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Thermodynamic Simulation of Producer Gas Combustion from Biomass Gasification

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Abstract

The use of new and renewable energy for the application on gas burners is beneficial for the environment. This study aims to determine the effect of excess air during the combustion of producer gas from biomass gasification to release heat used as a fuel gas burner. Simulations are carried out by applying mass and energy balance, showing that an increase in excess air will decrease the non-adiabatic and adiabatic flame temperature. The result showed that an increase in excess of air reduces the amount of heat released to the environment for the same flame temperature. The maximum adiabatic flame temperature is at 1725.43^{0}C, while the non-adiabatic ranges from 600 to 800^{0}C. Furthermore, heat is released in the range of 20.1 kW to 28.8 kW, and excess air from 0 to 40%.

Keywords: Simulation, Thermodynamic, Temperature, Heat release, Combustion, Producer Gas

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1. Introduction

Producer gas is an alternative used for substituting fossil fuels, specifically biomass gasification [1]. It has certain environmental advantages when used on the burner [2]. The combustion process results can be used for various applications, such as drying, gas turbines, and boilers. Several factors affect the flame, such as the amount of combusted air and heat released from the burner [3]. Simulation is a good method to detect the combustion process's specific temperature. This can also be obtained through various parameters. It reduces the design time and the experimental cost [4]. The amount of heat released during the combustion process and the quantity of nitrogen in the air are factors that specifically affect the flame temperature. It can be thermodynamically modelled to ascertain the effect of heat release and the quantity of nitrogen.

Several preliminary studies have been carried out on thermodynamic simulations. Vitázek [5] performed a similar analysis on biogas combustion using the mass and energy balance principle. Caligiuri [6] carried out a thermodynamic simulation of dual fuel diesel and producer gas in an internal combustion engine. This was performed by applying the first law of thermodynamics to a closed system. Larionov [7] carried out a similar analysis on the combustion of a mixture of methane and hydrogen fuel. This was also performed based on the first law of thermodynamics. Rahim [8] simulated the burning speed of the methane-air diluent mixture, while its mass fraction and temperature in the combustion chamber were determined by applying the conservation mass and energy equation. Saghaei [9] also investigated a porous-medium chamber using thermodynamic simulation, including energy and single-step equations, to explain the combustion process in a diesel engine. Hariram [10] carried out a zero-dimensional thermodynamic simulation of a compressed ignition engine. This was performed by using the first law of thermodynamics. Feng [11] simulated a zero-dimensional marine two-stroke engine by applying mass and energy conservation as well as ideal gas equations. Papagiannakis

[12] performed a thermodynamic simulation on a wood gas spark ignition engine using similar processes.

This study performed a thermodynamic simulation of single producer gas from biomass gasification by applying mass, and energy balance in an open system. It aims to determine the general effect of excessive air on flame temperature. The specific objective is to obtain the heat released during the combustion process at temperatures between 600 and 800^{0}C.

2. Methodology

The combustion process was analysed by applying the mass balance and the first law of thermodynamics (energy balance). The mass balance for the steady state condition is shown in Equation 2

$$M_{in} - M_{out} = \Delta M_{system} \qquad (1)$$

for steady state condition = 0, then

$$M_{in} = M_{out} \qquad (2)$$

The first law of thermodynamics is shown as follows:

$$E_{in} - E_{out} = \Delta S_{ystem} \qquad (3)$$

Furthermore, this combustion process occurs in an open system by applying the control volume. For steady flow (ΔEsystem = 0), the first law of thermodynamics is stated as follows:

$$E_{in} = E_{out} \qquad (4)$$

The components of inlet and outlet energies are heat, work, and mass flow. The equation then becomes:

$$Q_{in} + W_{in} + \Sigma\left(h + \frac{v^2}{2g} + gz\right)_{in} = Q_{out} + W_{out} + \Sigma\left(h + \frac{v^2}{2g} + gz\right)_{out} \qquad (5)$$

By ignoring kinetic and potential energies, including work done and heat entering the system, the earlier stated equation becomes:

$$\mathbf{Q_{out}} = (\mathrm{h_{in}} - \mathrm{h_{out}}) \qquad (6)$$

During the combustion process, a change was detected in the internal energy. This includes chemical and sensible energies. Based on this, the combustion process consists of formation and sensible enthalpies, as shown in the following equation:

$$h = \bar{h}_f^0 + (\bar{h} - \bar{h}^\circ) \qquad (7)$$

When the combustion process occurs adiabatically, the value of Q_{out} = 0. The equation is further stated as follows:

$$\Sigma N_{in} (\bar{h}_f^0 + \bar{h} - \bar{h}^\circ)_{in} = \Sigma N_{out} (\bar{h}_f^0 + \bar{h} - \bar{h}^\circ)_{out} \qquad (8)$$

The flame's temperature and quantity of heat released is started to calculate based on the fuel composition that written on chemical reaction equation. The fuel used in this simulation is producer gas from palm oil shell gasification. Its constituents are shown in Table 1 with a gas heating value of 6.1 MJ/Nm^3.

Table 1. Fuel Composition

No	Species	% Vol
1	CO	22.55
2	H_2	8.35
3	CH_4	8.21
4	CO_2	14.1
5	O_2	1.32
6	N_2	45.47

The stoichiometric equation is obtained by applying mass conservation, which is stated as follows:

$$(0{,}2255\ CO + 0{,}0835\ H_2 + 0{,}0821\ CH_4 + 0{,}141\ CO_2 + 0{,}4547\ N_2 + 0{,}0132\ O_2 + 0{,}3055\ (O_2 + 3{,}76N_2) \longrightarrow 0{,}4486\ CO_2 + 0{,}2477\ H_2O + 1{,}6033\ N_2 \qquad (9)$$

The mass and energy equation is applied using the earlier stated chemical reaction. The initial flame's temperature is used base on temperature of Nitrogen composition.

Simulations are carried out in accordance with varying excess air, namely 0%, 10%, 20%, 30%, 40%, and 50%. The mass flow of air and fuel is shown in Table 2. In the non-adiabatic simulation, the heat released from the burner gas is assumed to be relatively 70000 kJ/h (19.4 kW). This is within the range of the results obtained from the experiments carried out by [13-14]. Non-adiabatic simulations are performed using two methods. The first is to determine the effect of excess air on the fame's temperature at a constant heat value of 70000 kJ/h. The second is to determine the effect of an excess of air and the flame's temperature on the heat release rate. The simulation process is carried out based on a constant flame's temperature. A flow chart of the calculating procedure is shown in Figure 1.

Table 2. Parameter of Simulation

Excess of Air (%)	Air mass flow rate (kg/h)	Fuel mass flow rate (kg/h)
0	41.8169	27.1659
10	45.9984	27.1659
20	50.1799	27.1659
30	54.3615	27.1659
40	58.5430	27.1659

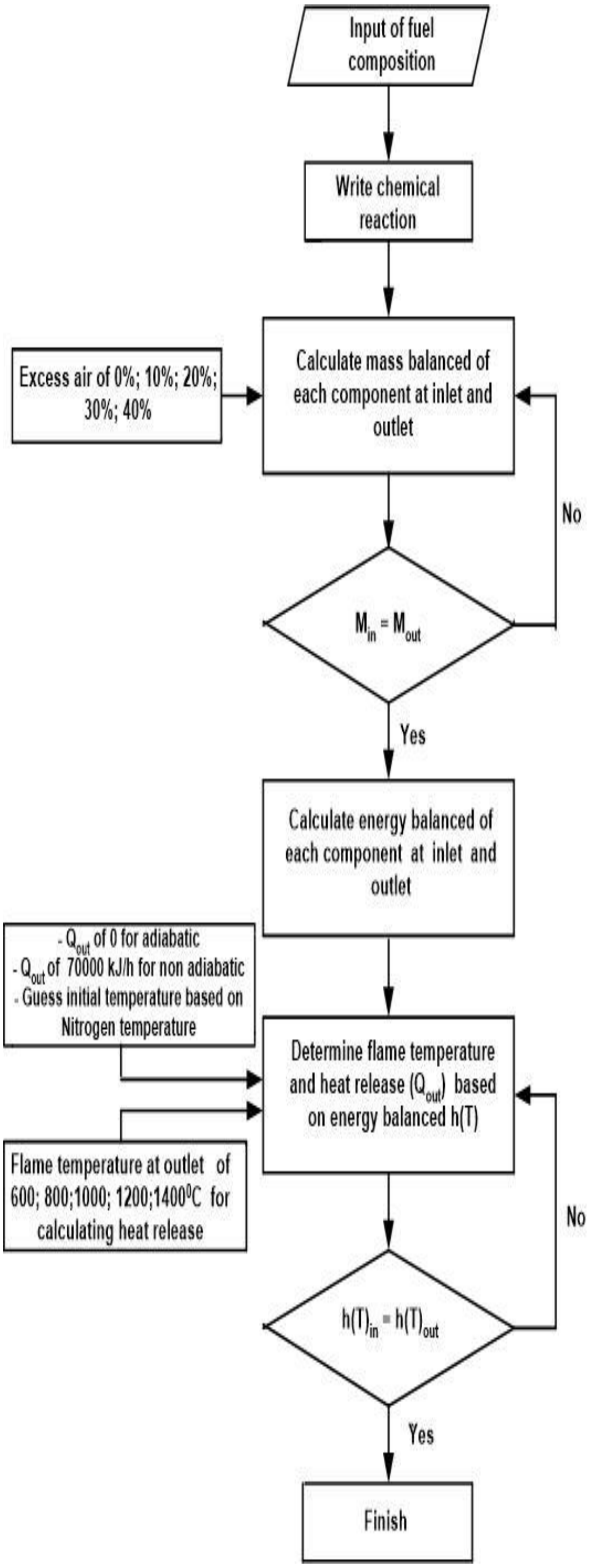

Figure 1. Flow Chart of Thermodynamic Model

3. Results and Discussion

3.1 The Thermodynamic Evaluation of Excess of Air on Flame Temperature of Producer Gas Combustion

Figures 2 and 3 show the effect of excess air on the flame's temperature under non-adiabatic and adiabatic conditions. Furthermore, excess air increases and reduces the flame temperature under both conditions. This is similar to the reports made by [15-18]. It is because an increase in excess air triggers the nitrogen content of the combustion product. This further absorbs the heat from the combustion process, reducing the flame temperature. In non-adiabatic conditions, with the heat released at 70000 kJ/h, the maximum flame temperature is 986.68^0C with excess air at 0%. Each increase in excess air at 10^0C reduces the temperature by 40 to 43^oC. Meanwhile, in adiabatic conditions, the maximum flame temperature is 1725^0C at excess air of 0%. Each increase in excess air at 10^0C reduces the temperature by 60 to 78^oC.

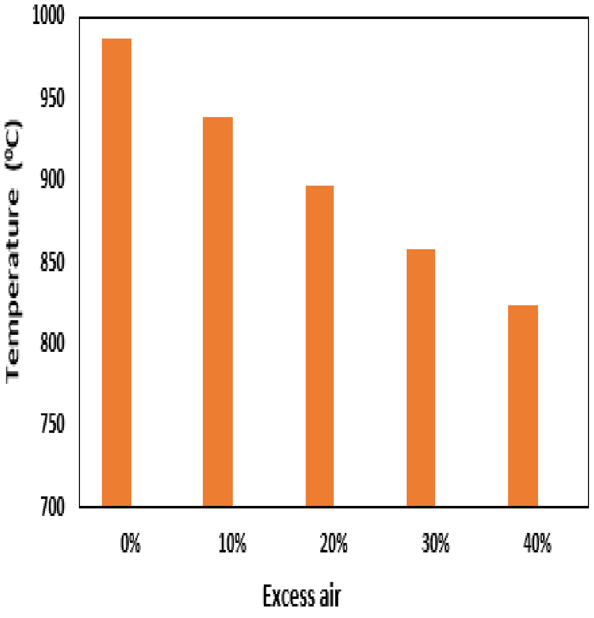

Figure 2. The Influence of Excess of Air to Non-adiabatic Flame Temperature

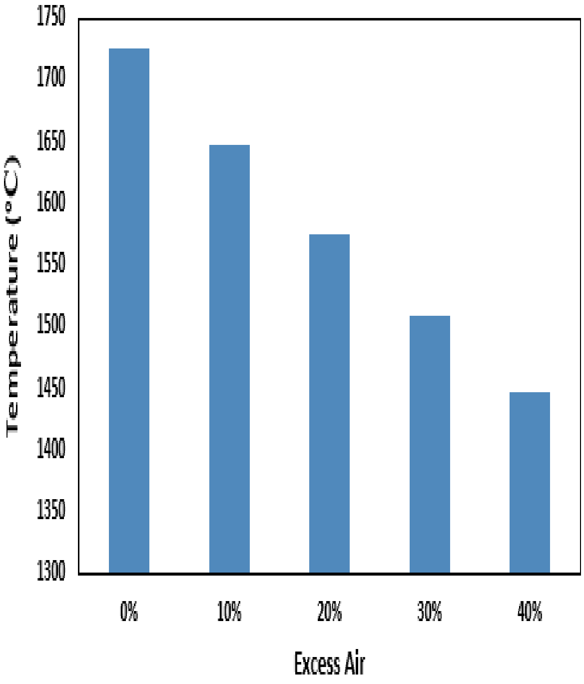

Figure 3. The Influence of Excess of Air to Adiabatic Flame Temperature

3.2 The Thermodynamic Evaluation of Flame Temperature on The Heat Release in Various of Excess Air

Figure 4 shows the effect of the flame temperature on the quantity of heat released from the combustion chamber at varying excess air. An increase in the flame temperature reduces the amount of heat released for various excess air. It is evident that for each flame temperature, the maximum quantity of heat released occurs at the lowest excess of air. This is because the energy from the combustion process is the least absorbed by excess air. The flame's temperature is within the range of 600 to 800^{0}C. The heat released during the process is 72490 kJ/h to 103800 kJ/h (20.1 kW to 28.8 kW). Similar studies reported a similar temperature range for the combustion of producer gas [19-20]. Excess air at 40% with a flame temperature of 1400^{0}C proved that the heat released is close to zero. However, in this circumstance, the adiabatic flame temperature for the excess air of 40% is 1447.78^{0}C.

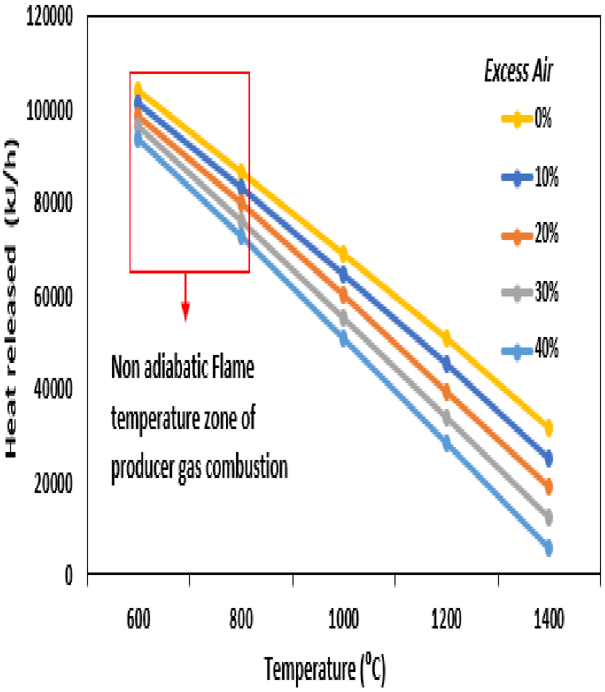

Figure 4. The Influence of Flame Temperature to Heat Release on Variation of Excess of Air

3.3 The Comparation of Thermodynamic Simulation and Experimental

Figure 5 compares the experimental by [21] and simulation processes carried out in adiabatic conditions. Punnarapong [21] reported that the experimental adiabatic flame temperatures obtained were 1260^{0}C. Meanwhile, this simulation resulted were 1725^{0}C, the differences is due to the difference in the producer gas composition, which uses an average heating value of 5.2 MJ/Nm^3 and 6.1 MJ/Nm^3 during the experimental and simulation processes, respectively. The simulation method adopted was also referenced [7, 22-25]. To remedy this situation, the future study must equalize the operating parameters and improve both the simulation and experimental aspects.

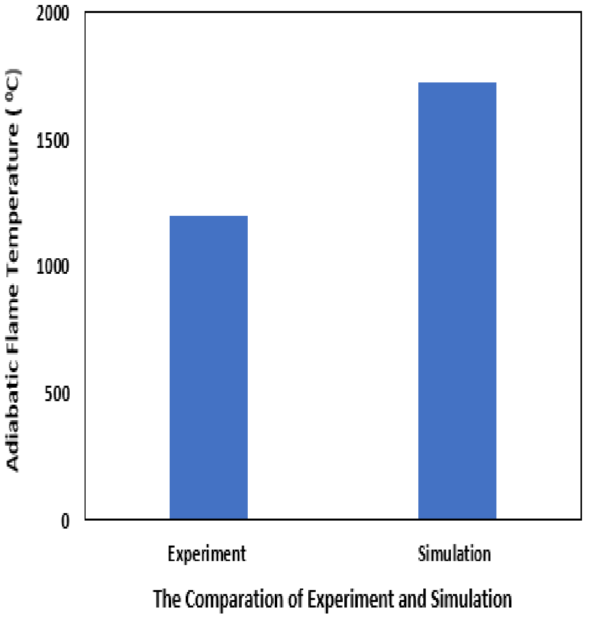

Figure 5. The Comparison of simulation and Experimental [21]

4. Conclusion

An increase in excess air causes a reduction in both adiabatic and non-adiabatic temperatures of biomass producer gas. The maximum and minimum adiabatic flame temperature are 1725.43^{0}C and 1447.78^{0}C at 0% and 40% excess air, respectively. The greater the resulting non-adiabatic temperature, the lesser the heat released during the combustion process for the excess air constant. The non-adiabatic flame temperature is usually 600 to 800^{0}C, while the quantity of heat released is within 20.1 kW to 28.8 kW, and the excess air is approximately 0 to 40%.

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Nomenclature

E_{in} - Total Energy Entering the System

E_{out} - Total Energy Leaving the System

ΔE_{system} - Change in the Total Energy of the System
Q_{in} - Energy Entering the System by Heat
Q_{out} - Energy Leaving the System by Heat
$\dot{W}_{in}$ - Energy Entering the System by Work
$\dot{W}_{out}$ - Energy Leaving the System by Work

m_{in} - Mass Entering the System
m_{out} - Mass Entering the System
h - Enthalpy
h_{in} - Enthalpy Entering the System
h_{out} - Enthalpy Leaving The System
$\bar{h}_f^0$ - Enthalpy Formation at the Standard Reference Temperature
$\bar{h}$ - Enthalpy at Specific State Temperature
$\bar{h}^{\circ}$ - Enthalpy at the Standard Reference Temperature
N_{out} - Mole Entering the System
N_{in} - Mole Entering the System