REKAYASA 22 (1) (2024): 11-21

REKAYASA

Jurnal Penerapan Teknologi dan Pembelajaran

http://journal.unnes.ac.id/journals/rekayasa

Addition of Germicidal UV-C Radiation Equipment in the Sterilization Process to Extend the Shelf Life of Cow's Milk

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DOI: https://doi.org/10.15294/rekayasa.v22i2.6239
Submit: 2024-03-28; Revisi: 2024-05-02; Accepted: 2024-07-17

Abstract

Cow's milk provides essential human nutrients, including calcium, protein, and minerals. However, it is highly susceptible to bacterial contamination, which leads to rapid spoilage. Pasteurization is the most common method to process cow's milk, effectively reducing microbial levels. However, some heat-resistant bacteria can survive the pasteurization process, limiting its effectiveness in ensuring long-term milk safety. This study investigates the use of chemical engineering technology by combining pasteurization and UV-C radiation methods, either sequentially or simultaneously, to improve the effectiveness of milk sterilization. The use of combined techniques aims to leverage the strengths of both processes, achieving superior microbial reduction and extending milk shelf life. Different operating temperatures and radiation durations were tested to identify optimal processing conditions. The findings revealed that this combined approach achieved a significant bacterial reduction of 99.95%, decreasing the microbial count from an initial 1.9×10^6 cfu/mL to 7.0×10^2 cfu/mL. Moreover, the shelf life of the milk was extended to five months, demonstrating the effectiveness of the hybrid method. The study also monitored the milk's acidity (pH) throughout the process, which remained within optimal conditions of 6.5 to 6.8. This indicates that the combined treatment does not compromise milk quality. Integrating pasteurization with germicidal UV-C radiation offers a promising alternative for milk sterilization, improving microbial control and significantly increasing the shelf life of cow's milk. The results suggest that this dual-method approach could be a valuable advancement in dairy processing, enhancing both safety and efficiency in the production and preservation of milk.

Keywords: total plate count, shelf life, milk processing, radiation, pasteurization.

INTRODUCTION

Cow's milk is highly nutritious and can fulfil many of the dietary requirements essential for human health. It contains vital nutrients such as calcium, protein, minerals, iron, lactose, and casein, all of which contribute significantly to human health and well-being (Susilawati et al., 2021). However, these nutrients make cow's milk susceptible to microorganisms. Milk functions as an ideal medium for bacterial growth, leading to rapid spoilage and a notably short shelf life (Hanum & Wanniatie, 2015).

The common processing method for raw milk is pasteurization, which involves heating milk to high temperatures to kill pathogenic bacteria. However, high-temperature heating can result in the loss of certain important nutrients, such as enzymes, vitamins, and heat-sensitive proteins, which may also affect the flavour and aroma of the milk. As a result, pasteurized milk often tastes less fresh compared to raw milk (Lee et al., 2016). Furthermore, some pathogenic or heat-resistant bacteria may survive pasteurization, especially if the process is improperly performed or if there are failures in the procedure (Wulandari et al., 2017).

Pasteurized milk remains vulnerable to contamination by pathogenic bacteria and other microorganisms due to post-pasteurization contamination through equipment, packaging tools, or unhygienic handling practices (Wahyuningsih & Pazra, 2023). Certain heat-resistant microorganisms, such as spore-forming bacteria, may persist in the milk despite undergoing pasteurization. The shelf life of pasteurized milk greatly influences its sensory characteristics, including taste and aroma. Over time, the taste of stored milk may become less fresh (Arini, 2017).

The quality and shelf life of milk are also affected by storage conditions after pasteurization. Improper storage can accelerate quality degradation and reduce shelf life (Teme et al., 2021). Handling and distribution methods for pasteurized milk are crucial, as clean equipment, containers, and a well-maintained cold chain are necessary to preserve product quality and safety during distribution (Amaliyah, 2017).

Although pasteurization effectively reduces bacterial counts, some lactic acid bacteria capable of growing at cold temperatures may still survive. Their growth can impact the taste and quality of the milk (Adine 2023). Thus, while pasteurization reduces contamination risks and enhances milk's durability, it does not guarantee indefinite preservation. Proper storage conditions and strict hygiene practices are essential to minimize shelf-life issues and maintain optimal milk quality (Sabil et al., 2015).

UV-C radiation has the potential to affect milk's nutritional components, such as vitamins and enzymes. Therefore, research is necessary to ensure that UV-C radiation does not cause significant degradation of essential nutrients. The proper selection of UV-C radiation dosage is crucial. Insufficient doses may be ineffective in reducing pathogenic microorganisms, while excessive doses can harm milk quality (Atik & Gumus, 2021).

UV-C radiation can effectively kill pathogenic microorganisms, but its efficacy may vary depending on the type of bacteria or microorganisms. Some microorganisms may exhibit greater resistance to UV-C radiation (Suryaningsih et al., 2022). The application of radiation technology in food processing, including milk, must comply with food safety standards and regulations. It is essential to ensure that this process does not violate existing food safety guidelines.

Implementing UV-C radiation technology requires investment and operational costs. It may also affect the taste and aroma of milk, making it important to understand and minimize these changes to preserve sensory quality. Sustainability considerations include assessing the environmental impact, focusing on energy use and waste management.

Additionally, worker safety must be prioritized to prevent radiation exposure.

The combination of pasteurization and UV-C radiation can provide dual protection against pathogenic microorganisms. Pasteurization effectively reduces microbial counts, while UV-C radiation can kill or deactivate residual pathogens (Yin et al., 2015). Combining these technologies can enhance milk's shelf life and safety by minimizing the risk of bacterial contamination.

While pasteurization can impact certain nutrients in milk (Alfiandaru, 2022), the addition of UV-C radiation may help reduce the required intensity of pasteurization, thereby minimizing nutritional losses. Moreover, UV-C radiation can reduce the risk of post-pasteurization contamination (Kaya & Unluturk, 2019) by eliminating microorganisms that might contaminate the milk after pasteurization (Hariono et al., 2018).

Optimizing the UV-C radiation dose is essential to effectively kill microorganisms without causing significant damage to nutrients or sensory quality (Delorme et al., 2020). To ensure the effectiveness of both processes, the pasteurization and UV-C radiation systems should ideally be implemented in separate devices, preventing cross-contamination or reduction in process efficiency.

This study aims to characterize cow's milk processed using a combined pasteurization and UV-C germicidal radiation system. The development of an integrated device offers a holistic solution to address contamination risks while improving milk quality. Further trials are necessary to determine optimal parameters and evaluate the long-term effects of this combination on milk quality and safety.

METHOD

The equipment used in this study included a pasteurization apparatus, a germicidal UV-C irradiation device, a thermometer, a filter, and a stove. The primary material was fresh cow's milk, milk in the morning from a farm in Jatirejo village, stored in 1-liter plastic packaging.

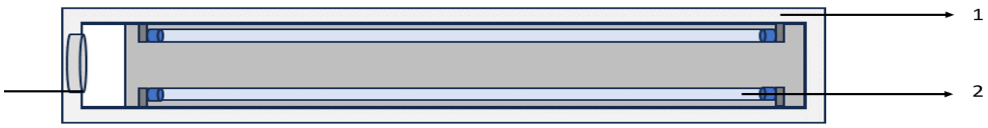
Milk Handling Procedure from the Farm

Freshly milked cow's milk was poured into clear plastic bags and tightly sealed. The milk was then placed in a cold box freezer at a temperature of -15 °C to prevent contamination from external air and to maintain its condition during distribution.

Pasteurization Procedure

Once the milk arrived at the laboratory, it was placed in a sealed pan for pasteurization, heated, and continuously stirred at specific temperatures (78 °C and 90 °C) for 15 seconds. After pasteurization, the milk was left in the sealed pan for 2 hours until it reached room temperature, which could be expedited by cooling around the pan. The milk was then poured into 250 mL food-grade polyethene terephthalate (PET) plastic bottles, filled to the brim, and tightly sealed. The detailed sample numbering and process variations are presented in Table 1, which outlines the sequence of the combined pasteurization and UV-C radiation process.

(a)



(b)

Figure 1. Design of a Set of UV-C Irradiation Tools
(a) empty box condition (b) arrangement of milk bottles description
Keterangan: 1) Wall material (Acrylic 0.75 cm), 2) UV-C Germicidal Lamp 40 W, 3) Exhaust Fan

Table 1. Milk Sterilization Treatment with a Combination of Pasteurization and UV Radiation

Code	Treatment Samples
1	Fresh milk without pasteurization and radiation
1A	Milk was pasteurized at 80 °C for 15 seconds, left in a closed condition for 2 hours, then irradiated for 1 hour
2A	Milk was pasteurized at 80 °C for 15 seconds, left in a closed condition for 2 hours, and then irradiated for 2 hours
3A	Milk was pasteurized at 80 °C for 15 seconds, left in a closed condition for 2 hours, and then irradiated for 3 hours
4A	Milk was pasteurized at 80 °C for 15 seconds, left in a closed condition for 2 hours, and then irradiated for 4 hours
5A	Milk was pasteurized at 80 °C for 15 seconds, left in a closed condition for 2 hours, and then irradiated for 5 hours
1B	Milk pasteurized at 90 °C for 60 seconds
2B	Milk is pasteurized at 90 °C for 60 seconds, and then left in a closed condition for 1 hour
3B	Milk is pasteurized at 90 °C for 60 seconds, and then left in a closed condition for 2 hours.
1C	Milk is pasteurized at 90 °C for 15 seconds, then left in a closed condition for 2 hours, and then irradiated for 5 hours
2C	Milk is pasteurized at 90 °C for 60 seconds, then left in a closed condition for 2 hours and then irradiated for 5 hours.

Milk Radiation Procedure

The radiation process was conducted using an acrylic box equipped with two UV-C lamps, as illustrated in Figure 1. The milk bottles were arranged horizontally inside the acrylic box between the two UV-C lamps, with the box capable of holding up to 10 bottles in this position. The box had to remain closed during UV-C lamp operation. Additionally, a fan was installed for ventilation to manage the heat generated by the lamps. After the radiation process, the lamps were turned off, and the system was left for 10 minutes before the box was opened and the milk bottles were removed.

Total Plate Count (TPC) Test Prosedure

This observation uses the TPC Pour method according to APHA 2001 Chapter 7 aims to determine the number of bacterial distributions in milk samples. The test was conducted at the Central Java Health Laboratory and Medical Device Testing Center. With the procedure: in the first step, sample preparation and sample dilution were carried out. Then the sample was inoculated 1 mL at each dilution in a separate, sterile and empty Petri dish. After that, 12-15 mL of Plate Count Agar (PCA) culture media was added which was previously melted and then cooled to 44-46 °C to the inoculated plate. Then the sample inoculum with the culture media was mixed with eight motion or in a circular motion, eight to ten times clockwise and then eight to ten times counterclockwise. After that, wait until the mixed media hardens. After that, incubation was carried out under the following conditions 32 ± 1 ° C for 48 ± 2 hours for dairy products. After incubation is complete, colony counting is carried out and the results are calculated (Da Silva et al., 2018).

RESULTS AND DISCUSSION

Analysis of Sterilization Pasteurization of Cow's Milk

Cow's milk is sterilized by pasteurization which is done by heating and adding time to reduce the temperature to room temperature. Analysis is carried out by testing the number of bacteria in the samples, namely fresh milk and milk after pasteurization, and analysis is carried out by adding time to reduce the temperature. The TPC test carried out on samples after pasteurization is shown in Table 2.

Table 2. Results of Total Plate Count Test of Milk After Pasteurization

Code	Treatment	TPC
1	Fresh milk without pasteurization and radiation	1.9 x 10^6 cfu/mL
1B	Milk pasteurized at 90 °C for 60 seconds, without boiling	3.7 x 10^3 cfu/mL
2B	Milk pasteurized at 90 °C for 60 seconds, then boiled for 1 hour	1,6 x 10^4 cfu/mL
3B	Milk was pasteurized at 90 °C for 60 seconds, then boiled for 2 hours.	2,6 x 10^3 cfu/mL

The results obtained from the TPC test of samples with pasteurization at 90 °C for 60 seconds and then boiled for 2 hours showed a decrease in bacterial TPC values of 99.0% with bacterial numbers at 2.6 x 10^3 cfu/mL compared to fresh milk without pasteurization or UV-C radiation treatment with a TPC of 1.9 x 10^6 cfu/mL. Based on research (Engin & Karagul Yuceer, 2012) pasteurization at a temperature of 65 °C with a pasteurization time of 30 minutes resulted in a decrease in the number of bacteria by 90%. In addition, the optimal temperature for milk pasteurization was obtained at a temperature of 90 °C (Widiatmo & Hendrarsakti, 2018) following the results of this study.

In the first hour, the milk experienced an increase in bacterial content in the sample because the optimum boiling time had not been achieved, which caused thermophilic, thermoduric, and spore-forming bacteria to still be able to survive and grow (Hickey et al., 2015). Using the boiling time will help the process of reducing bacteria, this is because the sterilization time will be longer. Pasteurization time that is too long causes more bacterial cells to be damaged and can damage some of the nutritional elements in milk (Watts, 2016).

Based on Table 3, the milk sample with the lowest microbial count during the double process was sample 5A, which underwent pasteurization at 80°C combined with 5 hours of radiation. This treatment resulted in a total plate count of 2.7×10^6 cfu/mL, achieving an effectiveness of 53.44% compared to the 1-hour double-process operation with the same conditions. The observed reduction in microbial count is attributed to the extended radiation time, which enhances the microbial inactivation effect during the process (Koca et al., 2018).

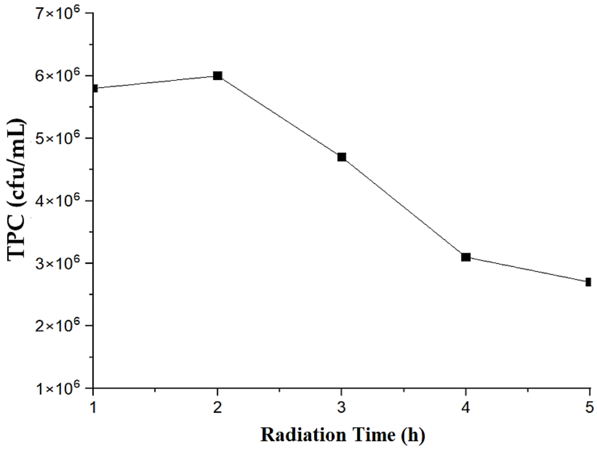


Figure 2. Effect of Radiation Duration on Total Microbe Count in Cow's Milk

Figure 2 illustrates the graph of the TPC of microbes in milk treated with a double process, consisting of pasteurization at 80 °C for 15 seconds followed by UV-C irradiation for varying durations (1, 2, 3, 4, and 5 hours). The results of the double process show a decreasing trendline in microbial counts over time. While UV-C germicidal radiation effectively damages bacterial nucleic acids, some bacterial cells may resume metabolic activity, as indicated by an increase in the microbial count during the first 2 hours of radiation. This phenomenon occurs because certain bacteria contain enzymes that repair damage, enabling cell reactivation after UV-C exposure (Suryaningsih et al., 2022). Radiation duration is a critical variable in determining the effectiveness of UV-C germicidal action (Delorme et al., 2020). Longer radiation times increase the UV dose per unit volume, thereby enhancing the destructive power of UV rays against microbes in milk (Atik & Gumus, 2021).

Milk samples pasteurized at 90 °C as show in Figure 3, both through the single process and the double process, demonstrated microbial counts that meet the quality standards for pasteurized milk as per the Indonesian National Standard (SNI 01-3951:1995). The maximum permissible microbial counts are 2.6×10^3 cfu/mL for the single process and 7.0×10^2 cfu/mL for the double process. However, these values are still higher than the microbial limits for UHT milk, which is <10 cfu/mL. When compared to pasteurization at 80°C, the process at 90°C results in significantly lower microbial counts. This can be attributed to the higher temperature effectively eliminating a larger proportion of thermophilic, thermoduric, and spore-forming bacteria. At 80 °C, the optimal conditions for pasteurization may not have been fully achieved, allowing such bacteria to survive and potentially regrow after sterilization (Hickey et al., 2015).

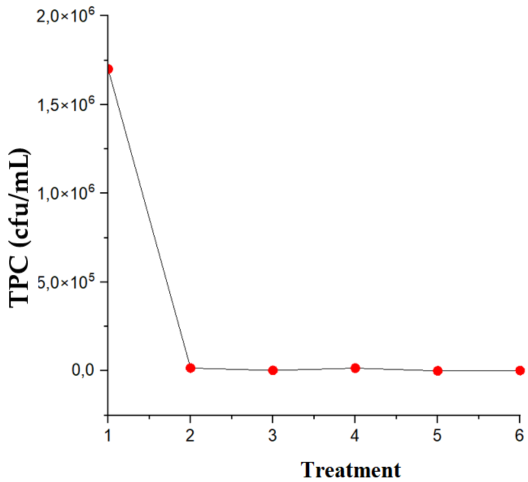


Figure 3. Graph of TPC in Cow's Milk Processed at 90°C

Table 3. ALT Test Results of Double Process Milk Samples at a pasteurization temperature of 80 °C

Code	Treatment	TPC
1A	Milk is pasteurized at 80 °C for 15 seconds, boiled for 2 hours, and then irradiated for 1 hour.	5,8 x 10^6 cfu/mL
2A	Milk is pasteurized at 80 °C for 15 seconds, boiled for 2 hours, and then irradiated for 2 hours.	5,1 x 10^6 cfu/mL
3A	Milk is pasteurized at 80 °C for 15 seconds, boiled for 2 hours, and then irradiated for 3 hours.	4,7 x 10^6 cfu/mL
4A	Milk is pasteurized at 80 C for 15 seconds, boiled for 2 hours, and then irradiated for 4 hours.	3,9 x 10^6 cfu/mL
5A	Milk is pasteurized at 80 °C for 15 seconds, boiled for 2 hours, and then irradiated for 5 hours.	2,7 x 10^6 cfu/mL

The treatment of milk with the lowest TPC value was obtained from sample 10, which underwent pasteurization at 90 °C for 15 seconds, followed by steaming for 2 hours and radiation for 5 hours. This resulted in a microbial contamination TPC at optimum condition is value of 7.0 x 10^2 cfu/mL, with a reduction percentage of 99.95% as shown in Table 4.

Table 4. TPC Results for Milk Processed with the Double Process at an Operating Temperature of 90°C

Code	Treatment	TPC Result
1	Fresh Milk Without Treatment	1.9 x 10^6 cfu/mL
1C	Milk is pasteurized at 90oC for 15 seconds, then boiled for 2 hours. Then irradiated for 5 hours.	7.0 x 10^2 cfu /mL
2C	Milk is pasteurized at 90oC for 60 seconds, then boiled for 2 hours. Then irradiated for 5 hours.	2.6 x 10^3 cfu /mL

UV-C light works by altering the DNA of microbes, preventing genetic processes from occurring (Koca et al., 2018). This causes the microbes to be unable to perform biological activities. Additionally, UV-C radiation has a germicidal effect that disrupts microbial activity, preventing growth (Yin et al., 2015).

Acidity Degree (pH) Analysis

The initial pH of fresh milk is recorded at 6.52, which falls within the standard range for fresh milk (6.5–6.8). Table 5 illustrates the results of pH testing for fresh milk, pasteurized milk, and milk subjected to combined treatments. The pH of fresh milk reflects its natural balance of lactose and minerals, untouched by microbial activity or processing. Pasteurization causes a slight increase in pH to 6.76. This increase is attributed to the inactivation of acid-producing microorganisms during heat treatment. By reducing microbial activity, pasteurization stabilizes the milk and prevents temporary pH drops caused by active microbial metabolism. However, when UV-C radiation is applied to pasteurized milk, the pH slightly decreases to 6.64. This decrease can result from UV-C's oxidative effects, which may accelerate the breakdown of lactose into lactic acid by residual lactic acid bacteria. While UV-C radiation effectively inhibits most microbial activities, some resilient bacterial species might survive and contribute to minor acidification.

The data reveal that pasteurization alone stabilizes milk by slightly increasing its pH, indicating that the process helps maintain the milk's chemical balance. In contrast, combining pasteurization with UV-C radiation results in a slight pH reduction, which can be attributed to chemical and microbial interactions caused by UV-C exposure. These findings underscore the distinct effects of each treatment on the chemical stability of milk. Additionally, they highlight the potential of these processes, individually and in combination, to enhance milk's stability and extend its shelf life, offering valuable insights for improving milk preservation methods.

According to the Indonesian National Standard (SNI 3141.1:2011) for Fresh Milk, the ideal pH value for milk products is between 6.3 and 6.8 (BSN, 2011). Meanwhile, the International Standard (DKS 2191:2015) states that the optimal pH range for milk is between 6.5 and 6.8 (Al-Farsi et al., 2021).

Table 5. pH Value of Milk Before and After Treatment

Treatment	pH
• Susu segar tanpa perlakuan	6.52 ± 0.00
• Susu Pasteurisasi	6.76 ± 0.00
• Susu Pasteurisasi di radiasi UV-C	6.64 ± 0.01

The sample aligns with the standards set by SNI (SNI 3141.1:2011) and international standards (DKS 2191:2015). Milk subjected to pasteurization at 90°C for 60 seconds exhibited an increase in pH, attributed to the activity of microorganisms that can survive certain temperatures (Samapundo et al., 2014). However, when the milk was treated with radiation, its pH decreased. This reduction may result from the activity of lactic acid bacteria, which convert lactose into lactic acid (Umar et al., 2014). Additionally, the decrease in pH can be attributed to the formation of various acidic compounds, including complex phosphate compounds, nitric acid, and dissolved carbon dioxide, which arise during the sample treatment process.

Shelf Life of Milk

Analisis masa simpan susu dilakukan dengan melakukan pengamatan pada visual dan rasa susu setelah penyimpanan selama 5 bulan dalam lemari pendingin (showcase) dengan suhu 4°C. Tidak ada perubahan yang signifikan pada rasa susu setelah penyimpanan 5 bulan namun pada kondisi visual susu mengalami kenaikan viskositas, hal ini dapat terjadi karena kadar lemak pada susu menyebabkan kenaikan kekentalan dalam kondisi dingin. Lebih kentalnya susu disebabkan karena banyaknya lemak, protein, karbohidrat, vitamin, dan mineral. Semakin rendah suhu susu dalam penyimpanan akan menyebabkan viskositas semakin tinggi yang diakibatkan adanya clumping dari globula-globula lemak (Mirza, 2017). Berdasarkan penelitian yang dilakukan oleh (EFSA Panel on Dietetic Products, 2016) menyatakan bahwa perlakuan radiasi UV pada susu pasterurisasi dapat memperpanjang umur simpan dari 12 hari menjadi 21, sedangkan dalam penelitian lain perlakuan *double process* pasteurisasi UV-C dapat meningkatkan umur simpan susu cair dari 7 menjadi 35 hari. Perlakuan UV untuk digunakan bersamaan dengan pasteurisasi terhadap susu juga terbukti dapat meningkatkan umur simpan susu hingga 30% (Cappozzo et al., 2015).

CONCLUSION

In this study, the factors that affect the ALT results are the operating temperature and the duration of radiation treatment. This study used the pasteurization method and the irradiation method with 2 UV-C germicidal lamps which resulted in a bacterial reduction process of 99.95% from the initial number of microbes in milk which was originally 1.9×106 cfu/mL to 7.0×102 cfu/mL. The shelf life of milk can reach 5 months without experiencing many changes in taste but the viscosity of the milk increases. The results also showed that the acidity level was still in an optimum state, namely in the range of 6.5 - 6.8 in conditions before and after treatment, either pasteurization alone or a combination of pasteurization and UV-C. Thus, it can be concluded that the addition of UV-C germicidal radiation equipment in the milk sterilization process can reduce the total plate count and increase the shelf life of milk.

ACKNOWLEDGMENT
This research was funded by the DPA LPPM UNNES 2024 with Grant Number 665.26.2/UN37/PPK.10/2024. The researchers would like to express their gratitude for the support and cooperation provided, which enabled the successful implementation of this study.

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