American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-15, Issue-6, pp-14-20
www.ajer.org
Research Paper Open Access

# Assessment Using The Second Law of Thermodynamics In The Biomass Gasification

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***ABSTRACT*** *: Biomass gasification can be one way to create a sustainable alternative energy source. So far, the efficiency analysis of the biomass gasification process has used the first law of thermodynamics. Where the analysis using the first law still has shortcomings, in this study an analysis was conducted using the second law of thermodynamics. This study aims to obtain the effect of the air and fuel ratio on the exergy produced, the exergy destroyed and the efficiency of the second law of thermodynamics in biomass gasification using a downdraft gasifier. The study was conducted with variations in the air and fuel ratio of 1.51; 1.52 and 1.63, respectively. Next, the fuel exergy, air exergy, syngas exergy, tar exergy, char exergy, ash exergy, exergy destroyed and the efficiency of the second law of thermodynamics were calculated. The results showed that increasing the air and fuel ratio tended to decrease the efficiency of the second law of thermodynamics. The maximum efficiency obtained was 43.7%.*

***KEYWORDS:*** *Gasification, Second Law, Thermodynamics, Exergy.*
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Date of Submission: 26-05-2026 Date of acceptance: 06-06-2026
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## I. INTRODUCTION

Reducing dependence on fossil fuels is a necessity in many countries today. Indonesia is promoting the use of new and renewable energy sources. One such approach is the use of biomass energy. Utilizing biomass for energy can be done through various processes. Gasification is one technology that can be used to convert biomass into energy. Through the gasification process, biomass is converted into gaseous fuel (producer gas). This gaseous fuel can be used for heating, drying, driving reciprocating engines, driving turbines, driving steam turbines, and driving fuel cells. The process of converting biomass into gaseous fuel is carried out in a gasifier. During the conversion process, it is crucial to assess conversion performance through process efficiency calculations.
The calculations have generally been carried out using the first law of thermodynamics to determine the amount of energy produced and efficiency. The first law of thermodynamics can only report energy in quantitative terms. However, calculations using the second law can describe energy in qualitative terms [1][2]. Calculations of the efficiency of the second law of thermodynamics will produce more realistic efficiency values than the first law of thermodynamics. From this background, this study conducted an analysis of the second law of thermodynamics in the biomass gasification process in a downdraft gasifier. The analysis included the exergy produced, the exergy destroyed and the efficiency of the second law of thermodynamics. This study aims to obtain the effect of the ratio of air and fuel on: the exergy produced, the exergy destroyed and the efficiency of the second law of thermodynamics.

## II. METHODOLOGY

In this study, the gasification process data used comes from reference [3]. The type of biomass used in this study is hazelnut shell and gasification uses a downdraft gasifier type as shown in Figure 1. In this study, the air and fuel ratio (AFR) used is 1.51; 1.52 and 1.63 respectively. The data used for the calculation are shown in Table 1, Table 2 and Table 3. Tar is modeled as benzene with the chemical formula $C_6H_6$ [4],[5]. Ash in this calculation uses the formula CaO [6]. The gasification product temperature used in calculating exergy is 300 $^{0}$C. The assessment carried out did not include condensate and total water in the calculation.

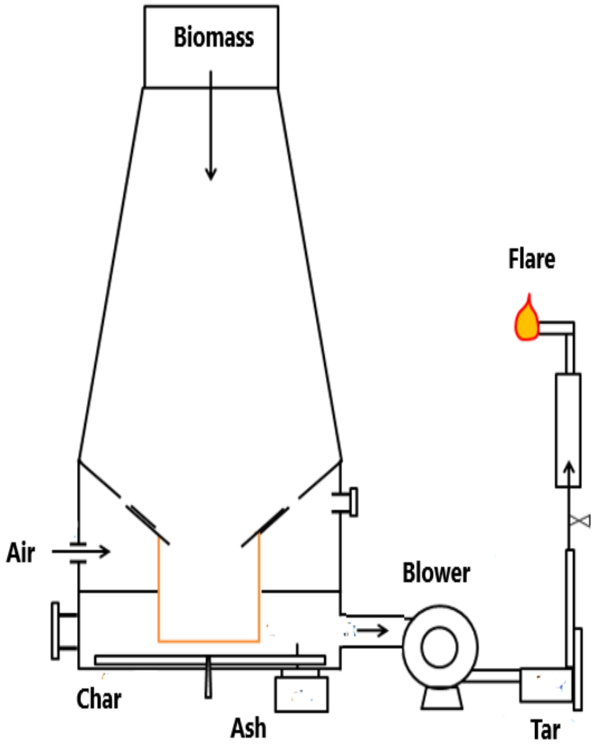


Figure 1. Downdraft Gasifier [3]

Table 1 Ultimate and Proximate Analysis of Fuel [3]

| Proximate Analysis | | | | |
|---|---|---|---|---|
| Moisture (%) | Volatile matter (%) | Fixed carbon (%) | | Ash (%) |
| 12.45 | 61.70 | 24.08 | | 0.77 |
| Ultimate Analysis | | | | |
| Carbon (%) | Hydrogen (%) | Oxygen (%) | Nitrogen (%) | Sulphur (%) |
| 46.76 | 5.76 | 45.83 | 0.22 | 0.67 |

Table 2 Producer gas from gasification [3]

| Producer gas mass flow rate ($Nm^3/h$) | AFR ($Nm^3/kg$) | $H_2$ (%) | $N_2$ (%) | $CH_4$ (%) | CO (%) | $CO_2$ (%) | $C_2H_2$ (%) | $C_2H_6$ (%) |
|---|---|---|---|---|---|---|---|---|
| 3.55 | 1.63 | 14.77 | 58.67 | 1.40 | 8.56 | 16.33 | 0.09 | 0.05 |
| 5.33 | 1.52 | 14.77 | 56.96 | 1.94 | 12.08 | 13.02 | 0.21 | 0.08 |
| 7.26 | 1.51 | 14.12 | 57.07 | 1.70 | 16.80 | 9.93 | 0.17 | 0.04 |

Tabel 3. Modification gasifier operating parameters and by-products [3]

| AFR ($Nm^3/kg$) | Fuel (kg/h) | Char (kg/h) | Ash (kg/h) | Tar (kg/h) |
|---|---|---|---|---|
| 1.63 | 1.73 | 0.094 | 0.015 | 0.0141 |
| 1.52 | 2.64 | 0.140 | 0.025 | 0.0185 |
| 1.51 | 3.69 | 0.183 | 0.035 | 0.0215 |

The equation used in the calculation

1. Exergy produced by Biomass

$$Ex_{biomas} = m_{biomas} \cdot \beta \cdot LHV_{biomas} \quad [7][8] \tag{1}$$

$$\beta = \frac{1,0412+0,216\left(\frac{H}{C}\right)-0,24990\left(\frac{O}{C}\right)\left[1+0,7884\left(\frac{H}{C}\right)\right]+0,0450\left(\frac{N}{C}\right)}{1-0,3034\left(\frac{O}{C}\right)} \quad [7][8][9] \tag{2}$$

2. Exergy produced by Air

$$x_{air}^{tot} = \sum x_i \left(\int_{T_o}^{T} c_p dT - T_0 \left(\int_{T_o}^{T} \frac{c_p}{T} dT\right)\right) + \sum_i x_i (ex_i^{ch} + RT_o \ln x_i) \quad [10] \tag{3}$$

3. Exergy produced by producer gas

$$x_{gas}^{tot} = \sum x_i \left(\int_{T_o}^{T} c_p dT - T_0 \left(\int_{T_o}^{T} \frac{c_p}{T} dT\right)\right) + \sum_i x_i (ex_i^{ch} + RT_o \ln x_i) \quad [10] \tag{4}$$

4. Exergy produced by tar

$$Ex_{tar(C_6H_6)}^{tot} = \left(\int_{T_o}^{T} c_p dT - T_0 \left(\int_{T_o}^{T} \frac{c_p}{T} dT\right)\right) + x_i (ex_i^{ch} + RT_o \quad [10] \tag{5}$$

5. Exergy produced by char

$$Ex_{Char(C)}^{tot} = \left(\int_{T_o}^{T} c_p dT - T_0 \left(\int_{T_o}^{T} \frac{c_p}{T} dT\right)\right) + x_i (ex_i^{ch} + RT_o \ln x_i) \quad [6][10] \tag{6}$$

6. Exergy produced by ash

$$Ex_{ash(CaO)}^{tot} = \left(\int_{T_o}^{T} c_p dT - T_0 \left(\int_{T_o}^{T} \frac{c_p}{T} dT\right)\right) + x_i (ex_i^{ch} + RT_o \ln x_i) \quad [6][10] \tag{7}$$

7. Exergy destroyed or Irreversibility (I)

$$\dot{E}x_{destroy}\,(\text{Irreversibility}) = \dot{E}x_{biomass} + \dot{E}x_{air} - \dot{E}x_{gas} - \dot{E}x_{tar} - \dot{E}x_{char} - \dot{E}x_{ash} \quad [11] \tag{8}$$

8. Efficiency of the second law of thermodynamics

$$\eta_{second\ law} = \frac{Ex_{gas}^{total}}{Ex_{biomass}+Ex_{air}} \quad [11][12] \tag{9}$$

## III. RESULT AND DISCUSSION

Figure 2 shows the effect of the air and fuel ratio on the exergy produced in the hazelmut cell gasification process, increasing the air and fuel ratio will decrease the amount of exergy produced. Figure 2 also shows that the inlet exergy in gasification is dominated by biomass exergy with a value between 9.2kW-19.6kW while the air exergy is only 0.0044 kW - 0.008 kW. The outlet exergy in gasification is dominated by the exergy in the product gas with an exergy value of 3.326 kW - 8.589 kW. Figures 3 to 5 shows the exergy produced in ash, char and tar. The exergy of ash, char and tar are in the range of: 0.008 kW-0.019kW; 0.4 kW-0.8 kW and 0.17 kW - 0.25 kW, respectively. If seen for the condition of the outlet exergy other than the gas exergy (producer gas exergy), the value is very small. Overall, there is a tendency for a decrease in the exergy produced, which correlates with the results reported by [13].

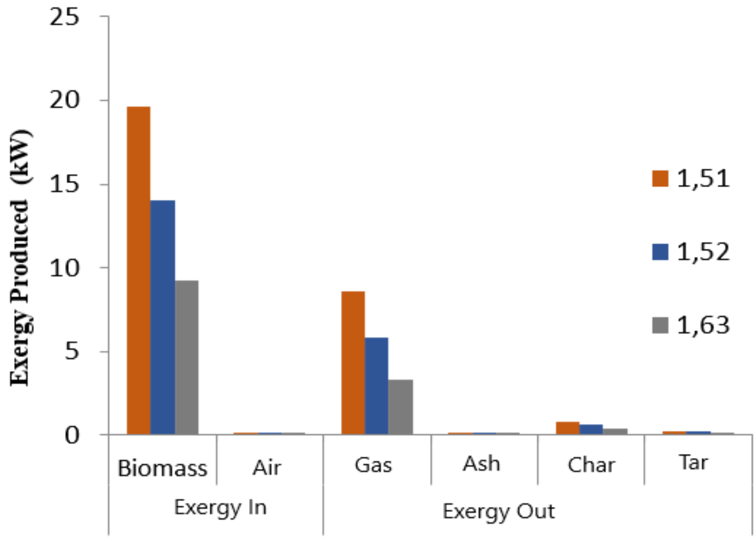


Figure 2. The relationship between AFR and the exergy produced

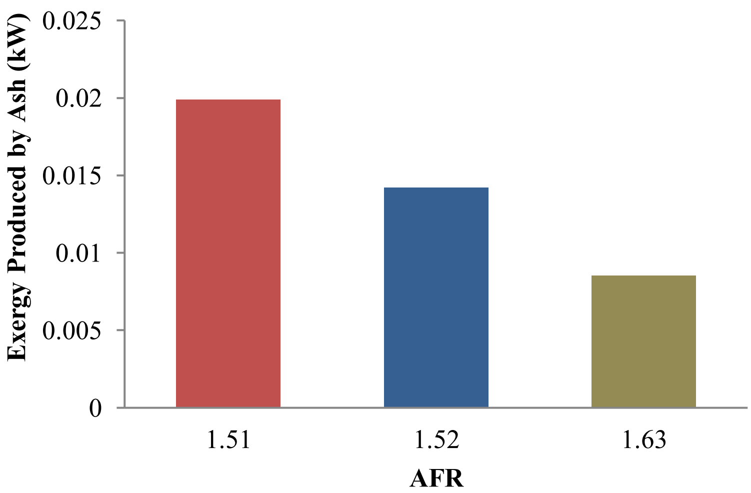


Figure 3. The relationship between AFR and exergy produced by ash

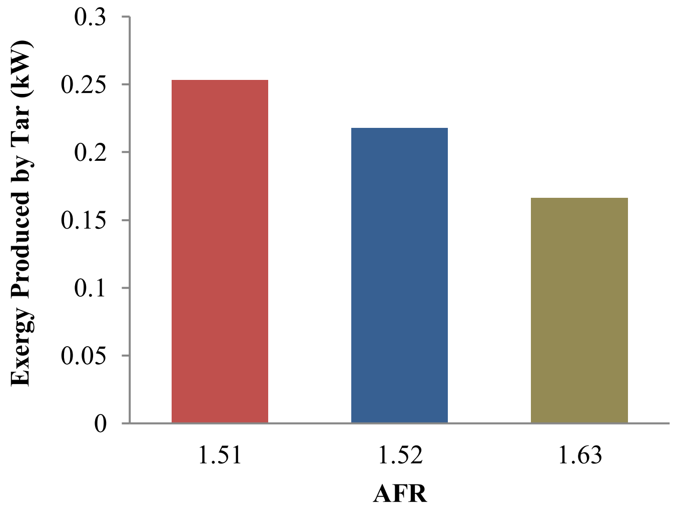


Figure 4. The relationship between AFR and the energy produced by Tar

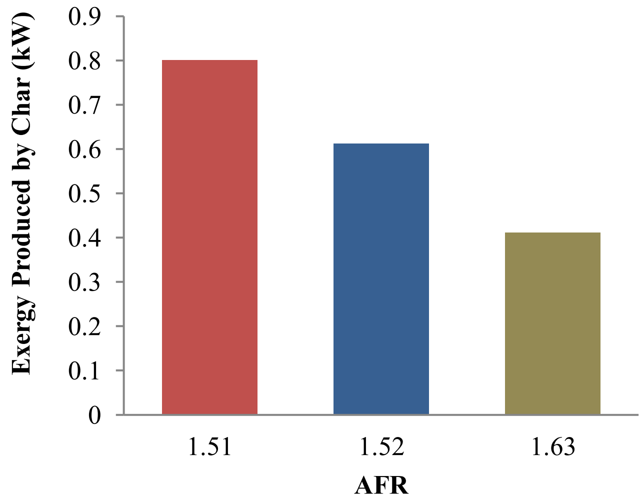


Figure 5. The relationship between AFR and exergy produced by char

Figure 6 shows that the largest exergy destroyed occurred at AFR 1.51 at 10 kW, followed by AFR 1.52 at 7.4 kW and the smallest was produced at AFR 1.63 with a value of 5.3 kW. This decrease in exergy destroyed is due to following the decreasing pattern of exergy produced at the inlet and outlet as shown in figures 2 to 5.

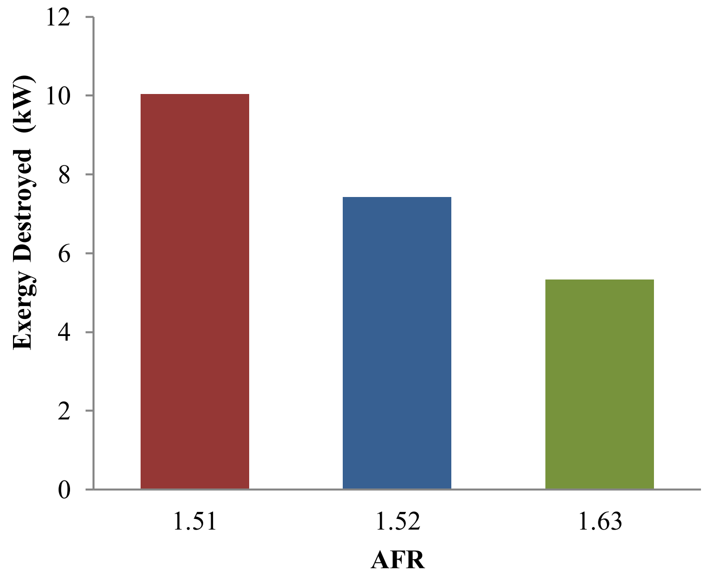


Figure 6. The relationship between AFR and Exergy Destroyed

Figure 7 shows that the highest exergy efficiency is produced at AFR 1.51 with a value of 43.7%, the second highest result is obtained from AFR 1.52 with an efficiency of 41.4% and the result at AFR 1.63 is 36%. There is a tendency for the efficiency of the second law of thermodynamics to decrease with decreasing AFR values, where the tendency is not much different from that reported by [14],[15]. The value of the efficiency of the second law of thermodynamics in the range of 36% to 43.7% is very realistic and not much different from the results reported by [11][16].

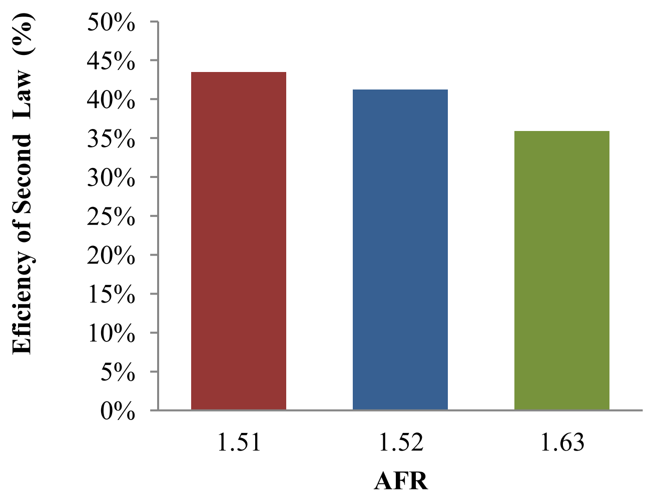


Figure 7. The relationship between AFR and The Efficiency of Second Law

## IV. CONCLUSION

From the analysis conducted on the biomass gasification process in the downdraft gasifier, the following findings were obtained:
1. Within the range of air-fuel ratios used, there was a tendency for a decrease in the efficiency of the second law of thermodynamics.
2. The maximum efficiency of the second law of thermodynamics was 43.7%.
3. At the inlet and outlet of the gasifier, the dominant exergy was fuel exergy and gas (producer gas) exergy.

## ACKNOWLEDGMENTS

Thanks to M Dogru et al for the use of the Gasification Results Data

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