Syakdani et al., 2019). This caused an increase in the density value from fresh to evaporated milk. Fresh milk still has a high water content; therefore, the volume of the liquid is larger. The water content in fresh milk is in the range of 87,87 – 89,13% (Hariono et al., 2018). This is in line with the research conducted by Istianah (2017), who studied evaporation using a falling-film evaporator to produce pineapple concentrate. The process produced pineapple concentrate with a density increase of 1% when the pineapple underwent an evaporation process.

Milk has a freezing point lower than that of water. This is because milk contains components such as carbohydrates, proteins, fats, vitamins, and minerals that interact with each other to affect its freezing point (Bouisfi & Chaoui, 2018). The freezing point of milk can also be used as a parameter to determine the quality of milk because the freezing point is strongly influenced by the composition of the milk components (Christi et al., 2022). Based on Table 1. It can be seen that evaporated milk has a lower freezing point than fresh milk does. From the statistical test results, the p-value obtained was 0,004, showing that there was a significant difference (p<0,05) in the freezing point parameter between fresh milk and evaporated milk. The freezing point is related to the interaction between the molecules and ions present in milk. When the evaporation process is carried out, the water contained between casein micelles (intermicellar water) and within casein micelles (intra-micellar water) evaporates. Inter-micellar water is more volatile than intra-micellar water; therefore, when this condition reaches the distance between casein micelles, the water between the micelles evaporates. The absence of water between micelles causes agglomeration of micelles, increasing their size of the micelles is getting bigger (Holt et al., 2013; D. Z. Liu et al., 2012). The larger the micelle size, the stronger the hydrophobic interaction, which causes the freezing point of evaporated milk to be lower than that of fresh milk (Yazdi et al., 2014). This is in line with the research conducted by Jayawardena et al. (2017), who showed that sucrose solutions with high Brix values would have a lower freezing point.

The higher the density value of milk and the lower the freezing point of milk, the greater the number of components contained in milk; thus, the nutritional content of milk also increases (Cais-Sokolińska et al., 2018). Viscosity is profoundly connected with tactile thickness when slurping is utilized as an indicator of evaluation, as compared to mouth feeling or gulping (Ismail et al., 2022). The greater the number of solute particles, the closer the distance between molecules, which causes stronger interactions between the particles and affects the viscosity of the solution (Sutariya et al., 2017). This is in line with the research conducted by Bista et al. (2020), who showed that samples with high concentrations had greater viscosity. Therefore, the physical characteristics (density and freezing point) would also affect consumer acceptance.

Chemical characteristics of evaporated milk

The quality of the evaporated milk was determined by chemical analysis. The analysis included moisture content, fat, protein, lactose, solid non-fat, and mineral content. In addition, the pH value was also one of the parameters analyzed at this stage. The chemical characteristics of the evaporated milk are shown in Table 2, the results of which were also compared with the values found in fresh milk.

Based on the analysis results in Table 2, the moisture content of evaporated milk is lower than fresh milk. The evaporation process used a climbing film evaporator that lasted for 25 min and reduced the moisture content of milk by 17,2%. Based on statistical analysis, the p-value for moisture content was 0,007, indicating that there was a significant difference in moisture content (p<0,05) between fresh and evaporated milk. The reduction in moisture content in evaporated milk is influenced by several factors including temperature, pressure, and evaporation rate (Syakdani et al., 2019). The evaporation processin milk reduces the moisture content, which causes an increase in osmotic pressure in milk. High osmotic pressure affects microbial growth in milk (Wood, 2015). This is in line with research conducted by Y. Liu et al., (2021), the higher concentration of the solution caused a decrease in microbial growth due to the greater osmotic pressure. If the number of microbes decreases, the shelf life of evaporated milk could also increase compared to that of fresh milk if stored in the same place (Hwang et al., 2007).

Table 2. Test results of chemical parameters of evaporated milk and fresh milk

Parameter	Fresh Milk*	Evapo-rated Milk*	p-value	% Change
Moisture content (%)	88,08±0,93	72,93±0,67	0,007[a]	-17,2 ▼
Fat (%)	2,91±0,13	6,04±0,05	0,001[a]	107,56 ▲
Protein (%)	3,36±0,24	5,88±0,11	0,003[a]	75 ▲
Lactose (%)	4,92±0,09	8,61±0,25	0,008[a]	75 ▲
Mineral (%)	0,73±0,03	1,05±0,04	0,028[a]	43,84 ▲
Solid non-fat (SNF) (%)	9,10±0,81	15,84±0,12	0,001[a]	74,06 ▲
pH	6,32±0,15	6,14±0,03	0,393[a]	-2,85 ▼

**Data presented as mean ± deviation*
[a] Paired sample t-test (significant p<0,05)
▲ *Increase*
▼ *Decrease*

Concentration is the ratio between the component to be measured and the volume of the component as a whole (mixture). If there is a reduction in one of the components owing to the evaporation process, the volume of the mixture will also decrease. Therefore, the content of each component in milk also increased. Therefore, the fat, protein, lactose, and mineral contents of evaporated milk are higher than those of fresh milk (Prestes et al., 2022). This is in line with research conducted by Braga & Palhares, (2007). This shows that the evaporation process of breast milk with a 30% reduction in water content could increase the levels of sodium, potassium, calcium, phosphorus, magnesium, protein, fat, and lactose by up to 38%. The statistical test results showed p-values of 0,001, 0,003, 0,008, and 0,028 for fat, protein, lactose, and mineral contents, respectively. This indicated a significant difference (p<0,05) in the chemical parameters tested. The significant difference in the chemical characteristics of evaporated milk compared to fresh milk affects the texture and flavor of the milk (Suhendra et al., 2020). Lactose and fat are components that contribute significantly to the texture and flavor of milk. Lactose is a group of disaccharides composed of D-glucose and D-galactose and is connected through glycosidic bonds that contribute to the sweet taste of milk (Mutaqin et al., 2020). However, lactose has a fairly low sweetness level compared to sucrose, which is only 20-40% (Dominici et al., 2022); thus, the sweetness of milk is not too strong. By adding lactose concentration up to 3,3 times, a sweetness level equivalent to sucrose will be obtained (Shendurse & Khedkar, 2015). Besides lactose, fat is a component that plays an important role in the characteristics of milk produced in terms of aroma, flavor, and texture (McCarthy et al., 2017). Research conducted by Chojnicka-Paszun et al. (2012) showed that a higher fat content in milk gives a creamy texture and savory taste to the milk produced. Thus, evaporated milk has a creamier texture, savourier taste, and is slightly sweeter than fresh milk.

Total solid nonfat (SNF) consists of proteins, lactose, vitamins, and minerals. The value of total solid non-fat in evaporated milk obtained was below the standard set by the Food and Drug Administration (FDA), which is the minimum value of 16,5% (FDA, 2023). In this study, the total solid non-fat content was 15,84%. SNF levels in evaporated milk below the FDA value can be caused by chemical changes in lactose and proteins in milk. When the temperature is too high, lactose isomerizes and degrades into lactulose and organic acids, which causes a reduction in milk lactose content and affects SNF content. In addition, high temperatures denature whey proteins to produce insoluble proteins. Changes in lactose and protein levels cause the SNF content of evaporated milk to be suboptimal because of the high heating temperature (Mandal et al., 2019). However, the SNF value of the evaporated milk was significantly different that from of fresh milk ($p<0,05$). This is due to the reduced amount of solvent in milk, which increases the ratio of total solid non-fat to total liquid.

Therefore, to improve the quality of evaporated milk, temperature control during the process must be maintained so that no components are damaged during the process. Thus, lactose and protein levels in evaporated milk can reach optimal values. The value of total solid non-fat in milk is influenced by lactose and protein levels, if the lactose and milk protein levels are high, the SNF value will also increase. Milk protein is influenced by the type of feed consumed by livestock (Astuti et al., 2020). Hence, the SNF value in milk can also vary because of diverse animal feeding. The addition of a protein source feed can increase milk SNF levels. This is in line with the research of Nouh et al. (2017), who conducted milk evaporation on various brands and produced SNF values that were quite diverse and met the FDA standards.

As shown in Table 2, evaporated milk had a lower pH value than fresh milk, which was 6,14. However, the pH value of evaporated milk has not been regulated in the Indonesian National Standard (SNI) 01.2780.1992. The decrease in the pH of evaporated milk is caused by changes in the ion equilibrium in the milk due to heating. Heating causes the amount of calcium and phosphate ions in milk to decrease due to molecular aggregation. Ions that is originally in the dissolved phase, becomes a colloidal phase. The change in ion equilibrium in milk causes an increase in the concentration of H^+ ions. Therefore, the pH of evaporated milk is lower (Prestes et al., 2022; Singh, 2007). The aggregation of calcium ions and phosphate ions occurs based on the following reaction equation $Ca^{2+} + H_2PO_4^- \rightarrow CaHPO_4 + H^+$, where the reaction shows that the heating process will lead to an increase in the formation of $CaHPO_4$, which is the aggregate of the calcium and phosphate ion reaction. In addition, the reaction shows that if the number of aggregates produced is greater, the number of H^+ ions produced also increases. The higher the H^+ ion content of the milk, the lower the pH of the milk (Anema, 2009). Research conducted by Nouh et al. (2017) showed that the average pH of evaporated milk from various brands was 6,2.

The decrease in pH observed in evaporated milk affects microbial activity within the milk. This affects the safety of the milk itself. Based on the results of the study, the pH value of evaporated milk is 6,14. This value is suitable for the growth of molds and yeasts as well as spore-forming bacteria because they can live and perform metabolic activities in the pH range of 4-7 (Maynou et al., 2017). However, with the heating process, microbial cells can undergo denaturation and damage to enzymes that play a role in the metabolic process. Therefore, the evaporated milk produced is safe for consumption (Chawla et al., 2021). The decrease in pH value in evaporated milk also affects the flavor of the milk produced. Based on research conducted by Sayel et al., (2023), evaporated milk had the lowest score on the flavor aspect compared to fresh milk and condensed milk. This is due to the low pH found in producing milk with a slightly sour flavor, thus reducing consumer preference.

Both calcium and phosphate are contributors to the determination of pH. Milk processing greatly influences the concentration of calcium and phosphate, which has an impact on pH. In addition, processing can also affect other components such as proteins that are unstable at high temperatures. Therefore, it is necessary to control the processing process, which includes temperature and heating time, to enhance the quality of the milk produced.

Conclusion

The evaporation process of cow's milk using Climbing Film Evaporator produced evaporated milk with higher physical characteristics than fresh milk. There was a significant difference in the freezing point of evaporated milk compared to fresh milk, but no significant difference in density. In the chemical characteristics, there were significant differences in the moisture content, fat, protein, lactose, minerals and solid non-fat While there was no significant difference in pH between evaporated milk and fresh milk.

Recommendations for further research are experimental studies related to evaporation conditions including temperature, pressure, and evaporation time using climbing film evaporators. These parameters can be studied further to improve the quality of evaporated milk produced.

Acknowledgment

The authors express their gratitude to the Food Engineering Laboratory, which facilitated this research.

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