Experimental Study of Tofu Processing Using a Horizontal Mini Boiler Fueled by Wood and Coconut Shell

First Aut Abdul Gafur, Erwin Martinis

Majoring in mechanical engineering Bengkalis State Polytechnic Indonesia
Abdulgafur@polbeng.ac.id, erwin@polbeng.ac.id

Abstract.The use of boilers in the tofu processing process is very helpful for Small and Medium Enterprises (SMEs). Heating using a boiler shows a greater increase in efficiency compared to using conventional methods. The use of a vertical boiler is considered less efficient for use in the tofu processing process because the steam capacity is relatively small and runs out quickly, this is possible because the heating area is also limited. Therefore, a horizontal boiler is used to increase the heating area so that the steam needed is sufficient to process the tofu. Apart from that, fuel also has a big influence on the boiler heating system. The aim of this research is to see how much energy efficiency the fuel used in horizontal boilers for cooking tofu has. The fuel used in this research was wood and coconut shells. The method used in this research is an experimental method by varying two types of raw materials and varying the air input for each fuel used. The changing parameters seen are the length of the tofu cooking process, distribution throughout the combustion chamber, steam capacity and steam pressure and energy efficiency. fuel used. The research results show that this horizontal boiler has steam production capacity, temperature and steam pressure distribution, energy efficiency and higher specific costs of steam production using coconut shell fuel which is better than wood fuel. This means that using wood fuel is cheaper but provides better performance. lower. The method used in this research is an experimental method by varying two types of raw materials and varying the air input for each fuel used. The changing parameters seen are the length of the tofu cooking process, distribution throughout the combustion chamber, steam capacity and steam pressure and energy efficiency. fuel used. The research results show that this horizontal boiler has steam production capacity, temperature and steam pressure distribution, energy efficiency and higher specific costs of steam production using coconut shell fuel which is better than wood fuel. This means that using wood fuel is cheaper but provides better performance. lower. The method used in this research is an experimental method by varying two types of raw materials and varying the air input for each fuel used. The changing parameters seen are the length of the tofu cooking process, distribution throughout the combustion chamber, steam capacity and steam pressure and energy efficiency. fuel used. The research results show that this horizontal boiler has steam production capacity, temperature and steam pressure distribution, energy efficiency and higher specific costs of steam production using coconut shell fuel which is better than wood fuel. This means that using wood fuel is cheaper but provides better performance. lower.

Keywords: Mini Boiler: Know; Wood Fuel; Coconut shell fuel.

M. U. H. Al Rasyid and M. R. Mufid (eds.), *Proceedings of the International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023)*, Advances in Engineering Research 230,
https://doi.org/10.2991/978-94-6463-364-1_97

I. INTRODUCTION

Tofu is one of the side dishes consumed in Indonesia. One of the important stages in the process of making tofu is cooking the soybean porridge. Apart from determining the quality of the product, the cooking process is also the stage that requires the most energy. The process of boiling soybean porridge in the tofu industry is generally still carried out using conventional equipment by boiling using fire made from wood fuel. The tofu industry really needs a lot of heat energy. Using conventional methods is very wasteful of fuel. The best way to produce a heat source to heat tofu is from steam produced by a steam boiler. The boiler functions as an energy conversion device that converts chemical (potential) energy from fuel into heat energy. A boiler is a device used to produce water steam for a power source or for a heating process (Chattopadhyay, 2000). A boiler or steam boiler is a device in the form of a closed vessel that is used to produce steam. Steam is obtained by heating a vessel containing water with fuel (Yohana and Askhabulyamin, 2012). A boiler consists of 2 main components, namely: a) a kitchen (combustion chamber) as a tool for converting chemical energy into heat energy, and b) a vaporizer (evaporator) which converts combustion energy (heat energy) into steam potential energy (heat energy). . The heat source from the resulting combustion will be the focus of this research.

The use of biomass raw materials for burning boilers has been widely carried out, one of which was Saputra (2010) who conducted a study on the use of bagasse biomass (and comparison with coal) as boiler fuel at a steam power plant in Asembagus, Situbondo Regency. One of the studies on the use of palm shells as boiler fuel in the rubber industry was carried out by Bahrin et al. (2011). Other research has been carried out by Mahidin et al. (2014) regarding the combustion characteristics of several types of biomass in fluidized bed boilers. The results of burning three types of biomass: crab wood chips, areca nut shells and dry wood twigs, show that each type of biomass has its own combustion characteristics.

Mini boiler operational costs consist of fuel costs and electricity costs for the pump and blower control and starting systems. The biggest operational cost is fuel costs. Therefore, reducing the operational costs of mini boilers can be done by reducing fuel costs, namely by utilizing materials that are available for free or at relatively low prices available around SMEs that use mini boilers. As an agricultural country, potential fuel that can be used as fuel is agricultural waste, for example wood twigs/firewood, husks, coconut shells, charcoal.

This research aims to analyze the performance of a horizontal mini boiler using wood fuel and coconut shell fuel. Mini boiler performance testing includes capacity/quantity and quality of steam produced, energy efficiency of the mini boiler, and specific fuel costs for steam production (Rp fuel/kJ steam produced) for each type of biomass. It is hoped that the results of this research can be used as a basis for the wider application of mini boilers in SMEs by selecting the type of fuel available.

II. METHOD

The method used in this research is an experimental method (experimental study). The data collected is primary data from experiments supported by secondary data. The mini boiler used is a horizontal type mini boiler. The type of fuel combustion in this mini boiler is the down draft type, that is, the fire is sucked down the fuel pile. The primary data collected is mini boiler and fuel test data. Boiler test data includes steam production capacity (kg/hour) and steam quality (pressure and temperature) produced, fuel consumption and energy efficiency. The biomass used is wood and coconut shells. Biomass fuel data includes measurements of caloric content and moisture content. Secondary data collected relates to fuel, water and steam properties.

The research was carried out in the Department of Mechanical Engineering at the House of Production and Appropriate Technology. The analysis carried out was focused on determining the performance and energy efficiency of mini boiler technology. Steam boilers use more energy in the form of thermal energy, so the analysis carried out is also more related to thermal efficiency. Efficiency is calculated based on measurement/experimental data.

Mini boiler capacity is the ability of the mini boiler to produce steam per unit time, (kg steam/hour). The capacity of the mini boiler is analyzed based on the results of measuring the amount of water input to the boiler, using the principle of conservation of mass (Equation 1).

$$\dot{m}_{air-masuk} = \dot{m}_{uap-keluar} \quad (1)$$

dimana:

$\dot{m}_{air-masuk}$ = laju massa air masuk ke *boiler*, kg/jam
$\dot{m}_{uap-keluar}$ = laju uap keluar dari *boiler*, kg/jam.

Boiler efficiency is a quantity that shows the relationship between the energy supply entering the boiler and the output energy produced by the boiler. In this research, what will be analyzed is fuel-to-steam efficiency. One way that is considered the most effective to determine boiler performance more precisely is to calculate its fuel-to-steam efficiency (also known as fuel efficiency). Apart from paying attention to the effectiveness of the boiler as a heat exchanger (thermal efficiency), calculate the boiler's fuel efficiency. also pay attention to losses due to radiation and convection heat transfer. Boiler fuel efficiency pays very careful attention to the amount of fuel consumed, so it is very appropriate to use as material for boiler economic analysis. To measure fuel-to-steam efficiency, it is done using a direct method. The direct method, or also known as the input-output method, is carried out by directly comparing the heat energy absorbed by water so that it changes phase to water vapor (output energy), with the heat energy produced by burning fuel in the boiler combustion chamber (input energy). A simple formulation of the direct method calculation (Equation 2).

$$\eta_{bahanbakar} = \frac{Q_{steam}}{Q_{bahanbakar}} \times 100\% = \frac{\dot{m}_{steam}(h_g - h_f)}{\dot{m}_{bahan\ bakar}\ GCV} \times 100\% \qquad (2)$$

dimana,

$\eta_{bahanbakar}$: Efisiensi bahan bakar *boiler* (%)
Q_{steam} : Energi panas total yang diserap uap air (kalori; Joule)
$\dot{m}_{steam}$: laju massa uap air keluar *boiler* (kg/jam)
h_g : Entalpi uap keluar *boiler* (kJ/kg)
h_f : Entalpi air masuk *boiler* (kJ/kg)
$Q_{bahanbakar}$: Energi panas yang dihasilkan dari pembakaran bahan bakar (kalori; Joule)
$\dot{m}_{bahan\ bakar}$: laju massa kebutuhan bahan bakar (kg/jam)

GCV : *Gross Calorific Value* atau nilai kalor spesifik bahan bakar (kkal/kg)

Specific fuel costs for steam production are the fuel costs required to produce each unit of energy contained in steam (Rp fuel/kJ steam produced). This cost analysis can be calculated using (equation 3).

$$BBS = \frac{\text{harga}_{\text{bhnbakr}}\ \dot{m}_{\text{bhnbakr}}}{\dot{m}_{steam}(\text{h}_g - \text{h}_f)} \qquad (3)$$

Dimana:

BBS : biaya bahan bakar spesifik produksi uap, Rp/kJ uap
$\text{harga}_{\text{bhnbakr}}$: harga bahan bakar, Rp/kg
$\dot{m}_{\text{bhnbakr}}$: konsumsi bahan bakar, kg/jam
$\dot{m}_{\text{steam}}$: laju massa uap air keluar *boiler* (kg/jam)
h_g : Entalpi uap keluar *boiler* (kJ/kg)
h_f : Entalpi air masuk *boiler* (kJ/kg)

The steps for collecting mini boiler test data start from filling the mini boiler with water to the maximum filling limit, then preparing the biomass fuel to be used with a certain mass which is estimated to be sufficient to operate the mini boiler for approximately 2 hours. Biomass fuel is introduced gradually into the mini boiler combustion chamber and for the heating process to occur, the steam outlet valve is still closed. The water filling system is set automatically, so that the water filling pump into the boiler turns on automatically when the water level in the mini boiler reaches the minimum point. This stage is called start-up, turning on the mini boiler until the steam produced reaches a pressure of 2 bar gauge and is ready to be used in the tofu cooking process. The time required for start up is recorded. After the steam pressure reaches 2 bar, the steam outlet valve is opened, and this is recorded as the start of the temperature and steam pressure measurements. The resulting temperature and steam pressure were recorded every 5 minutes for a total of 60 minutes of measurements. The total fuel used is measured by weighing the remaining fuel remaining. The amount of steam produced is measured by the amount of water filled into the mini boiler. The amount of water filled into the mini boiler is read from changes in the height of the water column in the mini boiler. All stages are carried out for each type of fuel. [7]. The total fuel used is measured by weighing the remaining fuel remaining. The amount of steam produced is measured by the amount of water filled into the mini boiler. The amount of water filled into the mini boiler is read from changes in the height of the water column in the mini boiler. All stages are carried out for each type of fuel. [7]. The total fuel used is measured by weighing the remaining fuel remaining. The amount of steam produced is measured by the amount of water filled into the mini boiler. The amount of water filled into the mini boiler is read from changes in the height of the water column in the mini boiler. All stages are carried out for each type of fuel. [7].

III. RESULTS

Steam Production Capacity

The first test was carried out by looking at the comparison of the steam capacity of a mini boiler using firewood (mangrove) and coconut shells as shown in Figure 1.

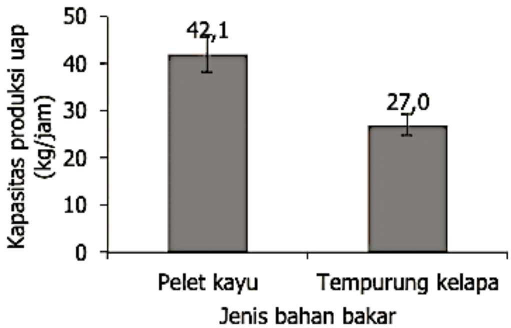

Figure 1. Mini boiler steam production capacity using wood and coconut shell fuel.

Operation using wood pellets requires a start up time (initial heating) of 21 minutes, the amount of fuel is 3.87 kg. Average fuel consumption is 10.85 kg/hour with a wood pellet calorific content of 4,111 kcal/kg. Steam production capacity 42 kg/hour. Operation using coconut shells requires a start up time (initial heating) of 31.5 minutes, the amount of fuel is 3.6 kg. Average fuel consumption is 6.93 kg/hour with a shell calorific content of 4194 kcal/kg. Steam production capacity 27 kg/hour. From the experimental results it can be seen that the boiler steam production capacity is directly proportional to the rate of fuel energy input. This is in accordance with experiments conducted by Firdaus & Sirait (2015) that the boiler steam production capacity is directly proportional to the fuel consumption rate for using the same type of fuel.

Temperature and Pressure of the Resulting Vapor

The steam produced by this mini boiler is saturated steam. The temperature and steam pressure produced by a mini boiler using wood pellet fuel is shown in figures 2 and 3.

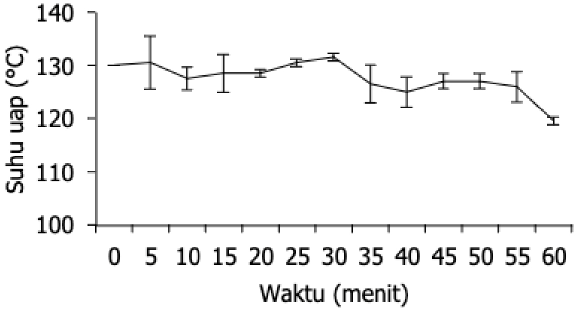

Figure 2. Temperature distribution of steam produced for 1 hour by a mini boiler with wood fuel

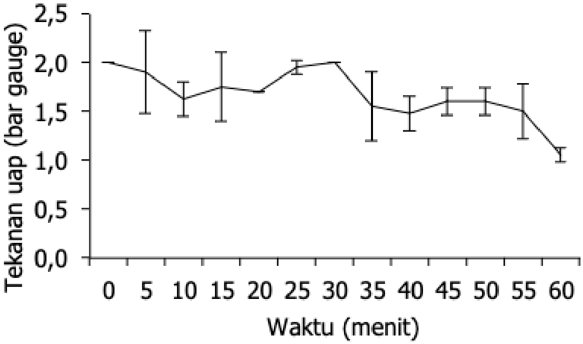

Figure 3. Steam pressure produced for 1 hour by a mini boiler with wood fuel

The temperature and steam pressure produced are relatively stable, namely in the temperature range of 120 °C - 130 °C with a steam pressure of 1.1 - 2.0 bar gauge. The temperature and pressure of the steam produced by a mini boiler using coconut shell fuel is shown in Figures 4 and 5. When the temperature and pressure are opened, the temperature drops to 104 °C.

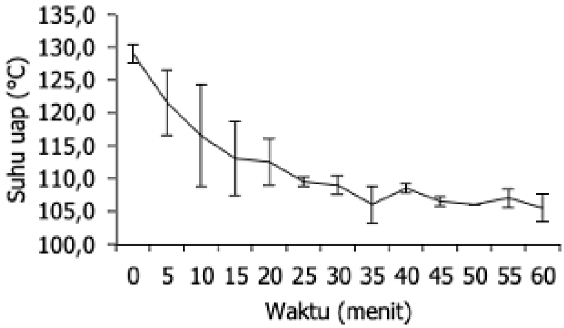

Figure 4. Temperature distribution of steam produced for 1 hour by a mini boiler fueled by coconut shells

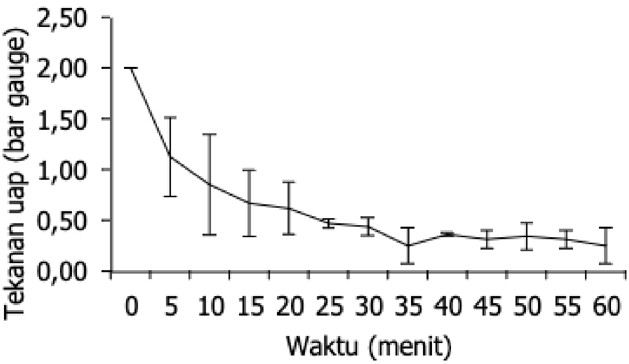

Figure 5. Steam pressure produced for 1 hour by a mini boiler fueled by coconut shells

Vapor pressure also decreased from 2.0–0.1 bar. Operations using coconut shells yielded less good results, this was because the combustion of the coconut shell experienced a slowdown in the combustion chamber after there was quite a lot of residual charcoal accumulated. The temperature and steam pressure produced by a mini boiler using coconut shell charcoal as fuel is less stable. After initial heating and the temperature reaches 130 °C, when the steam load is opened the temperature drops to 103 °C. Vapor pressure also decreased from 2.0–0.06 bar-gauge.

Observation results show that the temperature and pressure of the steam produced by the boiler are directly proportional to the rate of fuel energy input. This is in accordance with experiments conducted by Qamaruddin & Sikki (2016) that the temperature and pressure of the steam produced by the boiler is directly proportional to fuel consumption for the same type of fuel and the steam produced is less stable.

Energy Efficiency

The energy efficiency calculation carried out is fuel - water vapor efficiency (fuel-to-Steam). Regulagadda et al. (2010) in Barma et al. (2017) stated that the energy efficiency of boilers ranges from 20% to 92% depending on the type of fuel and the purpose of the boiler. The fuel efficiency of the mini boiler in this study is shown in Figure 6.

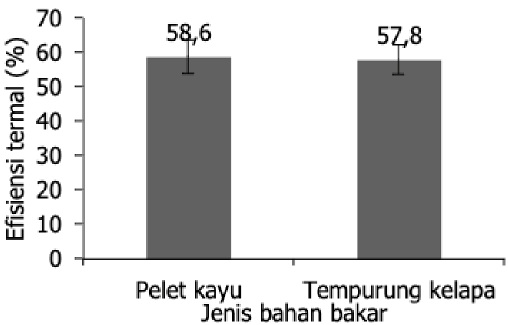

Figure 6. Thermal efficiency of a mini boiler using coconut shell and wood as fuel

The use of shell fuel has a lower efficiency compared to wood because when the shell burns, the flame shoots upwards, not all of it is sucked into the boiler. From the combustion chamber, there are many more heat losses to the environment through the combustion chamber door. Apart from that, the shell does not completely burn to ash, leaving a pile of charcoal in the combustion chamber.

The use of coconut shells also shows lower fuel efficiency, namely 49.76%. Even though the shell flame is relatively small in the form of coals with a small flame, unlike shell burning, the relatively dense and dense pile of shell charcoal flakes makes it more difficult for combustion air to be sucked into the boiler. The heat resulting from combustion actually loses a lot to the environment through the combustion chamber door. In addition, according to Gupta et al. (2011) in Barma et al. (2017) the presence of unburned carbon residue in the combustion chamber has a direct impact on reducing boiler energy efficiency. Even though it has a higher calorific value compared to wood pellets, the characteristics of shell combustion and the presence of piles of charcoal remaining from incomplete combustion cause poor performance results in this mini boiler which uses a downdraft burning system. If you are going to continue using these two fuels, you need to modify the combustion chamber. This result is also in line with Noviasri's (2012) statement that boilers using a mixture of shell fuel and shell charcoal in his research had low heat absorption effectiveness, resulting in low boiler performance.

Steam Production Specific Fuel Costs

The specific fuel costs for steam production are an important part of the total specific costs for steam production apart from other cost components, namely investment costs and maintenance costs (Lian et al., 2010). The specific fuel cost for steam production using shell fuel is cheaper, namely IDR 0.3/kJ compared to using wood pellet fuel, namely IDR 0.4/kJ. Meanwhile, the specific fuel cost for steam production using shells is more expensive, namely IDR 0.61/kJ. This calculation is based on market prices at the end of 2018, namely IDR 4,000/kg, IDR 3,000/kg and IDR 8,000/kg respectively for wood, shells and the cheapest use of coconut shells, however its use is only recommended for needs. small amount of steam, because the resulting temperature and pressure are relatively low. Cooking results per batch 10 kg soybeans, Using this mini boiler with shell fuel cannot meet the needs. The specific fuel costs in this study are generally still much more expensive than the specific costs of low pressure steam production presented by Lian et al. (2010), which is only 0.0150 $/kWh or the equivalent of IDR 0.06/kJ (assuming a dollar exchange rate of IDR 14,300).

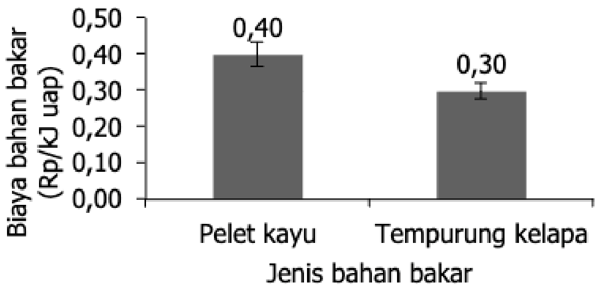

Figure 7. Fuel costs for mini boilers using coconut shells and wood

CONCLUSION

The horizontal type mini boiler in this study had higher performance and fuel costs when using wood fuel compared to using coconut shell fuel. Mini boilers using wood fuel have a steam production capacity of 42 kg/hour, steam temperature of 120 °C–130 °C with steam pressure of 1.1–2.0 bar-gauge, energy efficiency of 58.67% and specific fuel costs steam production IDR 0.4/kJ. Meanwhile, the use of coconut shell fuel in this mini boiler produces a steam production capacity of 27 kg/hour, steam temperature of 104 °C–129 °C with steam pressure of 0.1–2.0 bar-gauge, energy efficiency of 57.29% and cost specific fuel steam production Rp. 0.3/kJ.

ACKNOWLEDGMENTS

We would like to thank P3M Bengkalis State Polytechnic for funding this research, and thank the Mein Engineering department of Bengkalis State Polytechnic.

.

REFERENCE

1. Hanifah, U., Susanti, ND, & Andrianto, M.: (2019). Use of Agricultural Waste Biomass as Fuel in a 3 Pass Fire Pipe Type Mini Boiler. Agritech: Journal of the UGM Faculty of Agricultural Technology, 39(3), 200-206.
2. Sunaryo.: LH (2017). DESIGN AND CONSTRUCTION OF A KITCHEN STEAM BOOTHER, MINI FIRE PIPE, HORIZONTAL MODEL, TOUGHTER INDUSTRY SUPPORTING EQUIPMENT WITH BIOMASS FUEL TYPES. APTEK Journal, 9(1), 25-30.
3. Prastiyo.: VOE (2014). Design and Construction of a Mini Steam Boiler with a Capacity of 30 Liters/30 Minutes Combining Fire Pipe Type and Water Pipe Type. Simki, 1, 1-8.
4. Feri, F., Yahaya, HBI, Aleihydro, AA, & Prakoso, B.: (2023). Boiler Design for Modernization in the Tofu Industry Using Autodesk Inventor. Journal of Machine Innovation, 5(1), 1-6.
5. Hakim, L., & Subekti, P.: (2015). Design and Construction of a Mini Steam Boiler using the SNI Standard Approach Fueled by Palm Shells for the Needs of a Tofu Factory with a Capacity of 200 kg soybeans/day. Aptek Journal, 7(1), 45-52.
6. Kartika, AM, Setiawan, A., Suwandi, D., & Wardika, W.: (2018). Design and Construction of a Tofu Heating Boiler with a Capacity of 90 kW with a Gasification Furnace Fueled by Rice Husks. MECHANICAL, 8(2), 52-56.
7. Adnan, B.: (2019). DESIGN AND CONSTRUCTION OF A VERTICAL FIRE PIPE STEAM BOOTEL FOR THE TOFU INDUSTRY (Doctoral dissertation, University of Muhammadiyah Malang).
8. Oktaviani, E., Gafur, A., & Hajar, I.: (2021). Design of a Vertical Boiler for Distillation of Citronella Oil with a Steam Capacity of 100 Kg/Hour. INOVTEK-MACHINE SERIES, 1(2).
9. Agustira, R., Razi, M., & Syukran, S.: (2017). Design and Construction of a Vertical Fire Tube Boiler Made from LPG Gas for the Patchouli Oil Refining Process. Journal of Applied Science Engineering, 1(1), 57-60.
10. Putra, RC.: (2017). Design of a 5 M3 Capacity Pressure Vessel with a Design Pressure of 10 Bar Based on ASME 2007 Standards Section VIII DIV 1. Combustion Motors: Journal of Mechanical Engineering, 1(1).
11. Fatimura, M.: (2016). Boiler Water Quality Analysis Study Using American Society of Mechanical Engineers (ASME) Standards. Redox Journal, 1(1).
12. Suhatno, S., Yuwono, Y., Kusyanto, K., & Paid, A.: (2015, August). FBL-500 Boiler Performance at IEBE. In Proceedings of the 2015 EBN Research Results Seminar (pp. 328-334). Center for Nuclear Fuel Technology (PTBBN-BATAN).

13. Luthfi, M., Winarso, R., & Wibowo, R.: (2018). Design of a Boiler and Essential Oil Evaporation Tank in a Distillator Machine Using the Steam Method Made from Lemongrass Leaves (Cymbopogon Nardus). Crankshaft Journal, 1(1), 9-20.
14. Hakbar.: MA (2021). Boiler Working System.