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# CALCULATE ENERGY BALANCE IN POWER BOILERS USING BIOMASS TO DETERMINE ENERGY REQUIREMENTS

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**Abstract.** Boilers function to produce hot water or hot steam from combustion products to be converted as energy. Steam is used to drive turbines to produce electrical energy, apart from that steam is also used for heating. The boiler fuel uses biomass in the form of tree bark, namely acacia mangium. The aim of this study is to find out whether the process running in the Power boiler is good or not, it can be seen from its efficiency, so that the energy balance calculation is carried out on the Power boiler itself. Therefore, a study is needed to determine the energy balance of the unit. From the heat balance calculation, the heat data for producing steam was 1924,927,054 kcal, the latent heat of vaporization was 5732,620,038 kcal and the feed water heat was 11156296.65 kcal. So from the calculations obtained we can find out the energy balance in the boiler and the resulting Supply Steam Consumption

**Keywords:** Boiler, Energy Balance, Steam,

## 1. Introduction

Conventional energy in the form of oil, gas and coal is a non-renewable energy source. The increase in population influences the increase in energy consumption because the production process in industry increases to meet people's needs. Indonesia is a country where the majority of its industry still uses fossil fuels. Energy experts predict that in the future Indonesia will experience an energy crisis with the increasingly depleting fossil fuels. A boiler is a closed vessel where the heat of combustion is transferred to water until water vapor or steam is formed. The function of a boiler is to convert heat energy from fuel into heat energy in steam, consisting of three main parts, namely an economizer to heat the water to the phase transfer point, an evaporator to change the water phase into steam and a superheater to further heat the steam to a certain temperature. This unit has an incoming feed water capacity of 30 tonnes/hour (Ginanjar, Lubis, & Simanjuntak, n.d.). A boiler is a closed steel vessel where the heat of combustion is the formation of steam or steam in the form of work energy from the flow of water. Water is a useful and cheap medium for transferring heat to a process. Steam with a certain pressure and temperature has a high energy value and is then used to transfer heat in the form of thermal energy to the process (Parinduri & Arfah, 2019). Boilers are one type of Heat Exchanger (HE), where the use of the right ratio of fuel and combustion air in the HE can produce complete combustion and increase CO2 combustion gases so that fuel consumption can be saved and the efficiency of the HE also increases (Irawan, 2019). The factors that can influence thermal efficiency in boilers are flue gas temperature and fuel volatile ratio (Chao, Ke, Yongzhen, Zhitong, & Yulie, 2017), while (Gao, Qi, Lyu, Chen, & Huang, n.d.) states that controlling the boiler operation system online fuel feed, a combustion process that includes a ratio of fuel to combustion gases can improve thermal efficiency. Combustion is the simplest energy conversion method where the fuel is reacted with oxygen so that it decomposes the compounds contained therein and releases heat. In its application, the energy produced from combustion can be directly utilized by several sectors ranging from households, agriculture, transportation to industry. The industrial sector is the sector that consumes the most energy to carry out its operations, amounting to 3,691,993 terajoules, or around 53.4% of total energy consumption in Indonesia (Iswantyo et al., 2023). This energy is in the form of heat energy from combustion which can be used to generate electricity, dry industrial materials or as space heaters. Electricity generation is the first use of thermal energy, with coal occupying >50% of primary energy in thermal energy generation, the need for which continues to increase every year in line with consumption (Iswantyo et al., 2023). In the process, burning coal will produce more than 50% of global $CO_2$ emissions (Firdaus, 2021). Efforts to reduce $CO_2$ emissions have been made, one of which is by using new and renewable energy (EBT) such as biomass energy, energy originating from organic materials such as plants, animals and organic waste (Ang et al., 2022) which are environmentally friendly because of the carbon neutral principle. (Becker, Bouzdine-chameeva, & Jaegler, 2020). Currently, the potential for biomass energy in Indonesia is increasing every year with total biomass energy production amounting to 911,907 terajoules in 2022, but it is still very far compared to coal at 17,267,940 terajoules. The household sector occupies the largest use of biomass energy, followed by industry (Iswantyo et al., 2023). One of the government's efforts to encourage the use of biomass energy is through promoting energy plantation forests. The forest is an effort reservation of production forest areas specifically used to produce energy ("Optimalkan Hutan Tanaman Energi, Pemerintah Dorong Pembangunan PLTBm Di Pulau Halmahera," 2019). To reuse waste from cutting bark to be used in boilers, PT. X uses tree bark as fuel in the Power Boiler. Initially, the bark is sent from the drumbarker and stored in a shelter to the Power Boiler unit to be burned. The stages of the burning process are that the bark enters the Boiler and goes to the Bed Conveyer. Before the bark is put into the Boiler (Burning Room) there is sand which is used as a heating medium. The function of the Power Boiler is a place for the process of burning wood bark, but because it requires a high temperature in the furnace and produces a still high temperature in the Flue Gas, this condition is used to produce steam which is then used to spin a turbine which ultimately produces electricity. So in this research it is necessary to calculate the heat balance in the Power Boiler unit using wood bark as fuel.

## 2. Methods

a. Material Retrieval

The process of analyzing and retrieving the materials used was carried out at Industry X in the South Sumatra Province area during the 6 day operational period. The parameters taken are mass of bark (kg), composition of bark (%), temperature of incoming feed water (Celsius), temperature of bark before entering the boiler (Celsius), temperature of incoming air (Celsius), temperature in the flue gas after entering the boiler (Celsius), pressure of the steam produced (Kpa), temperature of the steam produced (Celsius), flue gas composition (%), Feed Water (tons/hour).

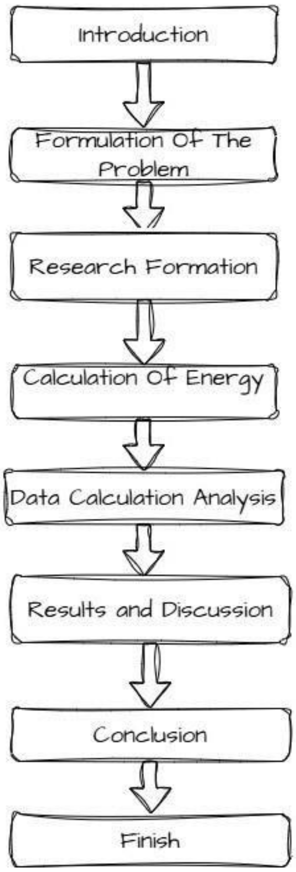


**Figure 1. Flowchart**

b. Systematic Calculations

Calculations are carried out using the energy method. The stages for calculating the mass balance value for a power boiler can be seen in Figure 2.

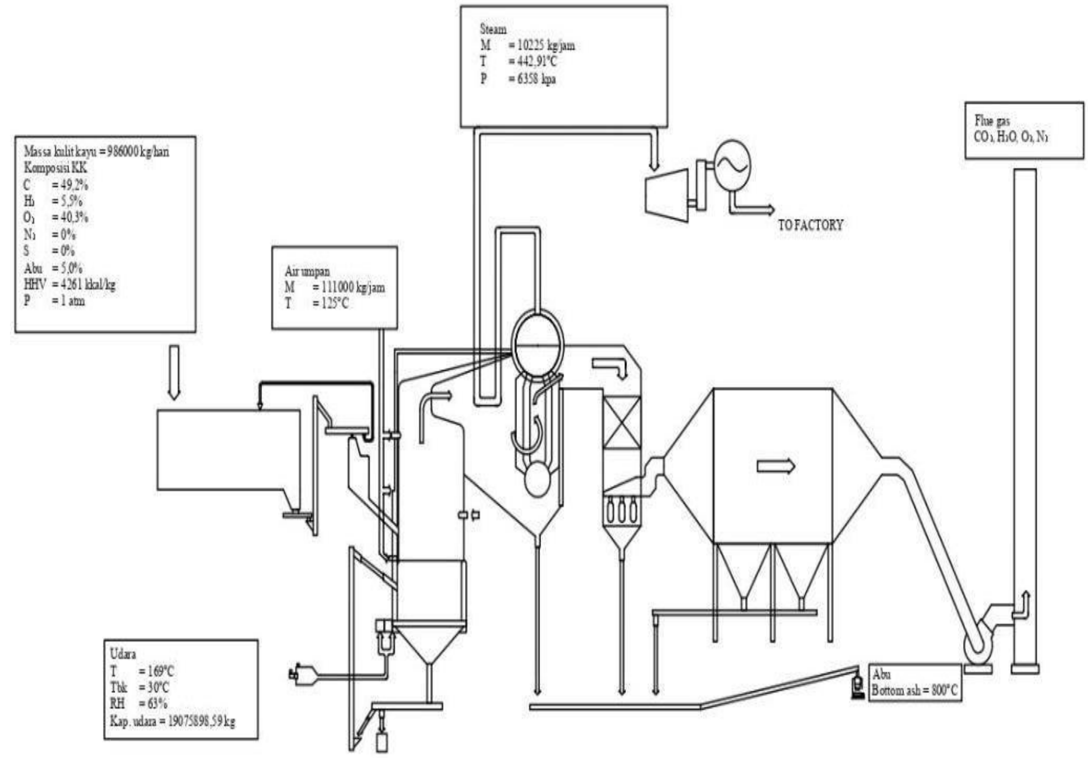


**Figure 2. Power Boiler**

1. **Heat Of Combustion Reaction ($\Delta H_{R,C}$)**

1.1. $Q_1$ = Standard Heat of Combustion of Fuel

**Table 1. Component Combustion Heat**

| Component | $-\Delta H°_{\in}$ (Kkal/Kmol) |
|---|---|
| C | 94,0518 |
| $H_2$ | 68,3174 |

Mol C = 40,426 kmol
$\Delta H°c, c = \Delta H°c \times$ n C
= 94,0518 kkal/kmol × 40,426 kmol
= - 3802138,067 Kkal
Mol $H_2$ = 27,115 kmol
$\Delta H°c$, H2 = $-\Delta H°_C \times$ n $H_2$
= - 68,3174 kkal/kmol × 27.115 kmol
= - 1852426,301 Kkal

1.2 $Q_2$ = **Heat of *Flue Gas* ($\Delta H_P$)**
$T_1$ = 25°$C$ + 273 = 298 K (temperature referen)
$T_2$ = 395,8°C + 273 = 668,8 K (temperature *flue gas*)

**Table 2. Values a, b, c Compensation (kcal/kmol) (K)**

| Component | A | B($10^{-3}$) | C($10^{-6}$) |
|---|---|---|---|
| $N_2$ | 6,457 | 1,389 | -0,069 |
| $O_2$ | 6,117 | 3,167 | -1,005 |
| $CO_2$ | 6,339 | 10,14 | -3,415 |
| $H_2O$ | 7,136 | 2,640 | 0,0459 |

Cp = $\alpha + \frac{b}{2}(T2 + T1) \; + \frac{c}{3}(T2^2 + T2.T1 + T1^2)$

$$Cp\,N_2 = 6{,}457 + \frac{(0{,}001389)}{2}(668{,}8 + 298) - \frac{0{,}000000069}{3}(668{,}8^2 + 668{,}8.298 + 298^2)$$

$$= 6{,}457 + 0{,}6714426 - \frac{0{,}000000069}{3}(735399{,}84)$$

$= 7{,}1115284$ Kcal/Kmol K

**Tabel 3. Gas Enthalpy Sensible Heat**

| Composition | Kmol | $\int Cp$ | ΔT (K) | Q (Kkal) |
|---|---|---|---|---|
| $CO_2$ | 40,426 | 10,4035458 | 370,8 | 155948743,7 |
| $O_2$ | 38834,99 | 7,4015689 | 370,8 | 106582697,9 |
| $N_2$ | 601799,8404 | 7,1115284 | 370,8 | 1586918936 |
| $H_2O$ | 69512,30848 | 8,4234276 | 370,8 | 217115227,7 |
| **Total** | | | | **2066.565.605** |

1.3 **$Q_3$ = Hot Air (ΔHR)**

Nair = 697209,31 Kmol

$T_1$ = 25℃ = 298°K (Temp. referen)

$T_2$ = 169℃ = 442°K (Temp. in)

Cp udara =

$$7{,}136 + \frac{2{,}64\,.\;10^{-3}}{2} \times (442 + 298) + \frac{0{,}0459 \times 10^{-9}}{3}(442^3 + (442 \times 298) + 298^2$$

= 8,119163025 kkal/kmol.K

Q = $n{\times}Cp{\times}(T_2 - T_1)$

= 697209,31 Kmol × 8,119163025 kkal/kmol.K × 144 K

= 815148871,3 kkal

1.4 **$Q_4$ = Heat Of Burning Bark**

$m_{bar}$ = 986.000 Kg

$HHV_{bar}$ = 4.261 Kkal/Kg Q

= m bark × HHV bark

= 986.000 Kg × 4,261 Kkal/Kg

= 4201.346.000 Kkal

1.5 **$Q_5$ = Laten Heat Of Vaporization (ΛH20)**

$\Delta H°_{H2O,}25°C$ = 44. 014 kJ/kmol (Hougem. 1943)

$Mol_{H20}$ = 27. 115 kmol

Laten Heat Of Vaporization ($\lambda_{H2O}$) = n × $\Delta H°_{H2O}$, 25°C

= 27.115 kmol × 44.014 $\frac{kj}{kmol}$

= 119.343.961 $kj \times \frac{1\ kkal}{4{,}18\ kj}$

= 285511868,4 $kkal$

$\boldsymbol{Q}$ = $\Delta H°_{R,C} = \Delta H°_{c,c} + \Delta H°_{C,H2} + \Delta H_P - \Delta H_R + HHV + , \lambda_{H2O}$

= ((-3802138,067)+(-1852426,301) + 2066.565.605 – 815148871,3+ 4201.346.000 + 2855118686,4) kkal

= **5732.620.038 kkal**

**2. Calculating The Heat Of The Feed Water**

T1 = 25°C $= 298\ K$ (T Referen)

T2 = 125°C $= 398\ K$ (T Feed Water)

T = 25°C hf = 104,89 kJ/kg

T = 125°C hf = 525,01 kJ/Kg

$Q_a$ = m × $(h_2 - h_1)$

= Mass feed water × $hf_{125°C} - hf_{25°C}$

= 111.000 kg × (325,01 – 104,89) kJ/Kg

= 46.633.320 kJ × $\frac{1\ kkal}{4{,}18\ kj}$

= 11156296,65 kkal

**3. Calculate The Heat Used To Produce Steam**

ms = 102,25 ton/jam = 2.454 ton/day

= 2,454.000 kg

P = 6358,583 Kpa = 6,358583 Mpa (source: P.L.2011 : 1-4)

Entalpy with pressure = 6 Mpa (source: Sutini P.L. 2011 : 1-4)

$H_{440C}$ = 3277,3 kJ/Kg

$h_{500c}$ = 3422,2 kJ/Kg

Entalpy with pressure = 8 Mpa (source: Sutini P.L 2011 : 1-4)

$h_{440c}$ = 3246,1 kJ/Kg

$h_{480c}$ = 3348,4 kJ/Kg

Interpolation for pressure 6 Mpa and temperature 442,91°C

$h_{6/442,91} = h_{440c+} \frac{(442{,}91-440)}{(500-440)} \times (h_{500c} - h_{440c})$

$= 3277{,}3 + \frac{(442{,}91-440)}{(500-440)} \times (3422{,}2 - 3277{,}3)$ Kj/Kg

= 3284,32765 kJ/Kg

Interpolation for pressure 8 Mpa and temperature 442,91°C

$h_{8/442,91} = h_{440c} + \frac{(442{,}91-440)}{(480-440)} \times (h_{480c-}\ h_{440c)}$

$= 3246{,}1 + \frac{(442{,}91-440)}{(480-440)} \times (3348{,}4 - 3246{,}1)$ kJ/Kg

= 3253,542325 kJ/Kg

Interpolation for pressure 6,358583 Mpa and temperature 442,91°C

$h_{6,358583/442,91} = h_{6/442,91} + \frac{(6{,}358583-6)}{(8-6)} \times h_{8/442,91} - h_{6/442,91)}$

= 3284,32765 + $\frac{(6{,}358583-6)}{(8-6)} \times (3253{,}5423225 - 3284{,}32765\ \frac{kJ}{Kg})$

$= 3278,808103$ kJ/Kg

$Q_S = ms \times h$

$= 2.454.000$ kg × 3278,808103 kJ/Kg

$= 8046.195.085 \text{ kJ} \times \frac{1\ kkal}{4{,}18\ kj}$

$= 1924.927.054$ kkal

## 3. Result And Discussion

The energy balance in a power boiler using biomass fuel is analyzed by measuring temperature of all components and identify the components present in the bark Components identified whether has latent or sensible heat. So calculations are carried out to determine calorific value or heat for each component. Results of energy balance analysis and calculations on a power boiler with wood bark fuel

**Table . 4. Composition Of Bark Moles**

| Component | Mass % | Mass (kg) | Mol (kmol) |
|---|---|---|---|
| $H_2$ | 5,5 | 54.320 | 27.115 |
| C | 49,2 | 4.855.112 | 40.426 |
| $O_2$ | 40,3 | 397.358 | 12417,4375 |
| $N_2$ | 0,0 | 0 | 0 |
| S | 0,0 | 0 | 0 |
| Abu | 5,0 | 49.300 | - |
| Total | 100 | 986.000 | 79958,4375 |

| Composition | | Input | Output |
|---|---|---|---|
| | | Mass (kg) | Mass (kg) |
| Bark | C | 485.112 | |
| | $H_2$ | 54.230 | |
| | $O_2$ | 397.358 | |
| | $N_2$ | 0 | |
| | S | 0 | |
| | Abu | 49.300 | 49.300 |
| | $H_2O$ | | |
| | Bark | 493.000 | |
| Air | $N_2$ | 16850395.53 | |
| | $O_2$ | 2.572.834 | |

| | | | |
|---|---|---|---|
| | $H_2O$ | 27015,5526 | |
| Exhaust Gas | $CO_2$ | | 1.778.744 |
| | $O_2$ | | 1.242.720 |
| | $N_2$ | | 16850395,53 |
| | $H_2O$ | | 1251221,553 |
| **Total** | | **21172381.08** | **211723381,08** |

In the research that has been carried out, a mass balance calculation was produced for the power boiler operating conditions on 1 day of operation. The fuel used for 1 day of operation is 986 tons x 1000 kg/ton = 986,000 kg. Pulp produced by PT. X is pulp that comes from 100% accasia mangium wood. This accasia mangium wood comes from industrial plantation forests. The cooking process uses the kraft process, where the white liquor consists of NaOH and $Na_2S$. The presence of $Na_2S$ will restrain the cellulose chain breaking reaction at the ends so that pulp with higher viscosity and stronger physical properties is obtained. Then, to reuse the waste from cutting wood (bark) which will be used in the boiler, PT. X. uses tree bark as fuel in the Power Boiler. Initially the bark is sent from the drumbarker and stored in the bark yard to the Power Boiler unit to be burned. The stages of the combustion process are that the bark enters the Boiler through the Bed Convenyor, before the bark is put in the furnace (combustion room) there is sand which is used as a heating medium. The function of the Power Boiler is a place for the process of evaporating water where the heat is obtained from the process of burning wood bark, but because it requires a high temperature in the Furnace and produces a still high temperature in the Flue Gas, this condition is used to produce steam which then used to spin a turbine which ultimately produces electricity. The purpose of calculating the mass balance is to determine the amount of material flowing in and out that can be seen. The boiler works with converting chemical energy from fuel into heat (thermal) energy through a process burning. The fuel's heat energy is used to heat the water until it changes temperature and the phase becomes pressurized steam (steam). Steam formation occurs imperfectly, this is the case influenced by feed conditions, piping containing sediment and the fuel used. Based on the calculation results, from the heat balance calculation, the heat data for producing steam was 1924,927,054 kcal, the latent heat of vaporization was 5732,620,038 kcal and the feed water heat was 11156296.65 kcal. So from the calculations obtained we can find out the energy balance in the boiler and the resulting Supply Steam Consumption. In the combustion process to maximize combustion performance by maintaining the right fuel and air ratio. If the fuel to air ratio is too high, the flame temperature will increase, resulting in more heat being lost through the exhaust gases. if the fuel to air ratio is too low, incomplete combustion occurs, resulting in additional heat loss through unburned fuel. Therefore, it is important to maintain the Fuel to air ratio within the recommended range by adjusting the combustion air/fuel ratio and monitoring exhaust gas composition.

## 4. Conclusion

Based on the analysis of energy balance calculations on the Power Boiler at PT.X. From the heat balance calculation, the heat data for producing steam was 1924,927,054 kcal, the latent heat of vaporization was 5732,620,038 kcal and the feed water heat was 11156296.65 kcal. So from the calculations obtained we can find out the energy balance in the boiler and the resulting Supply Steam Consumption. From this it can be concluded that the performance of the Power Boiler is good enough to achieve adequate production capacity and then the heat balance of a steam boiler can be significantly affected by boiler scale, corrosion, and fouling of heat transfer surfaces. Therefore, it is important to maintain the boiler regularly to prevent these problems. Regular maintenance includes descaling and cleaning the inside of the boiler, checking the combustion process, and inspecting the heat transfer surfaces for signs of corrosion or fouling.

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