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Design and Build Boilers for Modernization in the Tofu Industry Using Autodesk Inventor

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Abstract

Most tofu producers still use steamers as boilers, which poses a risk to tofu quality. To reduce the risks and losses caused by this, a safe boiler construction is designed according to ASME (American Society of Mechanical Engineers) design standards. This research uses a Research and Development (R&D) approach supported by software capable of analysing model characteristics. The boiler construction was designed according to the ASME (American Society of Mechanical Engineers) standard, then the boiler design was created using Autodesk Inventor and a theoretical analysis was conducted using internal pressure loads to evaluate stress and displacement in the boiler construction. The results of the study obtained the specifications for a horizontal type of boiler with an operating steam pressure of 2 bar and a design pressure 4 bar. Boiler dimensions 600 mm in diameter, 1200 mm in length. Fuel uses firewood and the maximum volume of water that can be filled in the boiler is up to 113.1 litters. The material used for the plate is 5 mm stainless steel plate 304.

1 Introduction

The production process is the heart of any industry. One particular sector that requires improvement in its production tools is the tofu industry. Tofu is a soft solid food product made by processing soybeans (Glycine Species) by deposition of proteins, with or without the addition of other permitted ingredients [1]. The basic ingredients used in tofu production include soybeans, water, salt, and other seasonings. Typically, the tofu-making process consists of soaking, washing, grinding, boiling or cooking, filtering, coagulation and seasoning, moulding, and pressing [2].

Many tofu producers still use traditional steamers for boiling, which poses a risk to the tofu's quality and can result in an unpleasant odor. In previous studies, it was stated that one of the determinants of the final quality of tofu is its diversity of soybean seeds, boiling, heating, and different types of coagulant [3], [4]. In most tofu production facilities, critical operations such as boiling are still carried out using basic steamers or repurposed drums. These methods are not only inefficient but also introduce several operational risks. Poor thermal control, heat losses, inconsistent steam generation, and non-standard safety practices frequently result in lower product quality, increased energy consumption, and higher chances of workplace accidents. Technological advancements provide opportunities to improve equipment used in tofu production. One such technology is the boiler, which functions to convert water into steam.

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A boiler is a closed vessel that functions as a place of combustion and heat transfer to water. This process makes water turn into hot water or steam. Furthermore, the hot water or high-pressure steam can be used to conduct heat to various industrial processes or other systems [5].

In the tofu production process, the boiler serves a vital role, just as crucial as the boiler system itself. It generates high-pressure steam, and any leaks can injure operators or cause explosions that damage surrounding areas. Therefore, a properly designed boiler suited for the tofu industry is essential. This research aims to design a horizontal steam boiler specifically for tofu production and to analyze its static structural integrity using theoretical calculations and model it is using Autodesk Inventor based on ASME (American Society of Mechanical Engineers) standards.

This study aims to address these issues by developing a horizontal steam boiler specifically tailored for the tofu industry. The design process integrates the use of Autodesk Inventor, a computer-aided design (CAD) software capable of both geometric modelling and structural simulation [6]. Autodesk Inventor provides complete facilities to visualize models in 3D, assembly drawings, working drawings (drawing), and animation of objects to be made digitally. The resulting digital data can help visualize, simulate, and analysed a product virtually without conducting prototype testing [7]. Therefore, Autodesk Inventor was chosen for its strong capabilities in design, simulation, and analysis. Through this software, the boiler is modelled in three dimensions, and a series of static analyses are performed to evaluate structural integrity, stress distribution, and displacement behaviour under simulated load and temperature conditions.

The objective of this research is twofold: first, to create a boiler design that adheres to safety and performance standards, and second, to provide a prototype framework that can be realistically implemented in small-scale tofu production facilities. Ultimately, this effort is intended to contribute to the modernization of traditional industries by bridging the gap between academic engineering design and practical industrial application.

2 Research Methods

This research employs a Research and Development (R&D) methodology to develop a boiler design suited for tofu production. In general, the design process of a product involves long iterations, over and over again [8]. The R&D method supports the design and validation of the boiler model through theoretical calculations grounded in classical mechanical analysis.

Modelling is based on earlier calculations and observations. Material properties such as Young's Modulus (GPa), Poisson’s Ratio, density (kg/m^3), thermal expansion, yield strength (MPa), and fatigue limit (MPa) are used in the theoretical equations for stress and displacement estimation. Assumptions were made to simplify the theoretical analysis, and classical formulas were used to estimate stress distribution and displacement across the structure.

Descriptive analysis is used to evaluate the results of theoretical calculations and ensure that the design adheres to established engineering standards. The analysis results in identifying strengths and weaknesses in the proposed design, ensuring compliance with ASME standards and meeting the operational needs of tofu production. This design can thus be developed into a physical prototype ready for implementation.

3 Result and Discussion

The development of the horizontal steam boiler began with establishing design parameters based on direct field observations and literature review regarding the operational needs of small-scale tofu producers. The objective was to create a steam generation system that could deliver saturated steam at stable pressure and temperature while remaining compact, cost-efficient, and easy to fabricate using locally available materials.

3.1 Design

The design of the boiler was informed by both empirical observations in the field and supporting engineering calculations derived from thermodynamic and mechanical design principles. The goal was to produce a unit that not only meets the functional requirements of tofu production but also complies with safety and performance criteria as outlined in relevant engineering standards. The design phase involved careful consideration of spatial constraints, fuel availability, steam output demand, and potential risks associated with operating under pressure. Based on these foundations, the initial specifications of the boiler are summarized as follows:

1. Boiler Type: Horizontal Steam Boiler
2. Boiler Diameter: 600 mm
3. Boiler Length: 1200 mm
4. Design Pressure: 4 bar
5. Steam Type: Saturated steam
6. Operating Temperature: 100°C – 150°C
7. Operating Pressure: 2 bar
8. Fuel Type: Biomass (firewood) and used cooking oil

The structural design of the boiler was developed in accordance with the standards set by the ASME, ensuring that all critical components are engineered to withstand operational stresses and thermal loads safely. This adherence to ASME standards provides a foundation for reliability, longevity, and user-safety essential factors in any boiler design.

The complete system consists of several integrated subsystems, each meticulously designed to fulfill a specific role in the steam generation and distribution process. At the heart of the system lies the main boiler body, which functions as the primary boiler. This chamber is responsible for converting water into saturated steam through controlled thermal input. Fabricated from 5 mm thick Stainless Steel 304, the cylindrical vessel is engineered to endure internal pressures up to 6 bar while maintaining its mechanical integrity under sustained thermal loads. Its proportions have been optimized to encourage uniform heat transfer and minimize stress concentrations along the shell.

Beneath the boiler body is the combustion chamber, which serves as the central source of thermal energy. This chamber is designed to contain and direct the combustion of firewood or used cooking oil, channeling the resulting heat efficiently to the base and lower walls of the boiler. Lined with refractory materials, the chamber retains and focuses heat on the vessel, thereby improving energy utilization and reducing heat loss to the surrounding environment. The steam generated within the boiler is routed through a network of high-temperature piping and conduits. These components are dimensioned and pressure-rated according to the ASME code to ensure safe transport of steam from the generation point to the application interface. The piping layout is designed to minimize pressure drops and thermal losses along the route. At the terminal end of the system is the steam distribution section, which connects directly to the tofu cooking vessels. This subsystem is specifically designed to deliver saturated steam in a consistent and evenly dispersed manner, enabling controlled heat application without exposing the cooking process to direct combustion. By eliminating open flames near the product, the system enhances both hygiene and safety.

Altogether, these subsystems form a unified thermal system that is efficient, safe, and maintainable. The modular design not only facilitates ease of fabrication and repair but also allows the system to be adapted for varying scales of production-ranging from home industries to semi-industrial tofu processing facilities. This flexibility ensures that the system can be integrated seamlessly into existing workflows while providing a significant upgrade in terms of performance and safety. Horizontal boiler design, parts, and the installation plan can be seen in Fig. 1, 2, and 3.

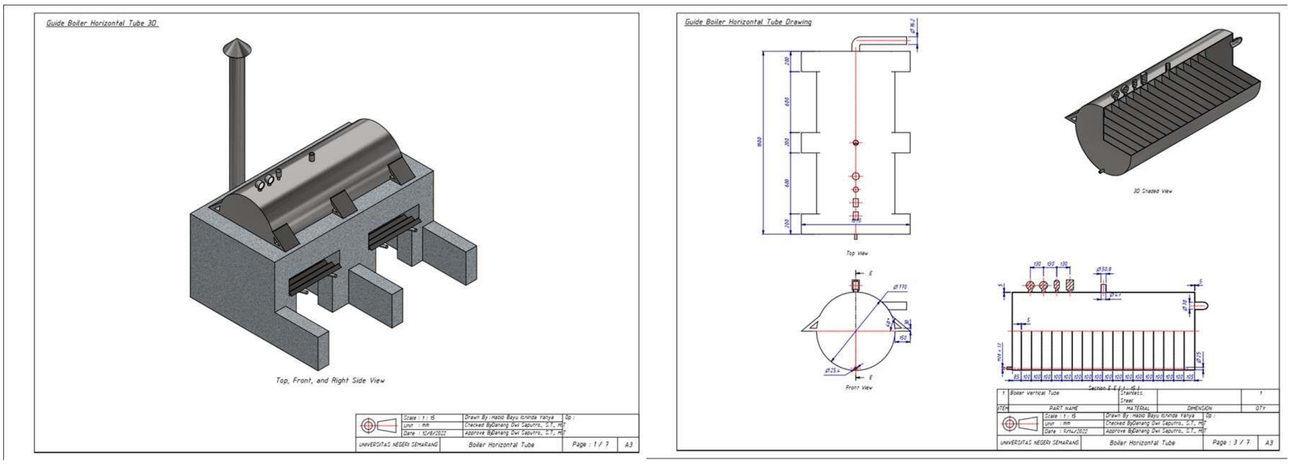

Figure 1. Horizontal Steam Boiler

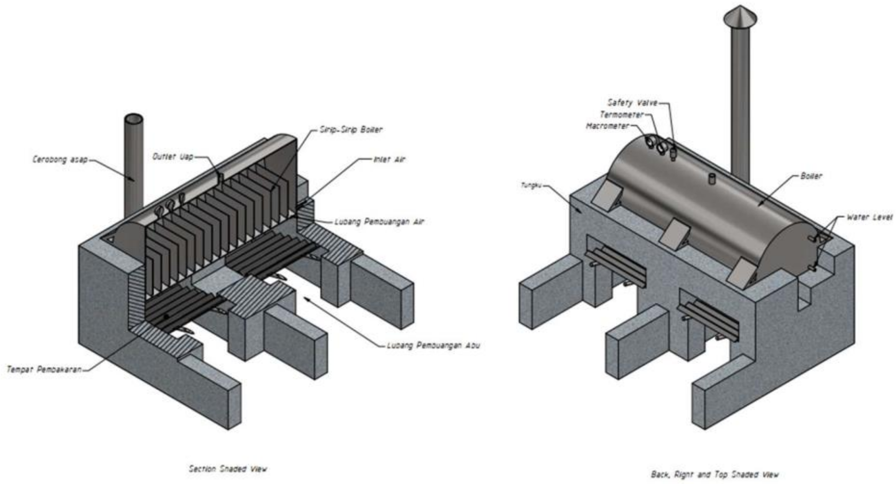

Figure 2. Horizontal Steam Boiler Parts

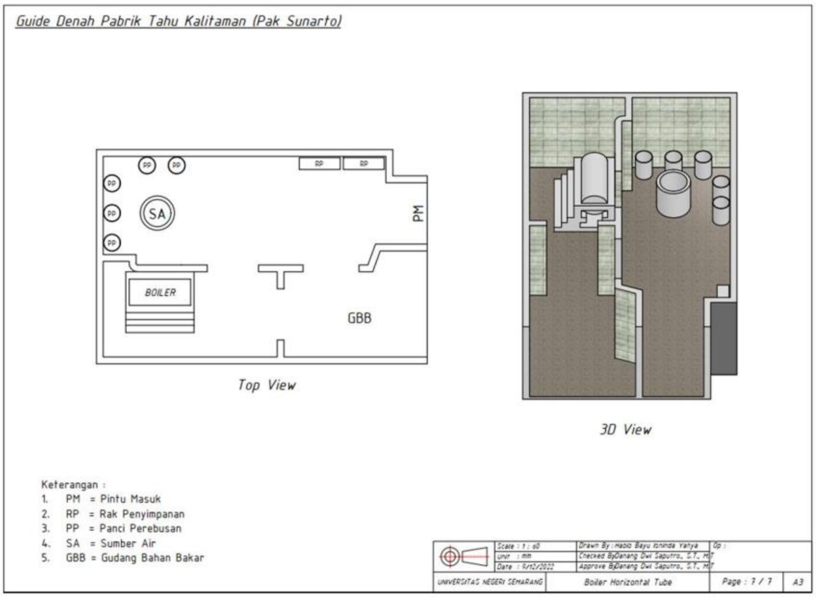

Figure 3. Boiler Installation Plan with Boiling Pot

As shown in Figure 1, the horizontal steam boiler consists of a cylindrical chamber designed to contain high-pressure steam. The combustion chamber located beneath the vessel is insulated with refractory cement to optimize heat retention. Figure 2 details the internal components, including the steam outlet, water level indicator, and safety valve. Meanwhile, Figure 3 illustrates the complete system installation, demonstrating the connection between the boiler and the tofu boiling pot, ensuring efficient steam distribution during cooking.

3.2 Material

Material selection plays a crucial role in both performance and safety. Stainless Steel 304 was selected for the main body and internal fins due to its corrosion resistance, thermal stability, and food-grade properties. The vessel wall thickness was specified at 5 mm to withstand the design pressure with sufficient safety margin, as per ASME Boiler and Pressure Vessel Code Section VIII guidelines [9]. Other components such as the combustion chamber were constructed using cas refractory cement to withstand high localized temperatures while providing thermal insulation. Supporting components include:

1. Safety Valve: Brass, ½” diameter, max pressure 10 bar
2. Steam Pipe: ½” diameter rated for high-temperature service
3. Cooking Vessel: Stainless Steel 304, 5 mm thickness
4. Instrumentation: Thermometer and pressure gauge with ½” threads, providing continuous monitoring

3.3 Structural Analysis

Stress and displacement were analyzed using classical thin-walled pressure vessel theory to estimate the structural response under internal pressure, a theoretical calculation of stress and displacement on the boiler shell was carried out using classical thin-walled pressure vessel theory. This method assumes a homogeneous cylindrical shell subjected to uniform internal pressure and neglects stress concentration effects from nozzles or local geometry. The objective is to validate the general magnitude of the numerical results obtained a theoretical calculation. Based on classical design equations found in Roark’s Formulas for Stress and Strain [10] and Mechanics of Materials [11], the theoretical estimation of Von Mises stress and radial displacement in thin-walled cylindrical pressure vessels can be calculated using the following formulas (1), (2), (3), and (4).

Hoop stress

$$\sigma_h = \frac{P \times r}{t} \tag{1}$$

$$\sigma_h = \frac{0.4 \cdot 10^6 \times 0.3}{0.005}$$

$$\sigma_h = 24\ MPa$$

Longitudinal stress

$$\sigma_l = \frac{p \times r}{2t} \tag{2}$$

$$\sigma_h = \frac{0.4 \cdot 10^6 \times 0.3}{2 \times 0.005}$$

$$\sigma_h = 12\ MPa$$

Von Mises equivalent stress

$$\sigma_{vm} = \sqrt{\sigma_h{}^2 - \sigma_h \times \sigma_l + \sigma_l{}^2} \tag{3}$$

$$\sigma_{vm} = \sqrt{(24)^2 - (24) \times (12) + (12)^2}$$

$$\sigma_{vm} = \sqrt{432}$$

$$\sigma_{vm} = 20.78\ MPa$$

Radial displacement of the cylindrical shell

$$\delta = \frac{P \times r^2}{E \times t} \times (1 \times v) \quad (4)$$

$$\delta = \frac{0.4 \cdot 10^6 \times 0.3^2}{1.93 \cdot 10^5 \times 0.005} \times (1 - 0.3)$$

$$\delta = \frac{0.036}{965} \times (0.7)$$

$$\delta = 2.6 \cdot 10^{-5} m \approx 0.026\ mm$$

From the theoretical calculations using classical thin-walled pressure vessel formulas, the boiler shell subjected to 4 bar internal pressure is estimated to experience a Von Mises stress of approximately 20.78 MPa, which remains well below the typical yield strength of Stainless Steel 304. Additionally, the predicted radial displacement is around 0.026 mm, indicating minimal elastic deformation under the given loading. These results confirm that, under the assumed conditions, the structural response of the boiler remains within safe elastic limits and adheres to fundamental mechanical design criteria.

4 Conclusion

This research aims to design and develop a safe boiler for the tofu industry using Autodesk Inventor and ASME design standards. The research methods used are Research and Development, with data obtained through theoretical calculations based on pressure vessel design principles. The results of the study show that the specification of a horizontal steam boiler with an operating steam pressure of 2 bar and a design pressure 4 bar, with dimensions of 600 mm diameter and 1200 mm length, using 5 mm Stainless Steel Plate 304.

Descriptive analysis was used as the data analysis technique, while Autodesk Inventor was employed solely for visualizing the boiler design in 3D. This research can assist the tofu industry in improving production quality and minimizing the risk of damage to the tofu during processing. In addition, this study introduces a new boiler design that incorporates internal fins, an element not commonly found in market-available boilers. These fins are intended to enhance heat transfer efficiency during the water heating process. The implementation of steam boilers in tofu factories ensures more hygienic tofu production.

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