



## Investigation on Effect of Equivalence Ratio on the Performance of a Downdraft Gasifier – An Experimental Approach

Md. Sanowar Hossain<sup>1,\*</sup>, Mujahidul Islam Riad<sup>1</sup>, Showmitro Bhowmik<sup>1</sup>, Sanjay Paul<sup>1</sup>, Sadman Soumik Nuhash<sup>1</sup>

<sup>1</sup>Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Bangladesh

### ARTICLE INFORMATION

Received date: 12th Oct 2023  
Revised date: 17<sup>th</sup> Dec 2023  
Accepted date: 31<sup>th</sup> Dec 2023

### Keywords

Organic waste  
Gasification  
Equivalence ratio  
Lower heating value  
Cold gas efficiency

### ABSTRACT

Biomass renewable energy is an important and diverse choice for transitioning towards a more sustainable energy system. It makes use of organic waste materials, reduces greenhouse gas emissions, and provides a source of energy that is both renewable and reliable. Using a biomass gasification device to make combined heat and power has become more popular because it is seen as one of the most promising ways to use renewable energy. Downdraft gasifiers that use only biomass as fuel have already been the subject of a lot of studies. Downdraft gasifiers are preferred to other gasifiers due to their simple construction, low cost, and minimal tar production, especially in developing countries for power and thermal applications. The equivalence ratio is one of the many factors that contribute to the performance of a gasifier. In this study effect of the equivalence ratio on the performance study of a small-scale downdraft gasifier has been investigated. The cold gas efficiency shows an increasing pattern with an increasing equivalence ratio in the range of 0.16 to 0.38 and was found to be optimum at 0.345. At an equivalence ratio of 0.345 the LHV was found to be 5.95 MJ/m<sup>3</sup> and the cold gas efficiency was 43.19%. In this investigation, Mango wood (*Mangifera indica*) pellets of size 50-60 mm are used as biomass feedstock.

### 1. Introduction

A secure and reliable energy source is essential to the development of any nation's infrastructure. It is the driving force behind economic growth, social progress, and improved living standards. Conventional energy sources have played a pivotal role in powering industrialization and technological advancements, but they come with several significant drawbacks. The dominance of fossil fuels is creating a carbon level imbalance. It is one of the primary causes of the rise in global temperature. As a result, there is a growing need to diversify our energy sources and adopt sustainable

alternatives that can meet the demand without causing further harm to the planet. Biomass energy is a substantial renewable resource that holds the potential to make a noteworthy contribution to global energy demands in an environmentally and sustainable manner [1]. The Gasification process is the conversion of solid biomass into gaseous product. In this process, biomass materials are heated in an oxygen-limited environment, producing a mixture of gases, primarily carbon monoxide (CO) and hydrogen (H<sub>2</sub>), known as syngas. Syngas is a flexible intermediate that can be burned to provide energy or utilized as a feedstock [2].

\* Corresponding authors: Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Bangladesh  
E-mail addresses: [sanowar122086@gmail.com](mailto:sanowar122086@gmail.com) (Md. Sanowar Hossain)

Gasification has advantages over other biomass conversion processes, making it a good choice in some cases, including high energy efficiency, variability, lower emissions, product output flexibility, and waste reduction. A multitude of gasification technologies are extensively employed for the conversion of biomass into fuel. The characteristics of a gasifier play a crucial role in determining the mechanisms through which fuel is introduced and interacts during the gasification process. The gasifier's ability to use a variety of fuels is a key benefit, and these feedstocks are widely accessible in rural Bangladesh. A small village may be able to meet its needs with a small or medium standalone gasifier and an internal combustion engine. The energy needed for gasification is a major constraint on gasifier design and thermal efficiency. Thus, significant advancement and improvement of the current gasification method are necessary to achieve sustainable utilization of biomass, a renewable natural resource [3]. The efficacy of biomass gasification is reliant on a multitude of parameters. The key factors that influence gasification are the equivalence ratio (ER), characteristics of the biomass, moisture content, surface velocity, operating temperature, gasifying agent, residence time, pressure, catalyst, and the impact of the biomass/steam ratio [4]. The equivalency ratio, denoted by the symbol ER, is the ratio of the actual air that is provided to the amount of stoichiometric or theoretical air that is used during the gasification process. The equivalence ratio (ER) is a critical factor in the gasification process as it significantly impacts the quality of the producer gas in terms of its heating value, gas composition, cold gas efficiency, tar content, and Particulate Matter (PM).

Among the several reactor designs used for gasification, downdraft moving bed gasifiers are good for small-scale heating and power applications (10–20 kg/h feed rate) with a capacity of 10–50 kW because of their cheap operating costs and low tar content in the product gas [5]. A number of researchers have investigated the implementation of downdraft gasification technology with biomass as the primary feedstock [6]. These researches examined how numerous critical criteria affect producer gas quality. Christus et al. [7] conducted the performance evaluation of the downdraft gasification of a mixture of rubber seed shell and coconut shell. The researchers conducted experimental performance evaluations across a broad spectrum of

equivalency ratios, ranging from 0.2 to 0.34, in order to achieve optimal efficiency. H Olgun et al. [8] designed and built a small scale fixed bed downdraft gasifier system that uses agricultural and forestry waste as fuel. They conducted performance test on a bench scaled downdraft gasifier and found out highest heating value at equivalence ratio 0.35. Narendrabhai et al. [9] developed a lab scaled downdraft gasifier and conducted performance test with the different sizes of wooden block and observed steady flame which shows clean combustible syngas. Chawdhury and Mahkamov [10] completed a performance a test of a 6 kw downdraft gasifier where they found out the thermal efficiency was around 90.1-92.4 %. The performance evaluation of bio-oil gasification for various equivalence ratios (ER) was conducted by Zheng et al. [11]. It was noticed that the concentration of H<sub>2</sub> and CO in the producer gas is higher when bio-oils are used compared to solid biomass. From the literature survey it is found that the huge amount of mango wood shavings and pellets produced in the saw mills and wood working shops of Rajshahi region is not utilized for producing power using gasification. This present study is concerned about design, development and performance evaluation of a downdraft gasifier for different equivalence ratio for mango wood shavings and pellets.

## 2. Methodology

For the experiment, a 5 KW lab scale downdraft gasifier was used. The dimensions and materials used for the gasifier is presented in **Table 1**. The CAD model and the actual experimental setup is presented in **Figure 1** and **2** respectively. Air was supplied via a compressor in the middle portion of the gasifier, and feedstock fed from the top of the gasifier. A rotameter with a flow measuring capacity of 200 lpm was used to monitor the rate of air flow. A ball valve was in charge of managing the airflow. The gas outlet was wired up to an infrared gas analyzer Portable SYN-600. The experiment was conducted using wood pellets as the feedstock, with an average size of 50–60 mm. For initial combustion stoichiometric air was supplied. The equivalence ratio was changed and the effect of changing equivalence ratio was observed in the gas analyzer. A sustained flame can be observed in the gas burner throughout the process, emanating from the ignition of clean syngas.

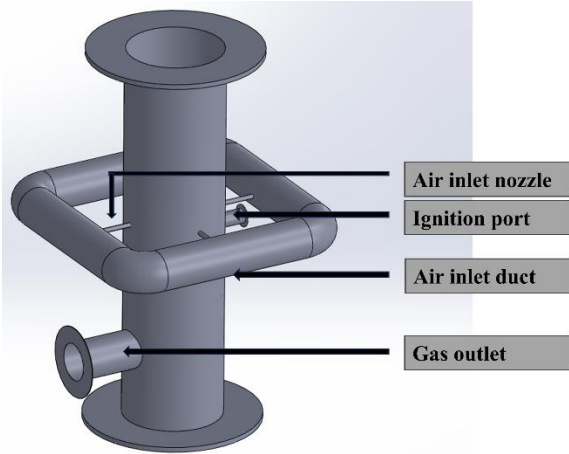


Figure 1. CAD model of the gasifier.

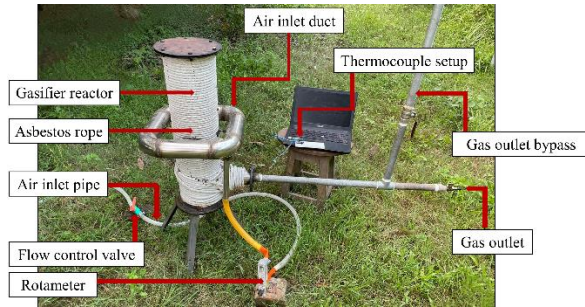


Figure 2. Experimental setup.

The equivalence ratio, lower heating value (LHV) and cold gas efficiency were calculated using equation (1-4) [12]

$$\eta = \frac{E_{syngas}}{E_{biomass}} \quad (1)$$

$$E_{syngas} = AFR \left( \frac{m^3}{h} \right) \times LHV_{pg} \left( \frac{MJ}{m^3} \right) \quad (2)$$

Where, AFR is Air Flow Rate and  $LHV_{pg}$  is the lower heating value of produced gas,

$$LHV_{pg} = \frac{(x_1 \cdot HV)_{CO} + (x_2 \cdot HV)_{H_2} + (x_3 \cdot HV)_{CH_4}}{100} \quad (3)$$

where  $x_1$ ,  $x_2$ , and  $x_3$  are the percentage of combustible gas CO,  $H_2$ , and  $CH_4$  in producer gas

$$E_{biomass} = CR \left( \frac{kg}{h} \right) \times LHV_b \left( \frac{MJ}{kg} \right) \quad (4)$$

Where, CR is biomass consumption rate and  $LHV_b$  is lower heating values of biomass.

Table 1. The dimensions for gasifier

Items	Material and Dimensions
Reactor	Height, $H = 710mm$ Diameter, $d_f = 180mm$ Stainless steel (2mm thick)
Air inlet nozzle	Number of nozzles :4 Diameter, $d_n = 6.48 mm$ Stainless steel (1mm thick)
Throat	Diameter, $d = 50mm$ Stainless steel (2mm thick)
Grate	Diameter, $d_g = 165mm$ Stainless steel, (2 mm thick + 5mm ss wire (10mm spacing))

### 3. Results and discussion

A range of 0.2 to 0.4 Equivalence Ratios (ER) have been observed as the effective gasification in the experiments [13]. The experimental run was performed on the following ten distinct ER: 0.159, 0.199, 0.212, 0.239, 0.265, 0.292, 0.318, 0.345, 0.371 and 0.385. The effect of equivalence ratio on air flowrate, lower heating value (LHV) and cold gas efficiency are reported below. In **Figure 3**, the variation of air flowrate due to the equivalence ratio is reported. As the equivalence ratio is controlled by changing the air flow rate, this result is expected. The LHV of the syngas was calculated using equation 3. From **Figure 4**, it is seen that the LHV increases from  $3.99 MJ/m^3$  to  $5.95 MJ/m^3$  between equivalence ratios of 0.212 and 0.345 and decreases after 0.345. Similar results were seen in a study by Upadhyay et al. [6]. This happens as the noncombustible  $N_2$  and  $CO_2$  gases increase in concentration and the  $H_2$  concentration decreases in equivalence ratio 0.371 and 0.385. The cold gas efficiency was calculated from equation 1. In **Figure 5**, the variation of cold gas efficiency in various equivalence ratios is portrayed. The efficiency shows an increasing pattern between equivalence ratios of 0.199 and 0.345, which is confirmed by other literatures [6], [14]. The highest efficiency was obtained in equivalence ratio 0.345 at 43.19% because the composition of CO and  $H_2$  was at its maximum in this equivalence ratio.

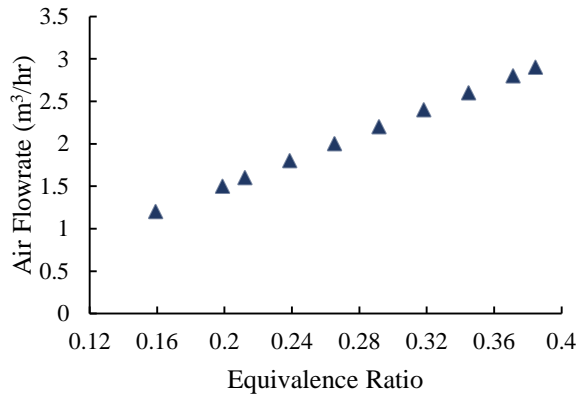


Figure 3. Flowrate in different equivalence ratios

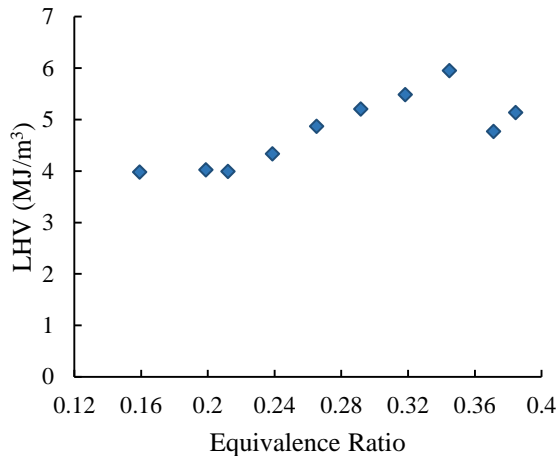


Figure 4. LHV in different equivalence ratios

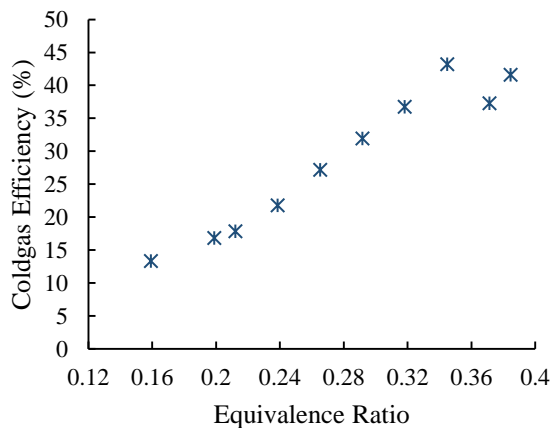


Figure 5. Cold gas efficiency in different equivalence ratios

#### 4. Conclusions

In this study, the impact of the equivalency ratio on the air flowrate, lower heating value, and cold gas efficiency in a pilot 5 KW gasifier was examined. In

this study, it was discovered that maintaining an equivalence ratio between 0.199 and 0.345 was crucial for improved gasification efficiency and LHV. Due to the altered composition of CO, H<sub>2</sub>, and CH<sub>4</sub> gas, the gasifier's effectiveness declines when the gasification process occurs outside of this specific ratio. However, the impact of temperature, moisture content on cold gas efficiency and LHV is not taken into account in this study. Furthermore, because the gasifier unit is a lab scale downdraft gasifier, additional advancements in the feeding system and gas cleaning system must be implemented in order to obtain a much better result. From this study it is clear that gasification of mango wood shavings and pellets is a cheap but good alternative source of energy with its moderate LHV. The downdraft gasifier is also proven to be a reliable but cheap energy conversion device. So it can be employed to small scale power generation purposes in isolated and remote communities.

#### References

- [1] Y. Kalinci, I. Dincer, and A. Hepbasli, "Energy and exergy analyses of a hybrid hydrogen energy system: A case study for Bozcaada," *Int. J. Hydrogen Energy*, vol. 42, no. 4, pp. 2492–2503, 2017, doi: 10.1016/j.ijhydene.2016.02.048.
- [2] S. Afzal *et al.*, "Techno-economic analysis and life cycle assessment of mixed plastic waste gasification for production of methanol and hydrogen," *Green Chem.*, vol. 25, no. 13, pp. 5068–5085, 2023, doi: 10.1039/d3gc00679d.
- [3] N. J. Rubinsin, N. A. Karim, S. N. Timmiati, K. L. Lim, W. N. R. W. Isahak, and M. Pudukudy, "An overview of the enhanced biomass gasification for hydrogen production," *Int. J. Hydrogen Energy*, vol. 49, pp. 1139–1164, 2024, doi: https://doi.org/10.1016/j.ijhydene.2023.09.043.
- [4] A. Kumar, D. D. Jones, and M. A. Hanna, "Thermochemical biomass gasification: A review of the current status of the technology," *Energies*, vol. 2, no. 3, pp. 556–581, 2009, doi: 10.3390/en20300556.
- [5] A. Fazil, S. Kumar, and S. M. Mahajani, "Gasification and Co-gasification of paper-rich, high-ash refuse-derived fuel in downdraft gasifier," *Energy*, vol. 263, 2023, doi: https://doi.org/10.1016/j.energy.2022.125659.
- [6] D. S. Upadhyay, A. K. Sakhiya, K. Panchal, A. H. Patel, and R. N. Patel, "Effect of equivalence ratio on the performance of the downdraft gasifier – An experimental and modelling approach," *Energy*, vol. 168, pp. 833–846, 2019, doi: 10.1016/j.energy.2018.11.133.

- [7] V. ChristusJeya Singh, S. Joseph Sekhar, and K. Thyagarajan, "Performance studies on downdraft gasifier with biomass energy sources available in remote villages," *Am. J. Appl. Sci.*, vol. 11, no. 4, pp. 611–622, 2014, doi: 10.3844/ajassp.2014.611.622.
- [8] H. Olgun, S. Ozdogan, and G. Yinesor, "Results with a bench scale downdraft biomass gasifier for agricultural and forestry residues," *Biomass and Bioenergy*, vol. 35, no. 1, pp. 572–580, 2011, doi: 10.1016/j.biombioe.2010.10.028.
- [9] S. S. Narendrabhai, M. H. Shaikh, and P. Sachin, "Design, development and experimental studies of downdraft gasifier," *Int. J. Adv. Res.*, vol. 4, no. 3, pp. 1279–1285, 2018.
- [10] M. A. Chawdhury and K. Mahkamov, "Development of a Small Downdraft Biomass Gasifier for Developing Countries," *J. Sci. Res.*, vol. 3, no. 1, p. 51, 2010, doi: 10.3329/jsr.v3i1.5613.
- [11] J. L. Zheng, M. Q. Zhu, J. L. Wen, and R. cang Sun, "Gasification of bio-oil: Effects of equivalence ratio and gasifying agents on product distribution and gasification efficiency," *Bioresour. Technol.*, vol. 211, pp. 164–172, 2016, doi: 10.1016/j.biortech.2016.03.088.
- [12] Y. Zhang *et al.*, *Gasification technologies and their energy potentials*. Elsevier B.V., 2019. doi: 10.1016/B978-0-444-64200-4.00014-1.
- [13] A. A. P. Susastriawan, H. Saptoadi, and Purnomo, "Small-scale downdraft gasifiers for biomass gasification: A review," *Renew. Sustain. Energy Rev.*, vol. 76, no. May 2016, pp. 989–1003, 2017, doi: 10.1016/j.rser.2017.03.112.
- [14] P. N. Sheth and B. V. Babu, "Experimental studies on producer gas generation from wood waste in a downdraft biomass gasifier," *Bioresour. Technol.*, vol. 100, no. 12, pp. 3127–3133, 2009, doi: 10.1016/j.biortech.2009.01.024.