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Decreasing Sterilization Time of Oil Palm Bunch with Direct Steaming Using Vacuum Pump

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ABSTRACT

This study investigated the reduction of sterilization time in direct whole bunch palm fruit sterilization using a vacuum pump. The research was divided into three methods: (1) a study of water boiling in a sterilizer to determine optimal conditions, (2) The Hybrid system involves opening valves to allow steam to naturally displace air. This process is optimized by starting air venting before reaching 100°C or 90°C., and (3) a study of palm fruit sterilization using a vacuum pump. In the first phase, water boiling tests were conducted under both vacuum and atmospheric conditions. By boiling 20 kg of water to a pressure of 2.5 bar, it was found that the -0.1 bar vacuum condition resulted in the shortest boiling time and the lowest energy consumption. Compared to the conventional method, this condition reduced boiling time by 47.91% and saved 28.22% in energy costs. These findings indicate that the -0.1 bar vacuum condition is a promising approach for further studies in palm fruit sterilization. In the second phase, palm fruit sterilization tests were conducted using vacuum pressures of -0.1. Approximately 200 kg of palm fruit bunches and 20 kg of water were used in each test, with the mixture sterilized to 2.5 bar and held for 30 minutes. Results showed that the vacuum system significantly reduced sterilization time and costs. The -0.1 bar vacuum condition was particularly effective. Moreover, the quality of the crude palm oil produced under all conditions met the acceptable standards, with an oil yield exceeding 18% based on fresh fruit bunch weight. Quality parameters such as free fatty acid, deterioration of bleachability index, peroxide value, and iodine value were within the established limits.

1. Introduction

The palm oil industry can be categorized into two main processing methods [1-3] separate kernel pressing and whole fruit pressing. Whole fruit pressing is primarily used in smaller-scale mills, which typically receive fallen palm fruits directly from farmers or palm fruit collection yards. The fruits are heated before being pressed. The heating process involves roasting in cement trays with a perforated iron grate allowing hot air to pass through. The hot air is generated by the combustion of fuels such as rubber wood or furnace oil. A fan is typically used to force hot air into the bottom of the roasting

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tray to ensure even distribution. A major drawback of this method is the lengthy roasting time (30 hours) [4]. Additionally, the temperature within the fruit pile is often inconsistent.

For the separate kernel pressing method, commonly employed in large-scale mills with high production capacities, whole palm fruit bunches serve as the raw material [5]. This process yields two products: palm oil from the mesocarp and oil from the kernel [6]. In the initial step, the fruit bunches undergo sterilization through steam sterilization at 120-130°C and a steam pressure of 2-3 bar to inhibit the formation of free fatty acids and soften the fruit bunches, facilitating the detachment of fruits from the bunch. Subsequently, the fruit bunches are conveyed to a rotary screen separator to separate the fruits from the bunch [5,7]. The fallen fruits are then fed into a digester to separate the mesocarp from the kernel. Both the kernel and mesocarp are then pressed using a screw press to extract oil from the mesocarp. This process avoids cracking the shell, ensuring that only oil from the mesocarp is obtained. The crude palm oil is then filtered to remove impurities and proceeds. After extraction, the crude palm oil (CPO) is treated through a filtration process using a vibrating screen, followed by water separation and moisture reduction using a vacuum dryer. For more detailed information on the oil palm milling process.

Sterilization is a crucial process in palm oil mills, as it softens bunches, inactivates enzymes, removes moisture, and facilitates oil extraction [8]. Thermal energy from steam breaks down resins and starch, producing foam oil. Inadequate sterilization can lead to secondary oxidation, resulting in discoloration and reduced bleaching index (DOBI). Hence, effective sterilization is essential for efficient palm oil production.

Recent research has focused on developing integrated palm fruit pressing systems that require the drying of fallen palm fruits. Hanifarianty *et al*., [9] designed and developed a rotary drum dryer to heat palm fruits, investigating the effects of the number of hot air vents on moisture reduction in palm fruits for application in palm oil mills. Alimalbari *et al*., [10] explored methods to reduce drying time by pre-crushing the palm fruits before drying. Their study revealed that pre-crushing significantly reduced drying time compared to non-crushed fruits. However, the free fatty acid content in crude palm oil from pre-crushed fruits was higher than that of non-crushed fruits.

Hadi *et al*., [11] investigated the percentage of fruit detachment from the bunch after steam sterilization at 140°C and 2.6 bar pressure for varying durations. Their results indicated that a 70-minute sterilization time resulted in complete fruit detachment from the bunch. Sukaribin and Khalid [12] studied the effectiveness of microwave heating on palm fruits still attached to the bunch, using a power range of 1-2 kW. Their findings showed that moisture loss in palm fruits increased with heating time, and the percentage of fruit detachment from the bunch generally increased with increasing heating time, although a decreasing trend was observed after a certain duration.

However, the steam sterilization method has its drawbacks, including the generation of a significant amount of wastewater, contributing to pollution [7,13,14]. Moreover, it requires complex machinery, resulting in high installation and maintenance costs. To address these issues, a direct hot air heating method has been developed, eliminating the need for steam and wastewater generation [15]. Nevertheless, this method has limitations. Whole fruit bunches cannot be heated directly; they must be chopped into before being fed into a fruit separator [16,17]. This results in two fractions of fruits: whole fruits and chopped fruits. The chopped fruit fraction, exposed to air (oxygen) before entering the heating system, is more susceptible to the formation of free fatty acids. Additionally, during the heating process, the oil within the fruits undergoes degradation, causing the oil to leak from the chopped portions, leading to product loss.

To address these issues, our research team has developed a direct steam sterilization system for palm fruit bunches, integrating the boiler and sterilizer into a single unit, as depicted in Figure 2. Studies have shown that this novel sterilization method can reduce water consumption by up to four times compared to the conventional method illustrated in Figure 1. Furthermore, this direct sterilization method can be further optimized to reduce sterilization time by employing a vacuum pump to evacuate the air within the sterilizer before heating. This approach can accelerate the boiling of water within the sterilizer. However, the increased energy consumption associated with the vacuum pump warrants further investigation to determine its overall cost-effectiveness.

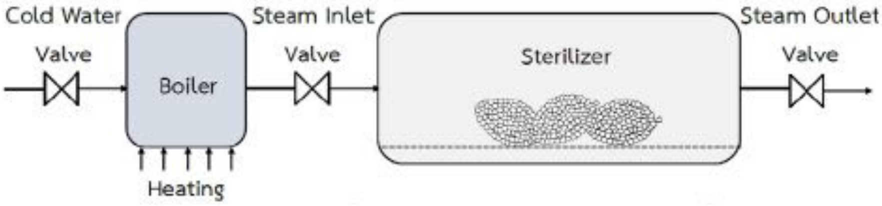


Fig. 1. Conventional method

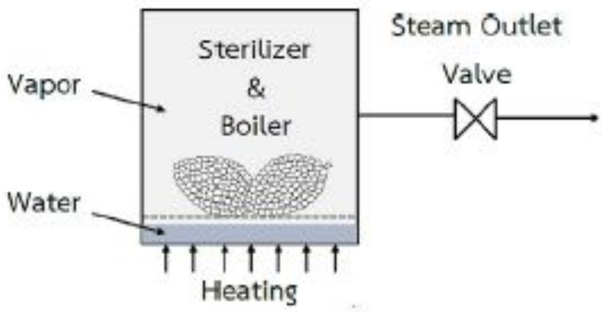


Fig. 2. Direct sterilization method

2. Methodology

Figure 3 illustrates the vacuum boiling system and its associated testing apparatus. The system consists of a sterilization pot placed on a natural gas stove. A pressure gauge, a thermocouple, and a vacuum port connected to a vacuum pump are mounted on the front of the sterilization pot for pressure measurement, temperature monitoring, and vacuum creation, respectively. A pressure relief valve is installed on the top of the pot to release excess pressure above 2.5 bar and to vent the system when required [12,17].

In this research, three experimental methods were employed. The first method, serving as a benchmark, involved a conventional approach where the sterilization pot was completely sealed from the beginning, allowing water and air to boil simultaneously. The second method, Air venting without a vacuum pump involves opening valves 1 and 2, allowing steam to naturally displace the air. This method is known as the Hybrid system. To optimize the process, air venting is initiated before the temperature reaches 100°C and 90°C, respectively, resulting in two variations: Hybrid system at 90°C and Hybrid system at 100°C. The third method utilized a vacuum pump, as depicted in Figure 3, to evacuate the air from the sterilization pot before boiling. The vacuum pump had a capacity of 1 hp, and the vacuum levels were set at -0.1, -0.3, and -0.6 bar.

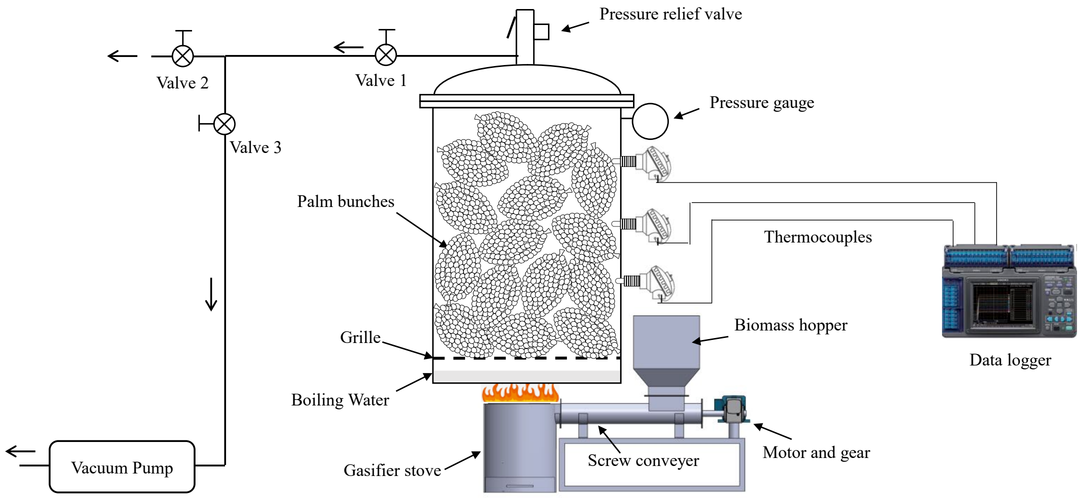


Fig. 3. Schematic diagram of direct steaming using vacuum pump

For the experimental procedure, the gas valve was initially opened, and the gas flow rate was regulated using a rotameter. The gas burner was then ignited, and a blue flame was maintained for complete combustion. Temperature readings were recorded every 10 seconds using a Hioki LR8400-20 thermometer, while pressure readings were recorded every 10 minutes. Once the pressure reached 2.5 bar, the temperature was maintained for 30 minutes. After this, the sterilization pot was opened, and the sterilized palm fruit bunches were removed and fed into a destoner to separate the fruits from the bunch. The separated palm fruits were then fed into an oil expeller to extract crude palm oil and palm kernel cake.

3. Results

3.1 Results of a study on direct water boiling in a sterilizer using a vacuum pump

The experimental results, as depicted in Figure 4, present the pressure profiles of the boiling water within the sterilizer for all six trials. The results indicate that the vacuum boiling method at -0.1 bar achieved the shortest pressure build-up time at 23.44 minutes, followed by -0.3 bar at 29.01 minutes, and -0.6 bar at 33.25 minutes, respectively. Subsequently, the conventional boiling method, hybrid system at 90°C, and hybrid system at 100°C required 45, 48, and 85 minutes, respectively. These findings clearly demonstrate that the vacuum boiling method significantly reduced the time required to build up pressure.

Case	Conv.	Hybrid 100 °C	Hybrid 90 °C	- 0.1 bar	- 0.3 bar	- 0.6 bar
Time (min)	45	85	48	23.44	29.01	33.25

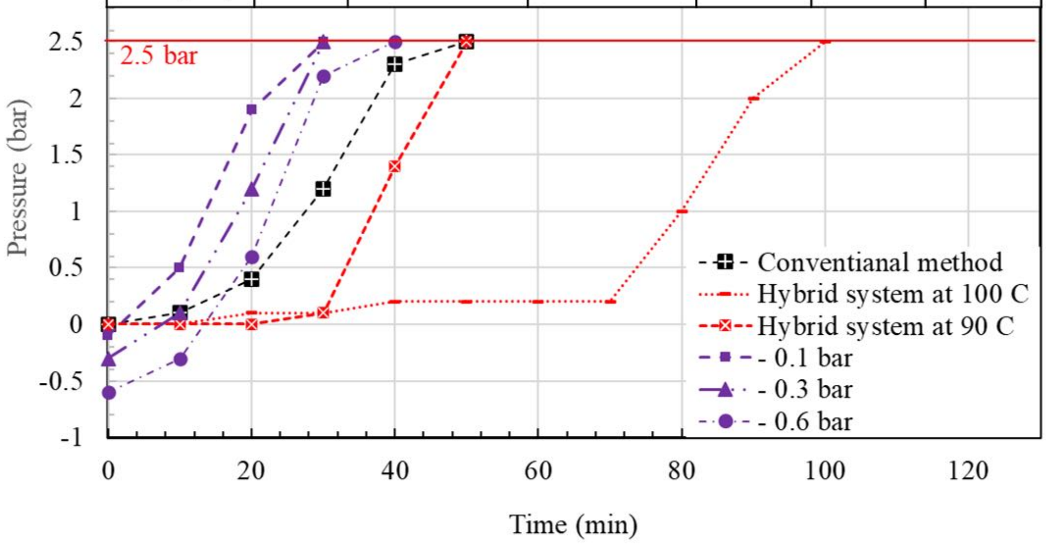


Fig. 4. Pressure profile of water boiling in a steam boiler

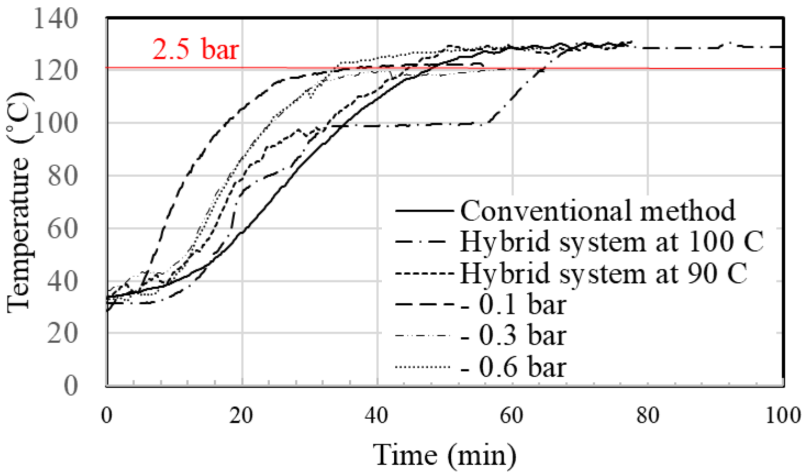
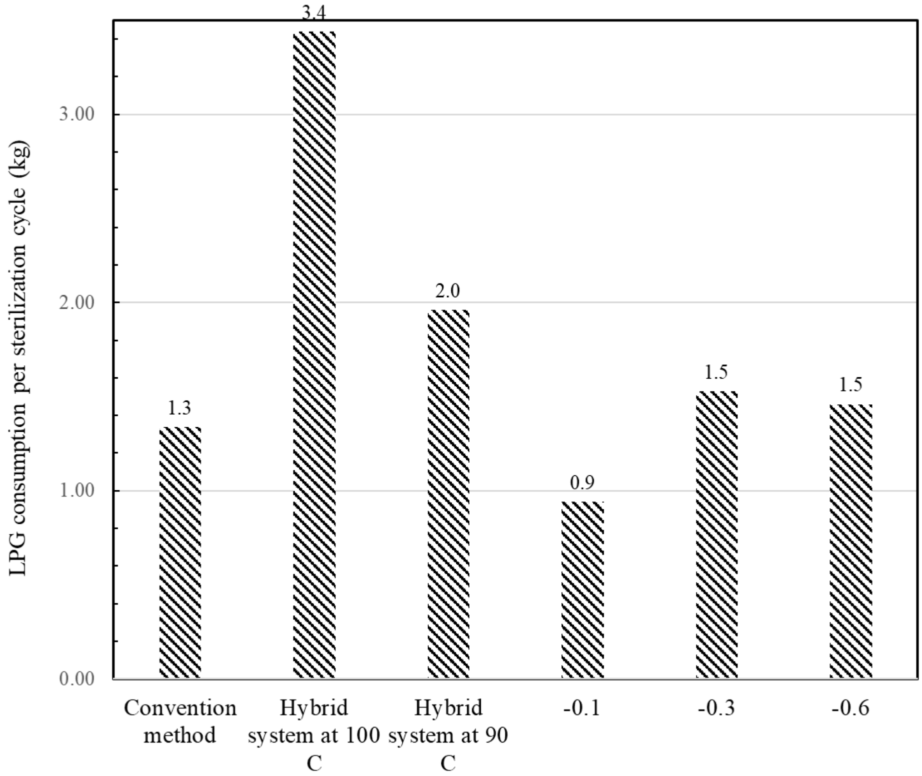


Fig. 5. Results of a study on temperature profiles within a sterilizer

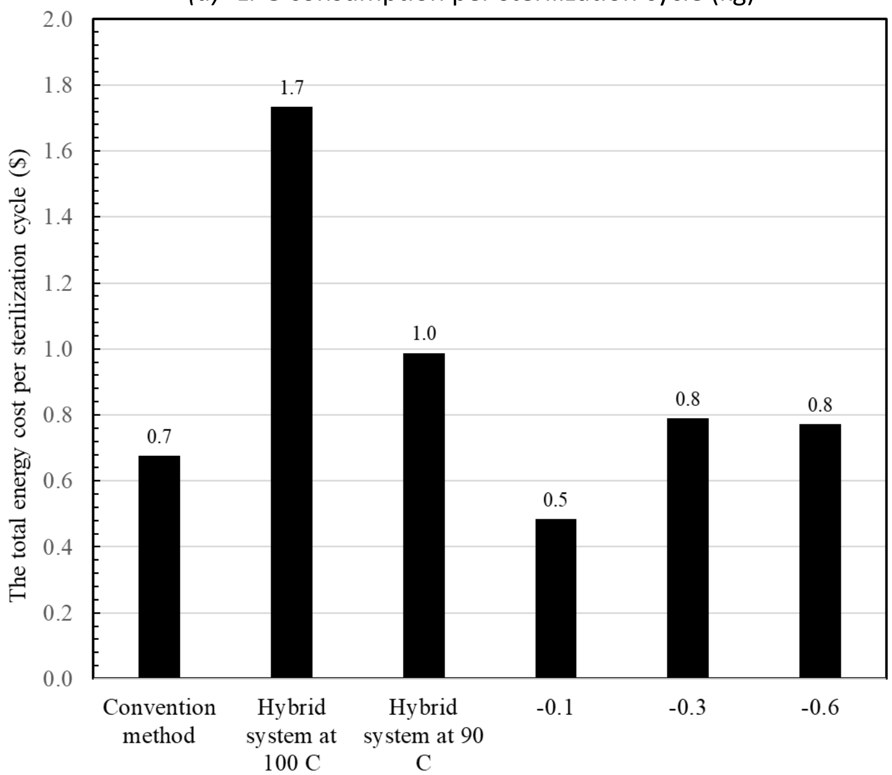
Figure 5 presents the steam temperature profiles for all six experimental conditions. The results demonstrate a close correlation between the increase in temperature and pressure, aligning with thermodynamic principles.

Considering the normal condition, the hybrid system at 100°C exhibited the longest pressure build-up time due to a three-stage temperature increase: 0-90°C, 90-100°C, and 100-121°C. The most time-consuming phase was between 90-100°C, corresponding to the phase change from liquid to vapor. Steam escaping from the pressure cooker without accumulating pressure caused a prolonged time to reach 100°C, resulting in increased energy consumption. The hybrid system at 90°C, on the other hand, showed a continuous temperature increase without this energy loss phase, thus requiring less time and energy.

For the vacuum boiling system, the -0.3 and -0.6 bar conditions exhibited similar temperature profiles up to 115°C. However, beyond this point, the -0.3 bar condition achieved a higher temperature more rapidly. Nevertheless, the -0.1 bar condition consistently demonstrated the shortest time to reach the desired temperature.



(a) LPG consumption per sterilization cycle (kg)



(b) The total energy cost per sterilization cycle ($)

Fig. 6. Results of a study on temperature profiles within a sterilizer

Figure 6(a) illustrates the LPG consumption for boiling water. The results show a direct correlation between boiling time and fuel consumption. The vacuum system at -0.1 bar exhibited the lowest fuel consumption at 0.9 kg, followed by the conventional method at 1.34 kg, -0.6 bar vacuum at 1.46 kg,

-0.3 bar vacuum at 1.53 kg, and the hybrid systems at 90°C and 100°C at 1.96 kg and 3.44 kg, respectively.

While the vacuum system at -0.1 bar demonstrated significant energy savings, its overall efficiency compared to the conventional method is complex due to the additional electrical energy required to operate the vacuum pump. To accurately assess the total energy consumption of the vacuum systems, the electrical energy must be converted to an equivalent fuel consumption. The total cost can then be determined by multiplying the energy consumption by the electricity rate. By considering both the fuel and electrical energy consumption, a more comprehensive comparison of the different methods can be made.

Figure 6(b) presents the total cost of boiling water for all experimental conditions. The results mirror those of Figure 6(a), showing that the overall cost is directly correlated with the LPG consumption. Although vacuum systems require both fuel and electrical energy, the electrical energy consumption for operating the vacuum pump is relatively minimal. Consequently, the total cost differences between the various methods are not significant.

However, a notable observation is the cost difference between the -0.1 bar vacuum system and the conventional method. While the difference is only 0.2 USD, the -0.1 bar vacuum system achieved a pressure of 2.5 bar significantly faster, saving approximately 21.56 minutes. This indicates that the -0.1 bar vacuum method offers both time and cost savings.

This study investigated four different boiling methods for whole palm fruit bunches in a sterilizer. The results demonstrated that vacuum boiling significantly reduced both boiling time and energy consumption. Among the tested methods, the -0.1 bar vacuum condition proved to be the most efficient. This research highlights the significant advantages of vacuum boiling over conventional methods and provides a promising foundation for future studies on palm fruit sterilization, as will be explored next topic.

3.2 The results of a study on palm oil extraction using direct steaming with a vacuum pump

Figure 7 presents the steam temperature profile in a pressure cooker under a vacuum condition of -0.1 bar. The results indicate a rapid initial temperature rise, followed by a more gradual increase from 100°C to 120°C at a pressure of 2.5 bar. The temperature increase is consistent and without any noticeable decrease. However, the -0.1 bar vacuum condition resulted in a slightly slower time to reach 2.5 bar pressure as the pressure increased. This research demonstrates that vacuum systems can indeed accelerate the temperature rise. Nevertheless, the overall energy consumption, particularly the gas consumption, should also be considered when evaluating the effectiveness of vacuum systems.

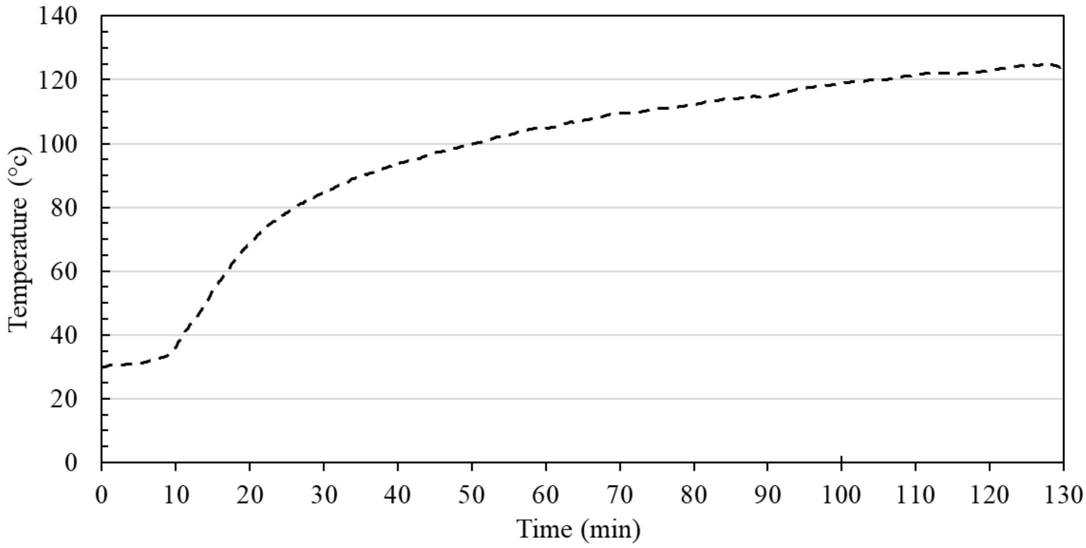


Fig. 7. Results of the steam temperature profiles for experimental conditions.

Table 1 presents the data on the consumption of palm fruit bunches, LPG fuel, cost, and processing time for sterilizing whole palm fruit bunches under a vacuum of -0.1 bar. The results show that 200.675 kg of palm fruit bunches required 4.52 kg of LPG for sterilization. Including the electricity cost for vacuum operation, the total cost per sterilization cycle was 1.92 USD. The sterilization process took 103 minutes.

Table 1
The energy consumption for case of vacuum – 0.1 bar

Condition	*Value*	Unit
Palm fruit bunches	200.675	Kg
LPG	4.56	kg
The total energy cost per sterilization cycle	1.92	USD
Sterilization time of palm fruit	103	minutes

Table 2 presents the quantity and quality of the extracted crude palm oil. Generally, an acceptable crude palm oil extraction rate is considered to be above 18%. The experimental results show that the average extraction rate meets this standard, as shown in Table 2. However, palm samples processed using a vacuum sterilization process at -0.1 bar yielded a significantly higher crude palm oil content of 23.84%.

Table 2
The quality of crude palm oil extracted through a sterilization process using a vacuum of -0.1 bar

Condition	*Value*	Acceptable value	Unit
CPO yield	23.84	>18	%
FFA	0.83	<5	%
DOBI	2.78	>2	-
IV	50.5	>50	g Iodine/100g
PV	0.72	<10	meq/kg
MC	1.06	>0.05	%

The quality of the crude palm oil was assessed based on several parameters including free fatty acid (FFA), deterioration of bleachability index (DOBI), iodine value (IV), peroxide value (PV), and moisture content [5,11,13]. The results indicate that the FFA, DOBI, and peroxide values were within the acceptable limits for palm oil sterilized under vacuum conditions. Moreover, the vacuum sterilization process was able to preserve the iodine value according to the established standards.

4. Conclusions

This research aimed to optimize the direct whole bunch palm fruit sterilization process by incorporating a vacuum pump. The study was conducted in two phases: (1) evaluating the impact of vacuum boiling on sterilization time and efficiency, and (2) assessing the subsequent effects on palm oil extraction.

Key findings from the boiling experiments revealed that vacuum boiling significantly reduced both boiling time and energy consumption. Specifically, a vacuum pressure of -0.1 bar demonstrated the most substantial improvement compared to conventional atmospheric boiling methods. This suggests that vacuum technology holds significant potential for enhancing the overall efficiency and cost-effectiveness of palm fruit sterilization.

Furthermore, the study examined the impact of vacuum sterilization on palm oil extraction. Results from the mass balance analysis indicated that the vacuum method yielded a higher oil content (23.84%) compared to traditional methods. Moreover, the quality of the crude palm oil produced, as measured by parameters such as percentage, free fatty acid content, bleachability index deterioration, and peroxide value, met industry standards.

Based on these findings, it can be concluded that the vacuum system effectively accelerated the initial temperature rise and reduced sterilization time in direct whole bunch palm fruit sterilization. The -0.1 bar vacuum condition, in particular, shows promise for further development and implementation in commercial palm oil processing facilities. Future research could explore the long-term effects of vacuum sterilization on palm fruit quality, as well as the potential for scaling up this technology for industrial applications.

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References
[1] Cheng, S. F., M. Nor L., and C. H. Chuah. "Microwave Pretreatment: A Clean and Dry Method for Palm Oil Production." *Industrial Crops and Products* 34, no. 1 (July 2011): 967–71. https://doi.org/10.1016/j.indcrop.2011.03.002.

[2] Tan, C.-H., H. M. Ghazali, A. Kuntom, C.-P. Tan, and A. A. Ariffin. "Extraction and Physicochemical Properties of Low Free Fatty Acid Crude Palm Oil." *Food Chemistry* 113, no. 2 (March 2009): 645–50. https://doi.org/10.1016/j.foodchem.2008.07.052.

[3] Morakinyo, T. A., and A. I. Bamgboye. "Optimization of Operation Parameters of a Vertical Sterilizer of Medium-Scale Oil Palm Mill Using Taguchi Method." *Journal of Food Process Engineering* 40, no. 3 (June 2017): e12453. https://doi.org/10.1111/jfpe.12453.

[4] Omar, A. K. M., et al. "Implementation of the Supercritical Carbon Dioxide Technology in Oil Palm Fresh Fruits Bunch Sterilization: A Review." *Journal of CO2 Utilization* 25 (May 2018): 205–15. https://doi.org/10.1016/j.jcou.2018.03.021.

[5] Vincent, C. J., R. Shamsudin, and A. S. Baharuddin. "Pre-treatment of Oil Palm Fruits: A Review." *Journal of Food Engineering* 143 (December 2014): 123–31. https://doi.org/10.1016/j.jfoodeng.2014.06.022.

[6] Hashim, K., S. Tahiruddin, and A. J. Asis. "Palm and Palm Kernel Oil Production and Processing in Malaysia and Indonesia." In *Palm Oil*, 235–50. Elsevier, 2012. https://doi.org/10.1016/B978-0-9818936-9-3.50011-3.

[7] Sivasothy, K. "Palm Oil Miling Technology." 2000.
[8] Olie, J. J., T. D. Tjeng, and T. D. Tjeng. *The Extraction of Palm Oil*. Incorporated Society of Planters, 1974. https://books.google.co.th/books?id=MlnKwAEACAAJ.
[9] Hanifarianty, S., A. Legwiriyakul, A. Alimalbari, C. Nuntadusit, T. Theppaya, and M. Wae-Hayee. "The Development of Rotary Drum Dryer for Palm Fruit Sterilization." *IOP Conf. Ser.: Mater. Sci. Eng.* 297 (January 2018): 012031. https://doi.org/10.1088/1757-899X/297/1/012031.
[10] Alimalbari, Ameen, Sherly Hanifarianty, Anil Kumar, Thanet Khomphet, TheeraEksomtramage, and Makatar Wae-hayee. "Effects of Pressed Palm Conditions on Acceleration of Palm Drying Rate and CPO Quality." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 55, no. 1 (2019): 12–19.
[11] Hadi, A. bin A., D. I. A. W. Mohammad, and M. S. Takriff. "Determination of Optimum Sterilization Condition Based on Calculated Heat Transfer Rate for Palm Oil Mill Process." *ARPN Journal of Engineering and Applied Sciences* 11 (2016): 8475–80.
[12] Sukaribin, N., and K. Khalid. "Effectiveness of Sterilisation of Oil Palm Bunch Using Microwave Technology." *Industrial Crops and Products* 30, no. 2 (September 2009): 179–83. https://doi.org/10.1016/j.indcrop.2009.05.001.
[13] Chavalparit, O., W. H. Rulkens, A. P. J. Mol, and S. Khaodhair. "Options for Environmental Sustainability of the Crude Palm Oil Industry in Thailand Through Enhancement of Industrial Ecosystems." *Environment, Development and Sustainability* 8, no. 2 (May 2006): 271–87. https://doi.org/10.1007/s10668-005-9018-z.
[14] Aziz, M., T. Oda, and T. Kashiwagi. "Design and Analysis of Energy-Efficient Integrated Crude Palm Oil and Palm Kernel Oil Processes." *Journal of the Japan Institute of Energy* 94, no. 1 (2015): 143–50. https://doi.org/10.3775/jie.94.143.
[15] Wae-hayee, M., S. Pakdeechot, S. Hanifarianty, and W. Suksuwan. "Minimizing Water Consumption in Oil Palm Sterilization Using Direct Steaming: Effects of Sterilization Pressure and Time." *Journal of Food Engineering* 315 (February 2022): 110804. https://doi.org/10.1016/j.jfoodeng.2021.110804.
[16] Fatin, Syakirah Alia, Rosnah Shamsudin, and Robiah Yunus. "Effect of Chopping Oil Palm Fruit Spikelets on the Free Fatty Acid Content Release Rate and Its Mechanical Properties." Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia.
[17] Ali, F. S., R. Shamsudin, and R. Yunus. "The Effect of Storage Time of Chopped Oil Palm Fruit Bunches on the Palm Oil Quality." *Agriculture and Agricultural Science Procedia* 2 (2014): 165–72. https://doi.org/10.1016/j.aaspro.2014.11.024.