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Research article

Technical Assessment and Engineering Analysis of a Horizontal Sterilizer Pressure Vessel for Palm Oil Processing: Case Study of a 14-Ton Capacity System

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Abstract: Palm oil processing represents a vital industry in Indonesia, which exported over 36 million tons of palm oil products in 2019. Sterilization is a critical process in palm oil extraction that directly impacts product quality and processing efficiency. This study presents a comprehensive engineering analysis and design specification for a horizontal sterilizer pressure vessel with a 14-ton capacity used in palm oil processing. Using a rational design methodology, we documented and analyzed the specifications of a sterilizer system operating at pressures of 2.8-3.0 kg/cm² and temperatures of 135-140°C. The research includes detailed calculations of vessel dimensions, wall thickness requirements, and volume characteristics. Results yielded comprehensive specifications including a vessel length of 21.5 m, diameter of 3 m, wall thickness of 15 mm, and total volume of 151.9 m³. These parameters establish a complete engineering basis for sterilizer design, fabrication, and maintenance. The study contributes to the limited scholarly literature on palm oil processing equipment design and provides valuable reference material for engineers developing similar systems. This documentation of industrial knowledge bridges the gap between theoretical pressure vessel design and practical applications in the palm oil industry.

Keywords: Crude palm oil, Engineering analysis, Horizontal sterilizer, Palm oil processing, Pressure vessel design

1. Introduction

Palm oil production represents one of the most significant agricultural industries in Southeast Asia, with Indonesia maintaining its position as the world's leading exporter. In 2019, Indonesia exported more than 36 million tons of palm oil products, highlighting the industry's economic importance for the nation [1]. The growing global demand for vegetable oils, coupled with palm oil's high yield efficiency compared to other oil crops, has driven the continuous expansion of production capacity across Indonesia [2]. Crude Palm Oil (CPO) production requires sophisticated processing facilities that can efficiently convert harvested Fresh Fruit Bunches (FFB) into high-quality oil while maintaining strict quality standards related to Free Fatty Acid (FFA) levels, moisture content, and impurities [3]. The processing efficiency and resulting product quality are significantly influenced by the initial thermal treatment of FFBs, which takes place in specialized pressure vessels known as sterilizers [4].

Sterilization represents a critical process in palm oil extraction, serving multiple essential functions. First, it inactivates the lipase enzymes that catalyze the hydrolysis of oil, thus preventing the formation of Free Fatty Acids that would reduce oil quality [5]. Second, it facilitates the separation of fruits from bunches and the breakdown of oil-bearing cells, enhancing oil extraction efficiency [6]. Third, it coagulates proteins within the mesocarp, disrupting stable oil-water emulsions and improving oil recovery [7]. Given these crucial functions, the design and operation of sterilizers directly impact both the quality and quantity of CPO production. Conventional horizontal sterilizers, which remain widely utilized throughout Indonesia, operate as batch-type pressure vessels that use saturated steam at temperatures of 135-140°C and pressures of 2.8-3.0 kg/cm² [8]. These vessels must be designed to withstand not only the operating pressures and temperatures but also to accommodate the mechanical stresses associated with loading and unloading lorries carrying FFBs [9]. Proper engineering design of these pressure vessels is essential for operational efficiency, safety, and longevity.

Despite their importance in palm oil processing, the specific engineering design considerations for palm oil sterilizers have received limited attention in scholarly literature compared to general pressure vessel design [10]. The optimization of sterilizer designs offers significant potential for improving processing efficiency, reducing energy consumption, and enhancing worker safety [11]. As palm oil mills seek to increase their processing capacity and improve their operating efficiency, the need for well-designed sterilization equipment becomes increasingly important.

PT Socfindo Seunagan plantation, located in Purwodadi, Kuala Pesisir District, Nagan Raya Regency, operates a palm oil mill with a production capacity of 23 tons/day. The facility, which underwent renovation in 1973, now encompasses a plantation area of 4,581.99 Ha. As part of ongoing efforts to maintain and potentially expand production capacity, the design specifications of key processing equipment, including sterilizers, require careful analysis and documentation [12].

This study aims to provide a comprehensive design analysis of a horizontal pressure vessel sterilizer with a 14-ton capacity as utilized at PT Socfindo Seunagan plantation. The research employs a rational design methodology to systematically analyze and document the specifications of sterilizer components, calculate key engineering parameters, and present detailed engineering drawings. The findings will contribute to the existing body of knowledge on palm oil processing equipment design and provide practical reference material for engineers involved in the specification, fabrication, or maintenance of similar equipment [13]. Furthermore, this research addresses the gap in specialized literature regarding palm oil sterilizer design by providing detailed calculations and specifications that can serve as a foundation for future design optimization studies [14]. By documenting the engineering parameters of an operational sterilizer system, this work also preserves valuable industrial knowledge that can inform both academic research and practical applications in the palm oil industry.

2. Methods

2.1. Design Methodology

This research employed a rational design methodology, which emphasizes a systematic approach to engineering design through structured analysis and documentation. As described in [15], the rational method expands the search space to facilitate comprehensive solution development while promoting systematic decision-making processes. For this sterilizer design analysis, the methodology was implemented in three distinct phases:

1. Data collection and specification documentation
2. Engineering analysis and calculation
3. Technical drawing development and verification

The initial data collection phase involved detailed measurements and documentation of the existing sterilizer units at PT Socfindo Seunagan plantation. This established the baseline specifications presented in Table 1, which formed the foundation for subsequent engineering calculations.

Table 1. Initial data of the sterilizer

Item	Specification
Material	Steel
Length	2,150 cm
Diameter	300 cm
Doors	2
Thickness	15 mm
Cover Width	350 cm
Cover Depth	100 cm
Normal Pressure	2.8 bar
Maximum Pressure	3.5 bar
Working Temperature	135-140 °C
Quantity	3 units
Type	Horizontal
Capacity	7 lorries

2.2. Sterilizer Components and Functions

A comprehensive functional analysis was conducted to identify the critical components of the horizontal sterilizer system. Each component was evaluated in terms of its functional requirements, operating conditions, and material considerations. The key components identified include:

2.2.1. Pressure Vessel (Sterilizer Body)

The main pressure vessel serves as the primary containment structure for the sterilization process. At PT. Socfindo Seunagan plantation, each vessel accommodates 7 lorries with a total capacity of 14 tons of FFB per batch. The vessel is designed to withstand operating pressures of 2.8-3.0 kg/cm^2 and temperatures of 135-140°C while maintaining structural integrity throughout repeated thermal and mechanical loading cycles.

2.2.2. Access Doors

Each sterilizer is equipped with two doors positioned at opposite ends to facilitate lorry entry and exit. The doors are designed to maintain pressure-tight seals during operation while allowing for efficient loading and unloading. Door design represents a critical safety component, requiring robust hinging mechanisms and secure locking systems to prevent accidental opening under pressure.

2.2.3. Steam Distribution System

The steam distribution system consists of inlet pipes, valves, and internal distribution manifolds that ensure uniform steam penetration throughout the FFB mass. As identified in [16], proper steam distribution directly influences cooking uniformity and process efficiency.

2.2.4. Condensate Collection System

The condensate system comprises drainage pipes, valves, and collection chambers that remove condensed steam from the vessel. Efficient condensate removal prevents water accumulation that could compromise sterilization effectiveness and potentially damage the vessel through water hammer effects.

2.2.5. Safety Systems

Multiple safety systems are incorporated into the sterilizer design, including:

- Safety valves calibrated to release pressure above 3.5 kg/cm²
- Pressure gauges (manometers) for continuous monitoring
- Temperature indicators to verify process conditions
- Rototherm recorders that document the sterilization cycle

2.2.6. Rail Track System

The internal rail system guides lorries through the sterilization process. This system must maintain alignment under thermal expansion conditions while supporting the substantial weight of FFB-loaded lorries.

2.2.7. Cantilever Rail Bridge

The cantilever rail bridge provides a transitional connection between external and internal rail systems. This component must securely support lorries during entry and exit operations while maintaining proper alignment with both rail systems.

2.3. Design Calculations

The engineering analysis phase employed established pressure vessel design principles to calculate key parameters based on the documented specifications. The calculations followed standard engineering practices for cylindrical pressure vessels with hemispherical ends, with particular attention to:

- Wall thickness requirements based on operating pressure
- Surface area calculations for thermal loading analysis
- Volume determinations for capacity verification
- Dimensional verification for functional requirements

2.3.1. Cylindrical Vessel Calculations

The cylindrical section represents the primary component of the sterilizer. Its surface area is calculated using equation (1).

$$A_s = 2\pi r \times L \quad (1)$$

where A_s is the surface area, $2\pi r$ represents the circumference of the circular cross-section, and L represents the height (length) of the cylinder. For verification purposes, the vessel length can be determined from the surface area using equation (2).

$$L = \frac{A_s}{(2\pi r)} \tag{2}$$

2.3.2. End Cover Calculations

The hemispherical end covers require specific geometric calculations. The outer radius is determined by equation (3).

$$R_o = 0.5 \times D_o \tag{3}$$

where R_o represents the outer radius and D_o is the outer diameter of the end cover. The spherical radius of the end covers, which defines the curvature, is calculated using equation (4).

$$R_s = \frac{\left(H^2 + {R_o}^2\right)}{(2 \times H)} \tag{4}$$

where R_s represents the spherical radius of the end cover and H represents the cover depth.

2.3.3. Surface Area and Volume Calculations

The total surface area of the vessel, including both the cylindrical section and end covers, is determined by equation (5).

$$A_t = 2\pi r(r + L) \tag{5}$$

where A_t represents the total surface area of the vessel. The internal volume of the sterilizer, which determines its processing capacity, is calculated using equation (6).

$$V = \pi r^2 \times L \tag{6}$$

where V represents the internal volume of the vessel, πr^2 represents the area of the circular cross-section, and L represents the length of the cylinder. These calculations provide the complete engineering basis for the sterilizer design, addressing all key dimensional, volumetric, and structural requirements.

3. Results and Discussion

3.1. Sterilizer Component Specifications

The comprehensive analysis of the horizontal sterilizer at PT Socfindo Seunagan plantation yielded detailed specifications for all major components. Table 2 presents the component data with dimensional information and material requirements, establishing a complete reference for the functional elements of the 14-ton capacity sterilizer.

The data collection and subsequent analysis confirmed that the sterilizer design incorporates appropriate components to fulfill all required functions in the palm oil sterilization process. Notably, the steam entry and exit systems utilize 8-inch diameter pipes and valves, providing sufficient flow capacity for the vessel volume. Safety systems, including pressure relief valves and monitoring instrumentation, meet industry standards for pressure vessel applications in this capacity range.

Table 2. Sterilizer Component Specifications.

Function	Components and Dimensions	Description
Steam Entry	8” Pipe 8” Elbow 8” Check Valve 8” Tee Connection 8” Valve	Strong material, corrosion resistant, Able to withstand pressure and heat as needed.
Steam Exit	8” Pipe 8” Elbow Connection 8” Tee Connection 8” Valve	Strong material, corrosion resistant, Able to withstand pressure and heat resistance as required.
Boiling Kettle	300 cm Kettle Wall Plate Diameter 2,150 cm Kettle Wall Plate Length 15 mm Kettle Wall Plate Thickness 300 cm Kettle Cover Diameter	Strong material, corrosion resistant, Able to withstand pressure and heat resistance as required.
Steam Temperature and Pressure Gauge	Thermometer Manometer Rototherm	Meter accuracy is High, strong, and easy to read.
Entry and Exit Lorries	Cantilever Rail Bridge Rail Track	Strong material from lorry impacts and corrosion-resistant.
Boiling Safety Devices	6” Safety Valve Pressure Gauge	Strong material, corrosion resistant, Able to withstand pressure and heat as needed.

3.2. Calculated Dimensions and Parameters

Using the equations presented in the Methods section, the cylindrical section of the sterilizer was calculated to have:

- Circumference: 942 cm
- Surface area: 2,025,300 cm^2
- Length: 2,150 cm
- Radius: 150 cm
- Diameter: 300 cm

The hemispherical end covers were determined to have:

- Outer radius: 175 cm
- Spherical radius: 203.125 cm
- Cover depth: 100 cm
- Cover width: 350 cm

The complete vessel calculations yielded:

- Total surface area: 2,166,600 cm^2
- Base area: 70,650 cm^2
- Total volume: 151,897,500 cm^3

The complete set of calculated parameters for the 14-ton capacity horizontal sterilizer is presented in Table 3. These dimensions establish the engineering basis for the sterilizer design and provide reference values for future maintenance or modification activities.

Table 3. Comprehensive Boiler Section Dimensions.

Section	Parameter Category	Dimension	Design Tolerance	Equation Reference
Vessel Geometry	Length	21.5 m	±0.5%	(2)
	Internal Diameter	3.0 m	±0.2%	$2 \times r$
	Wall Thickness	0.015 m	+1.0 mm, -0.0 mm	-
	Length-to-Diameter Ratio	7.17 : 1	-	$^{L}/_{D}$
End Cover	Cover Width	3.5 m	±0.2%	-
	Cover Depth	1.0 m	±0.2%	-
	Outer Radius	1.75 m	±0.2%	(3)
	Spherical Radius	2.03 m	±0.3%	(4)
Surface Area	Cylindrical Surface Area	202.53 m^2	±0.5%	(1)
	Total Surface Area	216.66 m^2	±0.5%	(5)
	Base Cross-Sectional Area	7.065 m^2	±0.4%	πr^2
Volume	Vessel Volume	151.9 m^3	±0.5%	(6)
	Processing Capacity	14 tons	-	-

3.3. Engineering Drawings

Based on the calculated dimensions and documented specifications, detailed engineering drawings were developed to illustrate the sterilizer geometry and component arrangement. Figure 1 presents front, side, and top views, providing comprehensive visual documentation of the sterilizer design.

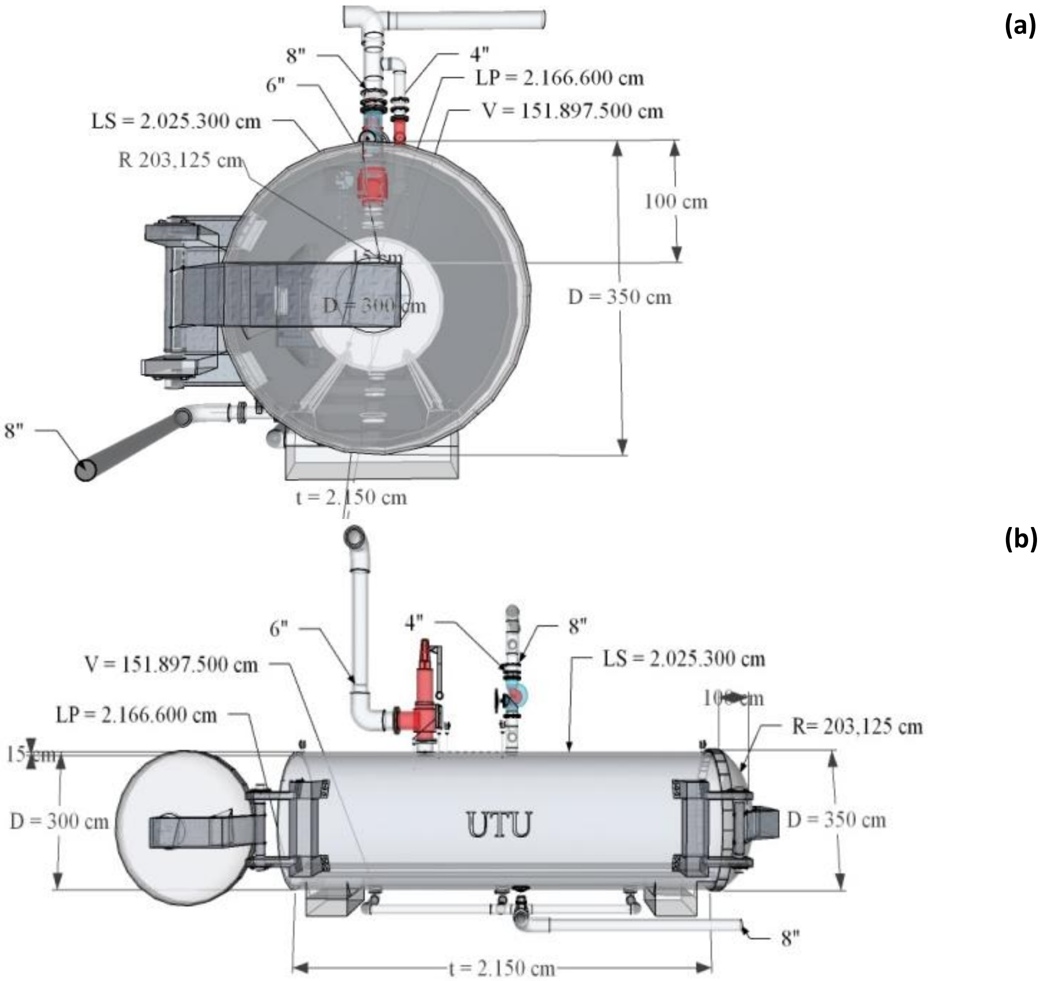
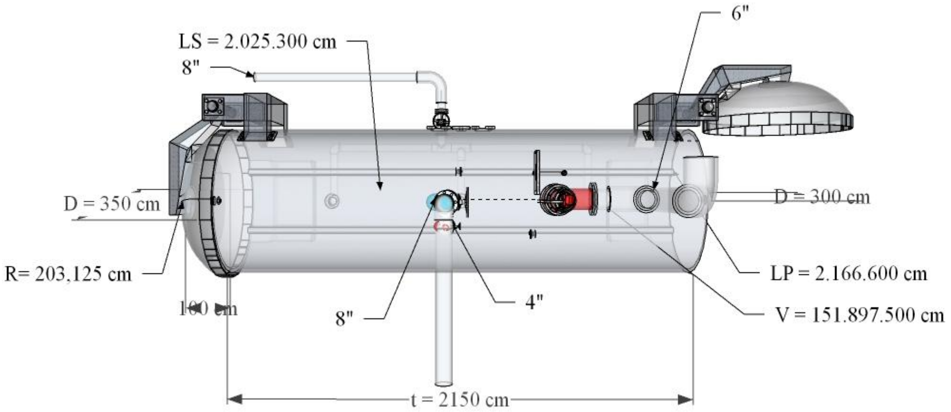


Figure 1. Engineering design of the sterilizer: **(a)** front view; **(b)** side view; **(c)** top view.

(c)



These drawings, combined with the calculated dimensions and component specifications, establish a complete engineering documentation package for the 14-ton capacity horizontal sterilizer.

3.4. Discussion

The analysis of the PT Socfindo horizontal sterilizer reveals several important design considerations specific to palm oil processing applications. The vessel's length-to-diameter ratio of approximately 7:1 (21.5 m length to 3 m diameter) represents a balance between processing capacity and structural considerations. When compared to industry standards for pressure vessel design, the PT Socfindo sterilizer incorporates all essential safety features recommended by relevant codes such as ASME Section VIII Division 1 [17]. The inclusion of dual safety valves, pressure monitoring systems, and robust door locking mechanisms aligns with best practices for batch sterilizer operations. Alternative sterilizer designs, particularly vertical continuous systems as described in [18], offer potential advantages in steam efficiency and labor requirements. However, the horizontal configuration analyzed in this study provides important operational flexibility for processing variable quality FFB inputs, which is particularly valuable in plantations with diverse harvesting schedules and fruit ripeness levels.

The calculated volume of 151.9 m³ provides sufficient space for the 14-ton FFB capacity while allowing adequate steam circulation around the loaded lorries. The surface area-to-volume ratio of the analyzed sterilizer influences both heating efficiency and heat loss characteristics. With a total surface area of 216.66 m² and volume of 151.9 m³, the vessel has a surface area-to-volume ratio of approximately 1.43 m²/m³. This ratio affects the energy requirements for initial heating and the rate of heat loss during operation. According to thermal efficiency studies in [2], proper insulation of sterilizer vessels can reduce heat losses by 25-30%, significantly improving overall energy efficiency. The large surface area of the PT Socfindo sterilizer (216.66 m²) underscores the importance of effective insulation systems to minimize steam consumption and improve processing economics.

The analysis reveals several potential opportunities for design optimization in future sterilizer installations or retrofits:

1. Steam distribution systems could be enhanced to improve cooking uniformity, particularly in the central portions of the vessel where FFB packing density may impede steam penetration.
2. Condensate collection systems might be optimized to reduce water accumulation and improve thermal efficiency, potentially through the incorporation of steam traps or condensate recovery systems.

3. Insulation systems represent a significant opportunity for energy conservation, with modern materials potentially offering improved thermal performance compared to traditional solutions.
4. Instrumentation and control systems could be enhanced to provide more precise process monitoring and automated cycle management, reducing operator intervention requirements and improving consistency.

The detailed documentation of sterilizer dimensions and specifications established in this study provides valuable reference information for maintenance planning and reliability assessment. Accurate dimensional data facilitates appropriate planning for inspection activities, component replacement, and life extension programs. Areas requiring particular attention in maintenance programs include door sealing surfaces, safety valve testing, and rail alignment verification. Regular inspection of these critical components helps ensure continued safe and efficient operation throughout the vessel's service life.

4. Conclusions

The comprehensive engineering analysis of the 14-ton capacity horizontal sterilizer at PT Socfindo Seunagan plantation has yielded precise documentation of key design parameters, including a cylindrical vessel of 21.5 m length and 3 m diameter with 15 mm wall thickness, optimized for operating pressures of 2.8-3.0 kg/cm². The calculations confirmed appropriate dimensional relationships, with a total vessel volume of 151.9 m³ and surface area of 216.66 m² providing suitable capacity for processing 14 tons of Fresh Fruit Bunches while maintaining structural integrity under combined thermal and mechanical loading conditions. These specifications align with industry standards for horizontal sterilizers while demonstrating appropriate safety margins.

This research contributes valuable engineering documentation to the scholarly literature on palm oil processing equipment by providing detailed technical specifications rarely presented in academic publications. The findings offer practical reference material for engineers involved in sterilizer design, operation, or maintenance, while establishing a foundation for future optimization studies focused on improving energy efficiency, oil extraction rates, and operational safety in palm oil processing facilities. Further research opportunities include computational fluid dynamics modeling of steam distribution, thermal efficiency analysis, and comparative assessments between horizontal batch systems and alternative sterilization technologies.

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