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Effect of Baglog Quantity on the Thermal Efficiency of a Steamer for Oyster Mushroom Sterilization

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ABSTRACT

Baglog sterilization is a crucial step in the oyster mushroom cultivation process to ensure that the growing medium is free from microbial contamination. This study aims to determine the effect of baglog quantity on the thermal efficiency of the steamer during the sterilization process. The number of baglog used varied at 5, 7, 10, and 14 units. The observed parameters included thermal efficiency, specific fuel consumption (SFC), and sterilization temperature. The results showed that increasing the number of baglogs is directly proportional to the increase in thermal efficiency and the decrease in sterilization temperature. The highest thermal efficiency of 6.49% was achieved with 14 baglog at the lowest sterilization temperature of 111°C, while the lowest efficiency of 3.10% occurred with 5 baglog at 135°C. SFC values also decreased as the number of baglog increased, from 0.0006278 kg/kJ at 5 baglog to 0.0003002 kg/kJ at 14 baglog. The decrease in SFC and temperature indicates that heat utilization becomes more optimal with a higher number of baglogs. Therefore, increasing the number of baglogs during sterilization can significantly improve the thermal efficiency of the steamer.

Keywords: *Baglog Steamer, Baglog Sterilization, Thermal Efficiency*

1. INTRODUCTION

Energy use in Indonesia continues to increase every year, in the industrial sector itself according to data from the Ministry of Energy and Mineral Resources, energy consumption in 2023 amounted to 556,638,954 Barrels of Oil Equivalent (BOE), an increase of 8.78% from 2022 [1]. Such massive energy use contributes significantly to primary energy supply. For LPG consumption alone in 2023 amounted to 74,254 thousand BOE. This shows how important energy sources are in various sectors of activity. So that it pressures to have to continue to contribute to supporting the National Energy Policy (KEN) contained in PP No. 79/2014 on improving energy efficiency. This energy saving is emphasized in all industrial sectors. So that the realization of this is not limited to large-scale industries only, it is also still pursued at every scale of industry, both small and medium.

One of the industrial sectors that face challenges in terms of energy consumption is the oyster mushroom cultivation industry, especially in the sterilization process which requires continuous heat supply from fuel for several hours. This sterilization process is generally carried out with a hot steam system that generally utilizes Liquefied Petroleum Gas (LPG) fuel as a source of thermal energy [2]. This sterilization process is very crucial because it concerns the success of the cultivation process, but it is often carried out without considering optimal energy efficiency due to the lack of control over operating parameters such as the type of fuel used, tool design and inappropriate load capacity. This results in high LPG consumption, increased operational costs and unnecessary emissions.

Based on data from the Directorate General of Horticulture (2023) the production of oyster mushrooms in Indonesia in 2021 was 69,243 tons and experienced a decrease in 2022 to 52,776 tons [3]. The main cause of this decline in productivity is that the sterilizers used do not meet the standards [4]. In the field, many farmers still rely on conventional methods such as the use of used drums that are modified. However, this method experiences obstacles such as uneven heat distribution, inconsistent sterilization duration, and high fuel consumption which results in increased production costs and the risk of sterilization failure [5]. The sterilization process using a simple device in the form of a vessel from a used drum heated with an LPG furnace/gas cannot reach the sterilization temperature (100°C) and the heating time is too long (6-8 hours) [6]. In the conventional sterilization process, the sterilization time reaches 9 hours. Meanwhile, testing using modified equipment shortens the sterilization process to 4 hours [7]. Research on the comparison of

performance between a special baglog steamer and a traditional drum as sterilization tools. The results show that the steamer has a heat efficiency of around 51.91% and is capable of producing a maximum sterilization level of up to 100% [5]. The addition of a steam boiler system to the sterilization equipment has the effect of reducing microbial contamination in the baglog sterilization process. Test results show that the contamination level is below 10%, with an average contamination level of 4.34% at an optimal temperature of 120°C and a steam pressure of 1.9 Bar [8].

In the absence of empirical studies that explicitly examine the relationship between baglog quantity and steamer thermal efficiency, it is necessary research that is able to answer this technical question systematically. This study aims to fill the void by conducting experimental testing of variations in the number of baglogs fed into the steamer and their impact on thermal efficiency, in order to obtain a fuel-efficient operating configuration that is still effective in achieving the required sterilization temperature.

2. MATERIAL AND METHODS

This research was conducted at the Energy Engineering Laboratory of Sriwijaya State Polytechnic.

2.1 Material

The materials used are oyster mushroom baglogs, LPG gas, and feed water. The equipment used is a baglog steamer and thermogun.

2.2 Methods

This research involves the following variables: Fixed Variable: baglog mass 1.3 kg, sterilization time 4 hours, feed water 24 liters, LPG fuel. Free Variable: variation in the number of baglogs: 5, 7, 10, 14.

Thermal efficiency is a measure of the extent to which heat energy entering a system can be effectively utilized to produce work or achieve a specific process objective. This efficiency is usually expressed as a percentage, which indicates the ratio between the energy utilized and the total energy supplied. Thermal efficiency can be calculated using the following equation [10]:

$$\eta = \left(\frac{Q\ Utilized}{Q\ Supply}\right) \times 100\%$$

where:

η : Efficiency Thermal (%)
Q Utilized : Amount of heat energy used (Btu)
Q Supply : Total heat energy supplied to the system (Btu)

Specific Fuel Consumption (SFC) is a measure of fuel efficiency in generating a certain amount of energy [7]. The lower the SFC value, the more efficient the fuel usage. SFC is measured by calculating the amount of fuel used over a specific period of time and comparing it to the amount of energy produced during the same period [9]. The specific fuel consumption value can be calculated using the following equation [7]:

$$SFC = \left(\frac{Fuel\ Conmsuption\ (kg)}{Q\ Utilized\ (kJ)}\right)$$

Where:

SFC : Specific Fuel Consumption (kg/kJ)

3. RESULT AND DISCUSSIONS

This study aims to analyze the effect of the number of baglogs on the thermal efficiency of the steamer in the sterilization process with variations of 5, 7, 10 and 14 baglogs within 4 hours. The actual data obtained then performed calculations and analysis to determine the thermal efficiency, SFC value and temperature achievements of the sterilization process. The research data can be seen in Table 1.

Table 1. Research Result Data

Number of baglogs	Efficiency Thermal (%)	SFC (kg/kj)	Temperature (°C)
5	3,10	0,0006278	135
7	4,17	0,0004675	133
10	5,39	0,0003617	125
14	6,49	0,0003002	111

3.1 Effect of the Number of Baglogs on Thermal Efficiency

Thermal efficiency is a form of comparison between useful heat in a process system to the amount of heat supplied to the system (Laila et al., 2024). The effect of the number of baglogs on thermal efficiency can be seen in Figure 1.

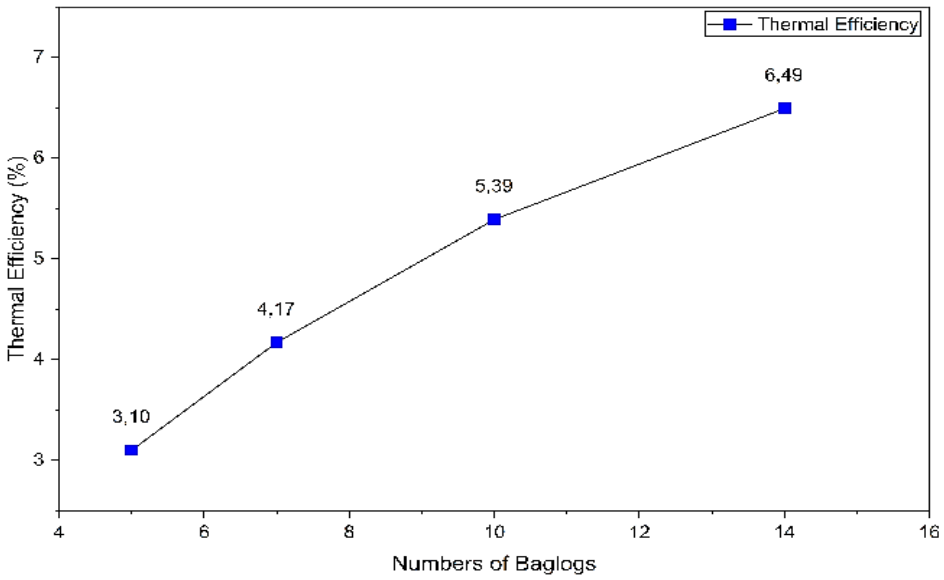


Figure 1. Effect of Baglog Quantity on Steamer Thermal Efficiency

When the steamer operates with a capacity of 5 baglogs, the total mass of the heated baglog is only 6.5 kg, so the heat absorbed by the baglog at this capacity is 1811.78 Btu with a resulting thermal efficiency of 3.10%. The heat used in this sterilization process is the sensible heat absorbed into the baglog. When the steamer is operated at a capacity of 7 baglogs the thermal efficiency generated is 4.17%. This increase in mass directly correlates to an increase in efficiency because the amount of mass heated will be directly correlated to Q or heat utilized. The total mass at a capacity of 7 baglogs is 9.1 kg so that based on the calculation of sensible heat the total heat utilized is 2433.03 Btu.

When operating with 10 baglogs the thermal efficiency increased by 1.22%. This increase is slightly greater than before which was only 1.07%. This is due to a greater increase in mass than the previous amount. The range of differences from the number of 5 baglogs to 7 is only a difference of 2 baglogs or 2.6 kg. While the increase from the number of 7 baglogs to 10 baglogs is a difference of 3 baglogs or 3.9 kg. So that the increase in total heat utilized in 10 baglogs also becomes slightly greater than the number of 7 baglogs. When the steamer is operated at maximum capacity, namely 14 baglogs, the increase in efficiency is not too large, namely only 1.1%, even though technically the increase in this number is greater than the previous variable which allows a greater increase in efficiency as well. This is due to the achievement of temperatures at full capacity being lower than before. This increase in mass does increase the total heat utilized but based on research data, this mass increase also reduces the sterilization temperature achievement which affects the temperature difference value (ΔT), which will be used to calculate the heat utilized [9].

Based on the graph of the research results above, it shows that the variation in the number of baglogs carried out is directly proportional to the thermal efficiency of the baglog steamer. The more baglogs that are sterilized will absorb more heat as well, so that the total heat utilized will be greater in number. But it should also be noted, in addition to reducing the thermal efficiency of the steamer, it will certainly affect the results of sterilization if it is not well managed in its optimal temperature range. In addition to the mass and temperature of the baglog, the heat capacity (Cp) of the material will also be affected if the composition of the media composing the baglog is different because Cp is a value that refers to the amount of heat or energy needed to raise the temperature of the material per unit mass [10]. However, this study did not further review how the effect of material composition on baglogs on the efficiency of the steamer, because the baglogs used in each process are the same, so the Cp contribution is also the same.

3.2 Effect of Baglog Quantity on Specific Fuel Consumption

The effect of the number of baglogs on Specific Fuel Consumption can be seen in Figure 2.

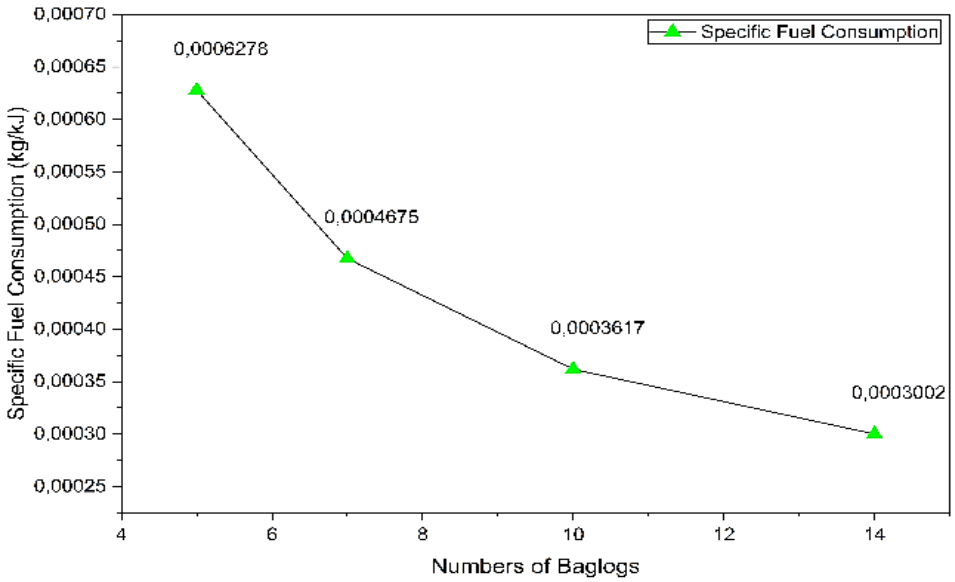


Figure 2. Effect of Baglog Quantity on Specific Fuel Consumption

Based on the figure 2, the SFC value is the smallest when the steamer operates with 14 baglogs with an SFC value of 0.0003002 kg/kJ. This value is getting smaller if the heat utilized is getting bigger, because this heat is used as a dividing factor in fuel consumption in the process. With heat of 3964.329 kJ at full capacity and 3344.925 kJ at 10 baglogs, the SFC value will tend to be smaller at full capacity of 14 baglogs. With fuel consumption tending to be the same within 4 hours of sterilization process. The energy utilized will still be different because the heat received depends on the amount of mass being heated. This applies equally to each of the previous variables, which means that efficiency will continue to be in line with the SFC value.

The more efficient the energy use of a process system, the better the fuel savings. This is what causes the SFC value when sterilizing 5 baglogs is greater because the comparison energy is smaller than when 14 baglogs. Of course this SFC value will be inversely proportional to the amount of mass in one sterilization cycle [11]. And it can be ascertained that the sterilization process with maximum capacity can save fuel usage in each sterilization cycle. The more baglogs that are sterilized, the smaller the SFC value is because the more baglogs, the greater the mass that receives the heat transferred. A smaller SFC value indicates that fuel usage in a process is more efficient [11].

3.4 Effect of Baglog Quantity on Sterilization Temperature

The effect of the quantity of baglogs on the sterilization temperature can be seen in Figure 3.

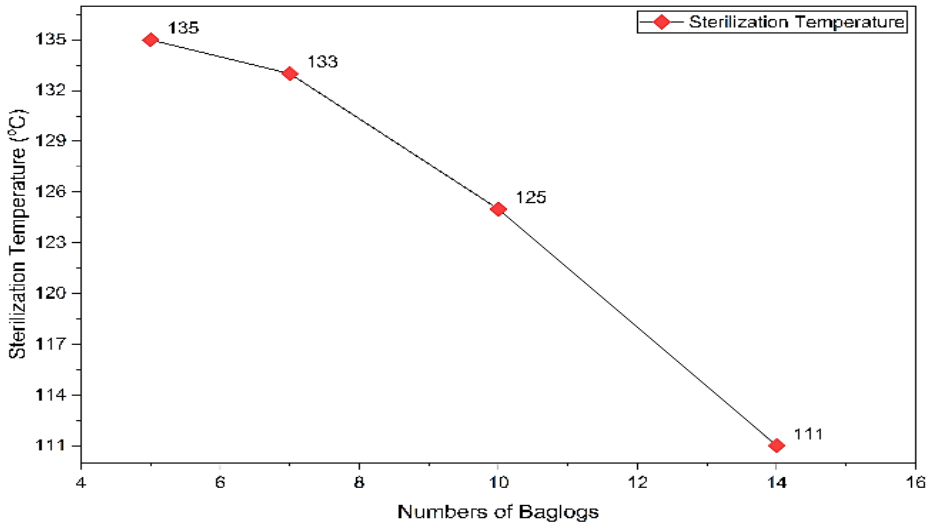


Figure 3. Effect of the Quantity of Baglogs on the Sterilization Temperature

Based on the figure 3, it shows that the more baglogs in the sterilization chamber, the lower the final temperature achieved. This is due to the increased energy requirement to heat a larger mass in the same amount of time. At a capacity of 5 baglogs, the temperature can reach 135°C due to the lighter heating load. Conversely, with a larger number of baglogs, the final temperature is lower because the available energy must be distributed over a larger mass. To achieve the same temperature, a larger energy supply or longer sterilization time is required.

Additionally, increasing the number of baglogs expands the surface contact area, affecting steam heat distribution, accelerating condensation, and disrupting steam distribution within the sterilization chamber [12]. Previous studies have shown that under full load conditions, steam flow becomes slower and uneven, leading to a decrease in average temperature and the formation of cold spots, particularly in the lower central part of the chamber. Conversely, too few baglogs can cause excessively high temperatures and damage the nutritional quality of the medium [13]. Therefore, steamer design optimization must consider the ideal baglog capacity, heat distribution efficiency, and precise heating time and energy settings. The more baglogs that are put in the steamer, the total energy required to reach the target temperature increases so that the steam temperature tends to be lower. Consequently, the formation of condensate will be faster and result in the formation of cold spots, especially in the area below the center. However, if the smaller number of baglogs in the steamer without optimal thermal loading can make the sterilization temperature very high and can cause degradation of nutrients in the baglog.

4. CONCLUSIONS

The steamer baglog achieves the highest efficiency when operating at full capacity, namely 14 baglogs, with thermal efficiency reaching 6.49%. The lowest efficiency is achieved when operating with only 5 baglogs. These results show that the number of baglogs is directly proportional to efficiency; the greater the thermal load during the sterilization process, the higher the energy efficiency.

The highest SFC occurs at a steamer capacity of 5 baglogs, because the heat energy used is only for a small mass, resulting in low efficiency. Conversely, when the number of baglogs is at its maximum, fuel consumption per unit of energy utilized becomes smaller, indicating higher combustion efficiency. Thus, sterilization at full capacity is more fuel efficient per process cycle.

The increase in the quantity of baglogs causes a decrease in the average sterilization temperature in the steamer chamber. The increase in the quantity of baglogs enlarges the contact surface area between the hot steam and the media, thereby accelerating the condensation process and lowering the average sterilization temperature. However, the results of the study show that even at full capacity, the baglog steamer is still able to maintain the sterilization temperature well.

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