Process Simulation and Performance Analysis of Combustion-Based Small-Scale Biomass Power Plant for Sustainable Energy Generation

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ABSTRACT

Due to increasing environmental concerns especially related to the use of fossil fuels, new solutions to limit the greenhouse gas effect and energy scarcity are continuously sought. Biomass has emerged in the renewable energy area with a high potential to contribute to the energy needs of both industrialized and developing countries. This study aims at the process simulation and performance analysis of combustion-based small-scale biomass power plants. The adiabatic flame temperature of the biomass waste in the combustion chamber was modeled and estimated in stoichiometric air and with excess air in a Microsoft Excel 2016 (GRG) Non-linear add-in solver. The achievable flame temperature under such conditions was estimated as 1706.3°C. The effect of increasing excess air in the achievable maximum temperature, for the combustion chamber, is also studied by considering different air-to-biomass fuel ratios. A comprehensive model of biomass Rankine cycle power plant feed with white eucalyptus biomass waste is modeled and simulated using Aspen plus chemical engineering software. A high enthalpy flow of 13293 KW enters the turbine and 910 KW power was produced.

Keywords: Adiabatic, Biomass, Flame temperature, Power plant, White eucalyptus

1. INTRODUCTION

Biomass is a type of renewable energy among various energy sources and has various advantages as it is estimated to have low cost and no CO_2 emissions (Gebreegziabher et al. 2014). According to a 2016 World Energy Council report, biomass as a flexible renewable energy resource can play an important role in meeting the global demand profile in energy sectors such as heat, power, buildings, and transport. Among different types of renewable energy, biomass is one of the largest energy sources, accounting for 14% of the 18% of renewable energy in the global energy mix (World Energy Council 2016). Biomass can be converted into useful energy forms through three main routes: thermochemical extraction, biochemical/biological extraction, and mechanical extraction (Do et al. 2014) and it is considered a suitable precursor technology for the production of commercial bio-based fuels and chemicals (Menin et al.,2020). Although biochemical conversion processes have been established on a commercial scale, they are economically unsustainable and exert market pressures on food crops and biodiversity (Shemfe, Gu, and Ranganathan 2015). The chemical composition of biomass fuels includes combustible elements such as carbon (C), hydrogen (H), and Sulphur (S). Of these elements, sulfur is undesirable because it reacts with moisture in the flue gas to form sulfuric acid, which is highly corrosive to metal elements in the incinerator. Other elements involved in the combustion process are: Oxygen (O) is present in the fuel because it is bound, and nitrogen (N) is considered an inert element in the development of biomass power plants and therefore does not react with other elements in the fuel. In the combustion chamber, nitrogen oxides, nitrogen dioxide, and other nitrogen oxides (NOx) are produced during the combustion process when fuel is burned at high temperatures (Paraschiv, Serban, and Paraschiv 2020).

In the process industry, there are various simulation packages used to simulate, analyze, and optimize different processes to achieve efficient operations and maximize profits. In the field of biomass conversion, many researchers modeled the process of thermochemical, biochemical, and mechanical conversion pathways by using the Aspen Plus process design program (Lan et al. 2018). An alternative source of energy that is promised to drive the future becomes more common in the energy mix (REEEP, 2014). Therefore, this study aims to determine the adiabatic flame temperature (Tf) of the waste biomass (white Eucalyptus) combustion as well as to simulate and analyze the performance of a small-scale biomass power plant using Aspen plus chemical engineering software.

2. MATERIALS AND METHODS

2.1. Process Modeling/Simulation

The design, operations, and innovation of products and processes are all influenced by the decisions made with the help of chemical engineering process simulation software, which also provides accurate insights. In this study, the simulation and modeling process was carried out using Aspen Plus v11 (produced by Aspen Tech), which can define processes containing solids in addition to vapor and liquid streams (Lan et al. 2018). FORTRAN blocks (calculators), sensitivity analysis, optimization, and design requirements are some of the performance analysis methodologies used for these models. Each flowchart variable or function of a flowchart variable can have a design value specified by the user through design specifications, which are utilized for feedback control. Design specifications change the flowchart variables, feed streams, or block inputs that you manipulate to achieve design values. Fortran instructions can be used within design specifications and operation blocks to estimate the functional values of a design specification (Magnusson 2011).

2.1.1. Defining the Process Flow Sheet

After specifying the inlet streams, all the blocks were specified according to the design operating condition using unit operation blocks and connecting material and energy streams. The pressures of all feed streams and UNIT operation blocks were specified according to thermodynamic conditions. Aspen Plus is based on minimizing the Gibbs free energy at equilibrium. This means that the residence time is long enough for the chemical reaction to reach an equilibrium state. The boiler, an Aspen Plus heater, was used to evaporate high-pressure liquid water into high-pressure steam at constant pressure. In this step, the amount of water with no vapor fraction is changed to completely vapor/steam. The turbine section is just a compressor, high-pressure steam was turned to use full work isotropic condition and a reversible adiabatic expansion of steam is considered.

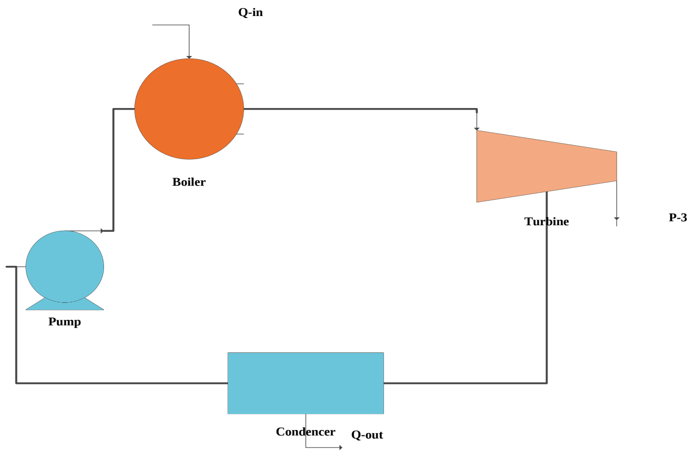

Figure 1: Simple steam Rankine cycle flow sheet layout

2.2. Process Evaluation

Process evaluation includes the thermodynamic analysis of the process. The thermodynamic part aims to maximize the power generation using the waste biomass (white Eucalyptus).

2.2.1. Determination of Adiabatic Flame Temperature

The adiabatic flame temperature of a white eucalyptus biomass combustion chamber assumes that all the heat produced by combustion is used only to increase the temperature of the combustion products, in other words, the calorimetric temperature and it was decided that determined only under adiabatic conditions (Mbada et al. 2016). The stoichiometric equations of combustion product are written as follows;

$$C+O_2 \rightarrow CO_2$$

$$S+O_2 \rightarrow SO_2$$

$$2H_2+O_2 \rightarrow 2H_2O$$

The above reaction equation represents the overall reactions in terms of starting materials and final products, the system efficiency, theoretical flue gas composition, and determining requirements of combustion air (Law et al., 2006).

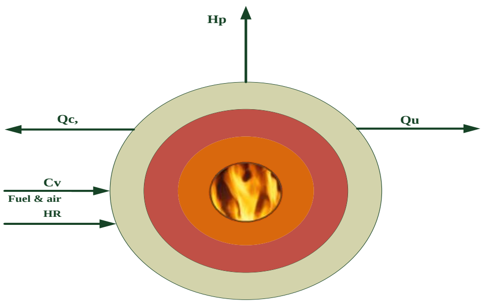

Figure 2: Energy balance under the combustion chamber layout (Frătiţa et al. 2020)

Energy balance was developed for the constant pressure combustion system, and the general energy balance system is estimated by using equation (1).

$$CV + Hr = Hp + Qc + Qu \qquad (1)$$

Where; CV is the calorific value of the fuel at a standard temperature of 25°C (KJ/Kg), Hr and H_P are enthalpies of reactant and product respectively at a standard temperature of 25°C in (KJ) and Q_c, case loss outside of the combustion system (KJ) and Q_u is useful heat of the system (KJ).

Here Q_c and Q_u are considered to be zero due to adiabatic conditions. Therefore equation (1) is simplified to;

$$CV + H_R = H_p \qquad (2)$$

Based on the above argument, CV is the net specific heat of the fuel and hence H_p includes only the sensible heat terms. The net specific heat of white eucalyptus biomass waste can be calculated by using the result of higher heating value (HHV) calculated from Messobo Cement factory (in KJ/Kg) by bomb calorimeter. To calculate the lower heating value (*LHV*), the moisture content is considered and Equation (3) is used in estimating it.

$$LHV = HHV - 9mH(hfg) \qquad (3)$$

Where; *mH* is the mass fraction of hydrogen in the solid fuel and h_{fg} is the enthalpy of vaporization of water/latent heat of vaporization of water.

The enthalpy of the white eucalyptus biomass waste fuel and air (ref.25°C) was estimated by using equation (4).

$$HR = (Ti - 25)\sum(mi * cpi)_R \qquad (4)$$

Where; R is a reactant and i, are components like O_2, N_2, etc., and the summation was carried out for each of the species present in the reactants.

The specific heats of the fuel, O_2, and N_2 were evaluated at the mean/average temperature by using equation (5).

$$Tm = (Ti + 25)/2 \qquad (5)$$

Where; T_m and T_i are the average temperature (mean temperature) and initial temperature respectively. The enthalpy of the reactants was then evaluated by using Microsoft Excel.

The enthalpy of the products of equation (6), however, is not as easily evaluated as it is defined by: -

$$Hp = (Tf - 25)\sum(mi * cpi)_p \qquad (6)$$

It is known that this relationship can't be solved explicitly for T_f as there will be a considerable difference between flame temperature and reference temperature 25°C. Therefore, the value of flame temperature was required to evaluate the specific heat of the combustion products. The specific heat of the combustion product was calculated by using a polynomial expression with a straightforward integer power series, using equation (7) (Hanby 1994).

$$Cp = a[0] + a[1]T + a[2]T^2 + a[3]T^3 + a[4]T^4 + a[5]T^5 \qquad (7)$$

Where; Cp is specific heat (KJ/Kg.K), T is the mean temperature a is a constant value. The data for all product gases are provided in Table 1.

Table 1: Coefficients of Equation (Linstrom 2003)

Com.	***T* (K)**	***a*[0]**	***a* [1]**	***a* [2]**	***a* [3]**	***a* [4]**	***a* [5]**	***a* [6]**	***a* [7]**
N_2	100 - 500	28.9864	1.8540	-9.6475	16.6354	0.0001	-8.6719	226.4168	0
	500- 2000	19.5058	19.8871	-8.5985	1.36978	0.5276	-4.9352	212.3900	0
	2000 – 6000	35.5187	1.1287	-0.1961	0.0147	-4.5538	-18.9709	224.9810	0
H_2O	500- 1700	30.0920	6.8325	6.7934	-2.5345	0.0821	-250.8810	223.3967	-241.8264
	1700 – 6000	41.9643	8.6220	-1.4998	0.0982	-11.1576	-272.1797	219.7809	-241.8264
CO_2	298 - 1200	24.9974	55.1870	-33.6914	7.9484	-0.1366	-403.6075	228.2431	-393.5224
	1200 – 6000	58.1664	2.7201	-0.4923	0.0388	-6.4473	-425.9186	263.6125	-393.5224
SO_2	298- 1200	21.4305	74.3510	-57.7522	16.3553	0.0867	-305.7688	254.8872	-296.8422
	1200 - 6000	57.4819	1.0093	-0.0763	0.0052	-4.0454	-324.4140	302.7798	-296.8422

O2	100- 700	31.3223	20.2353	57.8664	36.5062	-0.0074	-8.9035	246.7945	0
	700-2000	30.0324	8.7730	-3.9881	0.7883	-0.7416	-11.3247	236.1663	0
	2000-6000	20.9111	10.7207	-2.0205	0.1465	9.2457	5.3377	237.6185	0

Standard Generalized Reduced Gradient (GRG) Non-linear Solver in Microsoft Excel was used to solve the required maximum achievable temperature in stoichiometric air with the same procedure with adiabatic flame temperature in excess air was estimated by using the following addition formulas. The actual air which is used to calculate the heating value of oxygen in the reacting air is estimated by using equation (8);

$$\mathrm{AA} = \mathrm{EAR} * \mathrm{TOR} \tag{8}$$

Where: AA is actual air, EAR is Excess Air Ratio, and TOR is Total Oxygen required.

The unreacted oxygen which was used to estimate the amount of excess oxygen in the flue gas was estimated by using equation (9);

$$\mathrm{UO} = \mathrm{AA} - \mathrm{TOR} \tag{9}$$

Where: UO is Unreacted Oxygen

$$\mathrm{AR} = \mathrm{AA}/\mathrm{Oxygen.Wt\%} \tag{10}$$

Where: AR is air required

The heating value of nitrogen in the air was estimated from the amount of Nitrogen in the air and the amount of nitrogen in the air was estimated by using equation (11): -

$$\mathrm{NA} = \mathrm{AR} * \mathrm{Nitrogen(Wt\%)} \tag{11}$$

Where: NA is nitrogen in the air

The Nitrogen in the flue gas was then estimated by using equation (12).

$$\mathrm{NA} + \mathrm{N} \tag{12}$$

Where: N is the amount of product nitrogen in $\frac{\mathrm{Kg}}{\mathrm{Kg\ of\ fuel}}$.

To determine the stoichiometric and excess adiabatic flame temperature of a typical white eucalyptus woody biomass material (no-ash) General and Detailed Calculations of Air levels at various points were estimated using the Microsoft Excel add-in solver (GRG).

2.3. Rankine Cycle Simulation Model Development

A simple steam power plant operating in the steam/water Rankine cycle is considered and the cycle was developed by Aspen plus version 11 to estimate the thermodynamic properties of the steam power cycle. Modeling and simulating a simple Rankine cycle for power generation includes basic equipment such as a steam turbine, steam condenser, condensate pump, and the steam side of a boiler. Of course, an ideal steam combustion-based Rankine cycle would not include internal irreversibility, with isentropic compression in the pump, constant-pressure heat addition in the boiler, isentropic expansion in the turbine, and constant-pressure heat radiation in the condenser (Fitri, Zaman, and Azizi 2019). The red color streamlines out of the boiler show supper heated high-pressure steam and the blue color stream line flowing from the condenser shows condensed water.

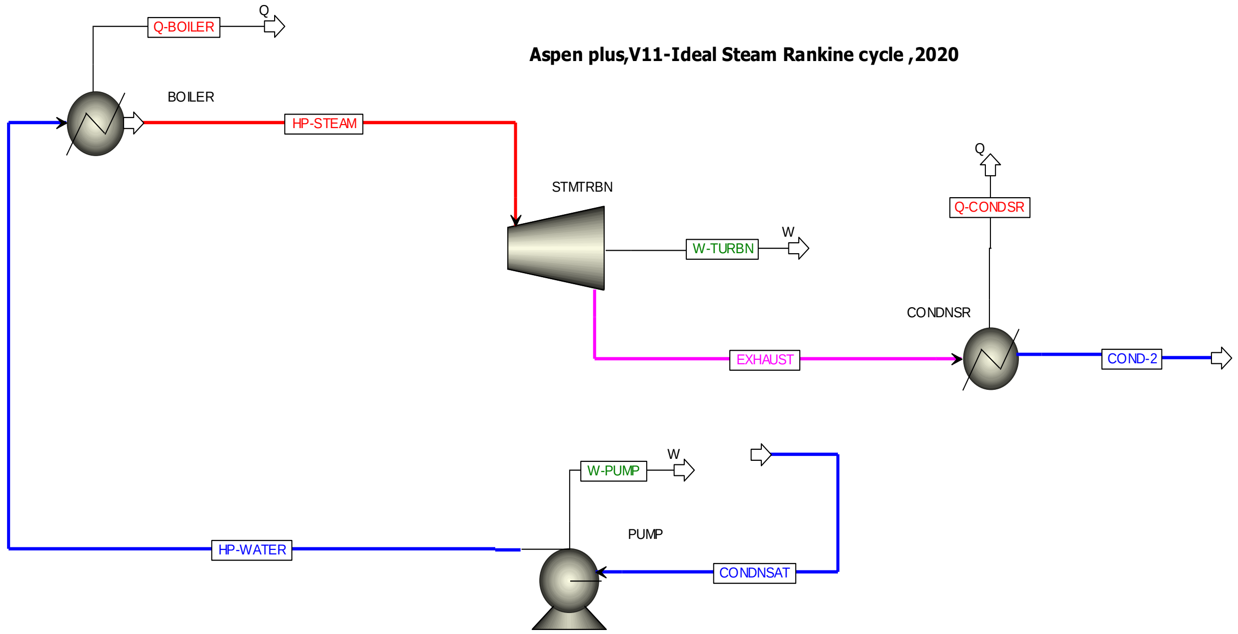

Figure 3: Aspen plus simulation model of steam Rankine cycle

By using the condition given around the pump, the density of the mass and energy rates are;

$$w_p = h_2 - h_1 \qquad (13)$$

Where, w_p is the work of the incoming power per unit of mass through the pump, h_1 enthalpy-1 and h_2, enthalpy-2.

Again, the rate of heat transfer from the energy source to the working fluid (Q_{in}) was calculated using the following formula.

$$Q_{in} = h_3 - h_2 \qquad (14)$$

Hence, the operating condition for the steam side of the boiler was specified under the flash type of degree of super-heating, in which the fraction is vapor, therefore the outlet stream was estimated as a saturated vapor. By ignoring the heat transfer with its surroundings, the equilibrium of the energy and mass rates for the volume set in a turbine in the soft condition becomes.

$$W_T = h_3 - h_4 \qquad (15)$$

Where W_T is the rate of work produced per unit of mass vapor through a turbine.

In the condenser, heat is transferred from the steam to cooling water flowing in a separate stream. A reversible constant pressure (steam to saturated liquid) heat recovery process was considered. The condensed steam and the temperature of the cooling water were increased step wisely. In steady-state, the equilibrium of the mass and energy rates for the regulating volume surrounding the condensation and heat exchanger part is:

$$Q_{in} = h_4 - h_1 \qquad (16)$$

Where; h_4 and h_1 are the heat of enthalpy in the exhaust stream from the turbine and the heat of enthalpy in the lower-pressure water section from the condenser section respectively.

To model the steam turbine of the biomass ideal Rankine cycle FORTRAN (The calculation is estimated by programming a subroutine in Fortran) in a calculating block (PIR-CALCULATOR)) manipulator was applied. Based on the Fortran declaration procedure, the exact pressure of the block steam turbine was estimated by using an executable Fortran statement.

$$P_{TRBN} = P_{CONDSR} \qquad (17)$$

From the above result, the thermal efficiency of the Rankine cycle is determined by using equation (18).

$$\eta th = W_{net,}\frac{out}{Q_{in}} = 1 - Q\_out/Q\_in \qquad (18)$$

Where; W-net is work net output from the cycle, Q_{in} is heat in from the source and Q_{out} is heat out from the cycle. So, the work net out of the cycle is then calculated by equation (18).

$$W_{net,out} = W_{Turbine,out} - W_{Pump,in} \qquad (19)$$

2.3.1. Steam Turbine

The steam turbine is a prime mover that changes kinetic energy in steam into rotational mechanical energy through the impact of the steam against the blades (Kareemetal.,2018). The performance of a turbine having an isentropic process is expressed by an isentropic efficiency of 1% in the Aspen Plus software. The turbine steam inlet pressure drop is a major parameter affecting turbine performance. To control the design efficiency of the steam turbine, the steam inlet pressure should be maintained. Lowering steam inlet pressure affects to reduction of turbine efficiency and increases steam consumption. A 10% example sample increase in steam pressure in the whole steam Rankine cycle is going to reduce steam consumption by about 1% in a condensing steam turbine and by about 4% in a back-pressure steam turbine. The consequence of efficiency for a 10% increase in pressure is about 1.5% for a condensing steam turbine and 0.45% for a backpressure steam turbine (Gladysz et al. 2020). The back pressure turbine in the combined heat and power system flow diagram layout is depicted in Figure 4.

The turbine stream inlet temperature is also another major parameter affecting turbine performance. As mentioned earlier, reducing steam inlet temperature reduces the enthalpy of the turbine, which is a function of both the inlet temperature and pressure. At higher steam inlet temperatures, heat extraction by the turbine is also increased. An estimated increment of about 50 °C temperature will reduce the steam consumption by about 6.6% in a condensing steam turbine and 8.8% in a back-pressure turbine. At 55°C temperature, the efficacy of the turbine is increased by 0.6% for a condensing steam turbine and 0.65% for a back-pressure turbine. It is proved that the overall efficiency in the utmost cases for a condensing steam turbine (30–35%) is about double of a back-pressure turbine (18–20%) (Schröder, Andreas;et al,2013).

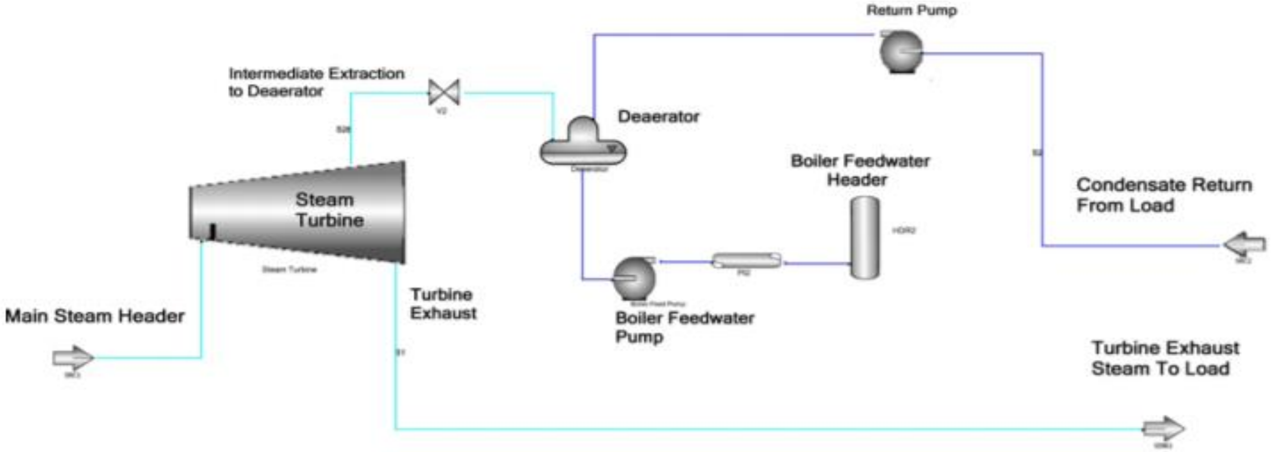

Figure 4: Back pressure turbine

Pump Efficiency

More pump efficiency means that the pump can increase the discharge fluid pressure before the boiler and less output power of the Rankine cycle will be used for pump work. Discharge pressure increase from the pump means; larger boiler pressure is produced. To examine how the pump efficiency affects the steam Rankine cycle performance, by using equations (ηth total) (20), and (21). A different value is tasted in the Engineering Equation solver computer (EES) model.

$$Pump\ work = m(h1 - h2) * \eta_{pump} \tag{20}$$

Where: m stands for mass flow rate in the cycle, η_{pump} stands for efficiency of the pump, and h1 and h2 are the amounts of enthalpy before and after the pump.

And work net of the whole steam-based Rankine cycle is estimated using the equation (21): -

$$W_{net} = W_{turbine} - W_{pump} \tag{21}$$

Where W_{net} stands for work net, $W_{turbine,}$ and W_{pump} stands for work turbine and work of the pump.

3. RESULT AND DISCUSSION

3.1. Effect of Moisture Content on Calorific Value (LHV)

The standard measure of the energy content of waste biomass fuel is its heating value (HV), also called the calorific value or heating value (KJ/Kg) of combustion. The calorific value of white eucalyptus biomass waste decreases with an increase in its moisture content. The LHV of the fuel increases as the hydrogen content increases. The legend for row 1 of the graph below shows the decrease in the lower

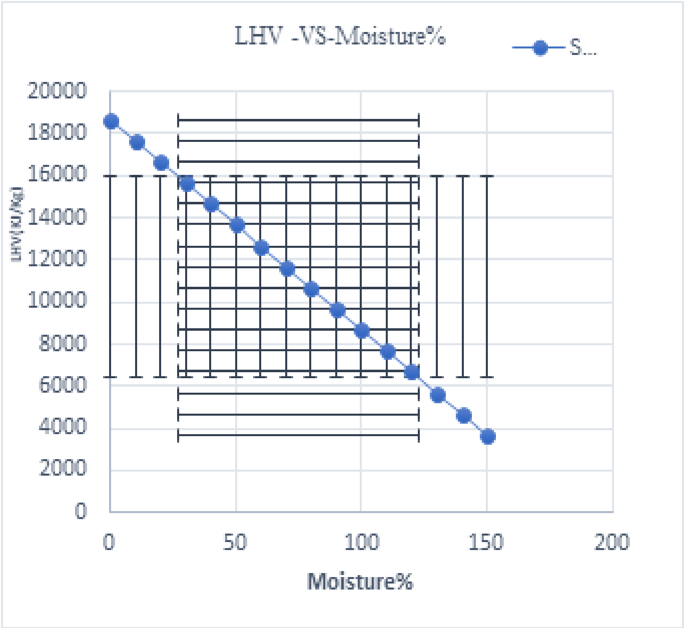

Figure 5: Graph of LHV vs. moisture content of the white eucalyptus biomass waste

A higher calorific value is achieved when all the water produced during combustion is liquid. A lower calorific value is achieved when all the water produced during combustion is steam. The higher heating value outweighs the lower heating value by the energy required to evaporate the liquid formed.

3.2. Effect of Moisture and Air-Fuel-Ratio on Flame Temperature

The air-fuel ratio, which indicates the mass of air supplied per 1 kg of fuel required for combustion of white eucalyptus biomass waste, is directly proportional to the excess air ratio (n) and it also leads to a reduction in adiabatic flame temperature, as shown in Table 2. When the air-fuel ratio in the combustion chamber changes; the adiabatic flame temperature also changes inversely. The adiabatic flame temperature of white eucalyptus biomass waste is 1706°C at n = 1 and 1280 °C at n = 1.5, while at n = 3, the combustion temperature is 742 °C and the response to temperature drops shown in Table 2.

Table 2: Result of adiabatic flame temperature concerning another parameter

If the fuel is burned with exactly stoichiometric air requirements, there is no oxygen present in the flue gas and the enthalpy of carbon dioxide reaches up to 3890 (KJ/kg), and the maximum temperature achievable also up to 1706 °C relative to excess air supply. As the supply of excess air increases, the enthalpy of carbon dioxide on the product side decreases (2870 kJ/kg) and the amount of excess oxygen in the exhaust gas gradually increases from 0 (kJ/kg) to 2140 (kJ/kg). Generally, the adiabatic flame temperature reaches its maximum at the stoichiometric air/fuel ratio. When there is excess or lack of air in the combustion chamber, the adiabatic flame temperature drops rapidly [Figure 6]. Excess air simply passes through the system as a passenger and is warmed in the process, which inevitably leads to a reduction in system efficiency. This causes incomplete mixing of fuel and air.

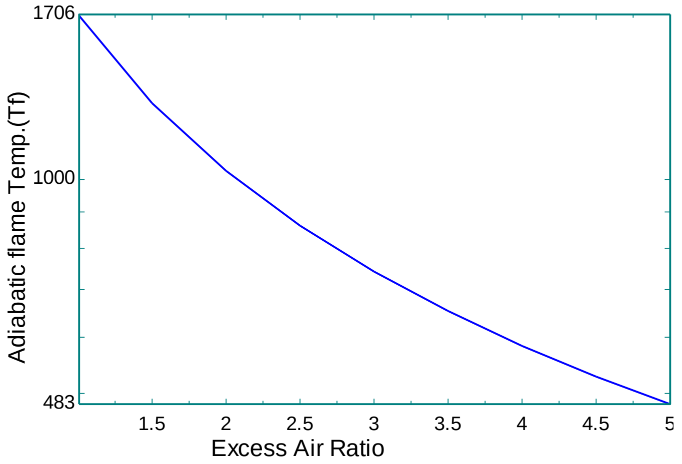

Figure 6: Variation of biomass fuel flame temperature and Excess air ratio

As shown in the graph in Figure 7, by increasing the air excess ratio and moisture content of biomass fuel, the mass of flue gas increases uniformly with respect to the mass of fuel with a corresponding reduction in achieving maximum flame temperature. In the corner of the graph, the moisture content is less than 10 %, the excess air ratio is from 1.5 up to the stoichiometric air, and at this point, the maximum amount of flame temperature is occurred in the range of 1217°C up to 1706°C. The estimated relationship between the excess air ratio, moisture content, and the adiabatic flame temperature is shown in Figure 7.

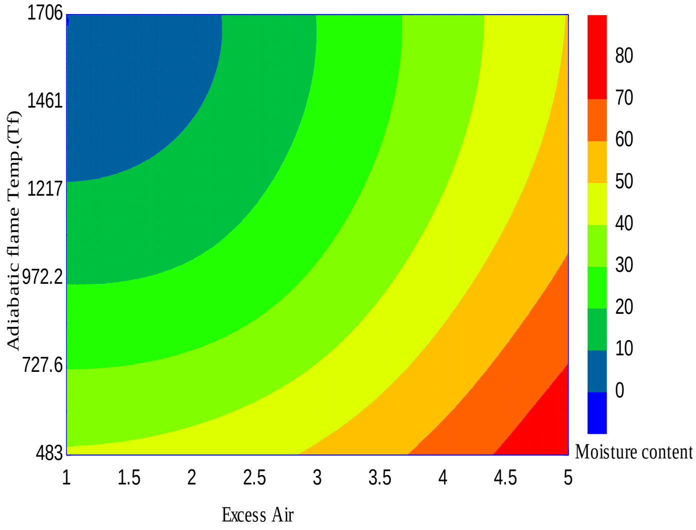

Figure 7: Graph of Adiabatic flame temperature, Excess Air, and Moisture content

Burning a fuel below the total stoichiometric air requirement is generally not beneficial, as not only is some of the energy contained in the fuel wasted, but it also has a serious impact on emissions in the exhaust gas. The excess air requirement means that the carbon dioxide produced is diluted by the additional nitrogen in the flue gas, making additional NOx gas products available in the flue gas. The presence of additional nitrogen in the combustion air influences the efficiency of a combustion process as it reduces the flame temperature in the combustion chamber and increases the heat loss due to sensible heat in the flue gases exiting the chimney (Paraschiv, Serban, and Paraschiv 2020).

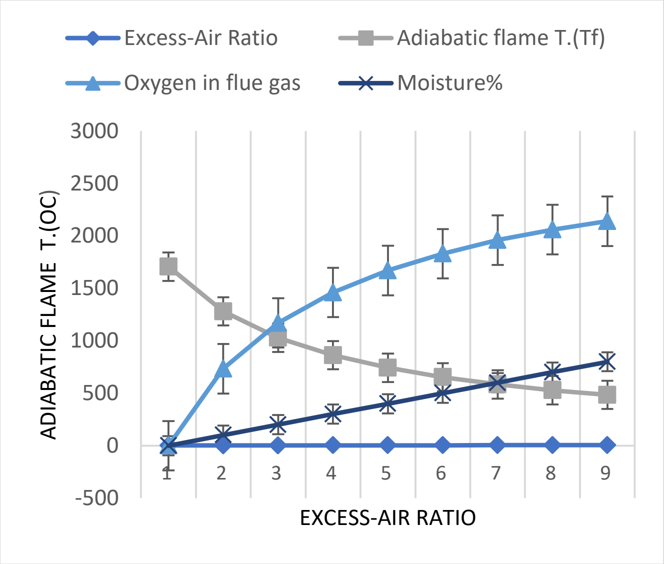

Figure 8: Oxygen in flue gas, MC (%), Excess air ratio, and Adiabatic flame temperature

The adiabatic flame temperature of the combustion chamber defines the temperature of the products after all chemical reactions have reached equilibrium and no heat can enter or leave the combustion chamber (Mbada et al. 2016). In most systems, such as cogeneration biomass power plants, heat is intentionally removed from the burning mixture for heating or other purposes. Complete combustion of flammable elements requires a minimum amount of oxygen in the air.

3.3. Analysis of the Steam Rankine Cycle

The biomass waste flow rate to the boiler and the steam flow rate throughout the cycle are constant and by using equation (22), the steam flow rate of the power plant is estimated at 1kg/sec. According to the conservation of mass;

$$M1 = M2 = M3 = M4 = M \tag{22}$$

Where: M = steam flow rate of the working fluid.

A schematic diagram of the power plant and the *T-S* diagram of the cycle are shown in Figure 9. Considering the power plant operates on an ideal Rankine cycle, the pump and the turbine are isentropic, there are no pressure drops in the boiler and condenser, and steam leaves the condenser and enters the pump as a saturated liquid at the condenser pressure. The boiler and the condenser of the ideal Rankine power cycle do not involve any work, and the pump and the turbine are assumed to be isentropic. Then the conservation of work for the pump and condenser are 13 Kw and 1542 Kw respectively.

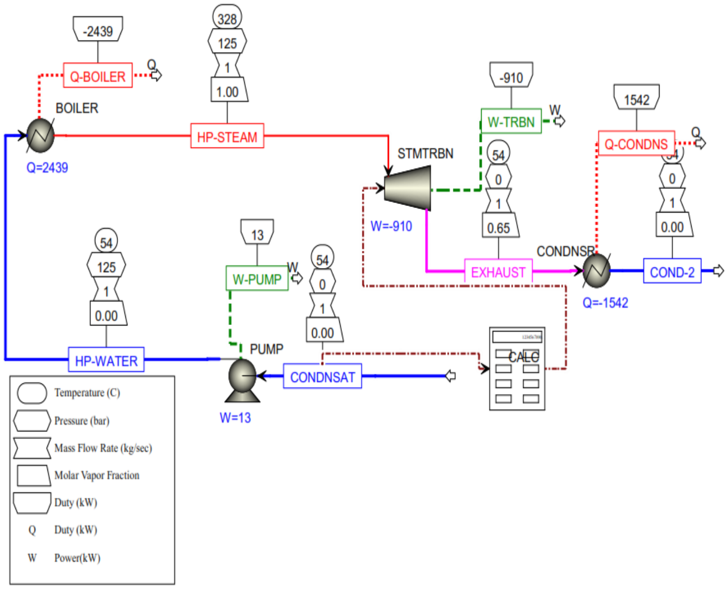

Figure 9: Aspen plus based thermodynamic simulation result of steam Rankine cycle

In a real power plant, all of the mechanical energy of the steam cannot be utilized to operate the power generation system due to losses due to friction, viscosity, blade bending, and others. Most of the thermal energy generated in the boiler is 2439KW and is discarded to 1542KW in the steam condenser. The net power delivered by the Rankine cycle is the difference between the turbine power of 910 kW and the pump power of 13 kW yielding 897 kW. Hence, one of the significant advantages of the Rankine cycle is that the pump power is usually quite small compared with the magnitude of the turbine power. According to Abdelhady, Borello, and Shaban 2018; the efficiency of the steam Rankine cycle power plants in Egypt is reported to be between 25% and 40% (Abdelhady, Borello, and Shaban 2018). Here, the efficiency of the estimated power plant is 36.7% which is within the range of values under consideration. This thermal efficiency measures the effectiveness of this simple steam Rankine cycle.

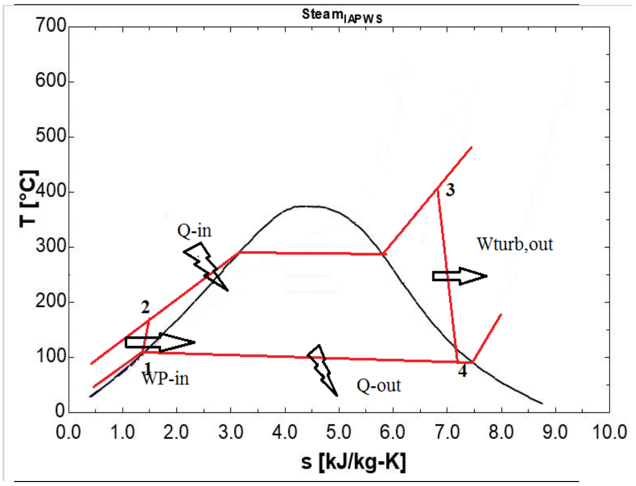

Figure 10: T-s diagram of the simple ideal Rankine cycle using EES

Low-pressure steam leaving the turbine in state 4 is first condensed to liquid in state 1, then pressurized by a pump to state 2. This high-pressure liquid water then passes through a steam generator to the steam chamber to state 3 and is reused in the Rankine cycle, as shown in Figure 10. Both the steam generator (boiler) and condenser act as heat exchangers. The steam Rankine cycle operates between two fixed pressure levels: the pressure in the steam generator and the pressure in the condenser. As a pressure change device, the pump guarantees a discharge pressure of up to 125 bars, and the turbine controls the pressure drop between these levels.

Table 3: Summary of Aspen plus based thermodynamic simulation result of steam Rankine cycle

Unit Operations	Temperature (°C)	Pressure (bar)	Mass flow rate (kg/s)	Molar vapor fraction	Duty (KW)
Boiler	328	125	1	1	2439
Pump	54	0	1	0	13
Turbine	54	0	1	0.65	-910
Condenser	54	0	1	0	-1542

3.3.1. Efficiency of the Pump

Based on this formula, Table 3.3 presents the estimation results of pump efficiency, cycle efficiency, and work net.

Table 4: Relationship of pump efficiency with W_{net} and cycle efficiency by EES

η pump	Efficiency of the Rankine Cycle	Worknet
0.4	0.1499	847.9
0.4556	0.151	854
0.5111	0.1518	858.8
0.5667	0.1518	862.7
0.6222	0.1525	865.9
0.6778	0.1535	868.6
0.7333	0.1539	870.8
0.7889	0.1543	872.7
0.8444	0.1546	874.4
0.9	0.1548	875.9

It is known that the efficiency of the pump has a significant effect on the pressure within the boiler, and the enthalpy of the boiler is a function of temperature and pressure, hence the formation of steam within the boiler. Therefore, the steam flow rate of the cycle determines the amount of power generated from the power plant. The graph of the relationship between Rankine cycle efficiency, work net, and pump efficiency shows that these parameters are directly related to each other. As a result, it is important to choose the right pump for the power plant to gain the desired amount of pressure after the pump. An ideal centrifugal pump with a discharging capacity of 125 bar is used for this work.

4. CONCLUSION

The use of renewable energy sources, particularly biomass, for power generation has gained considerable interest in recent years. In this context, one key parameter is adiabatic flame temperature, which represents the maximum temperature achieved when the fuel burns completely with a stoichiometric amount of air, meaning the exact amount of oxygen required for complete combustion. In this study, this temperature was found to be 1706.3 °C under stoichiometric air conditions. However, as the air-fuel ratio increases beyond the stoichiometric amount (excess air is supplied), the combustion temperature decreases due to the diluting effect of the additional air, which absorbs heat without contributing to the combustion process. As a result of simulation research, it was concluded that 910kW of power could be generated from biomass waste generated on the factory premises.

Authors' Contributions

LTG, TGG, and **FAB** conceived the problem of the study, prepared research proposals, and developed the overall design of the research; prepared the first draft of the manuscript as well as approved the manuscript for submission.

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Availability of data

The data sets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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Competing Interests

The authors declare no competing interests.

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