IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 20, Issue 1 Ser. III (Jan. – Feb. 2023), PP 40-46
www.iosrjournals.org

Experimental Investigations on Integrated Downdraft Gasifier for Heating& Power Applications Using Segregated Dry Municipal Solid Waste (SDMSW) and Biomass Blends.

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Abstract: *This experimental study investigates the use of an integrated downdraft gasifier for heating and power applications, using segregated dry municipal solid waste (SDMSW) and biomass blends. The study aims to evaluate the gasification performance and to develop an efficient gas-cleaning system to achieve tar-free producer gas.*
Background*: The proper management of solid waste has become a critical concern in modern times due to its significant impact on the environment and human health. Segregated Dry Municipal Solid Waste (SDMSW) is a type of solid waste that has potential as a renewable energy resource, but its management and disposal have been a challenge for municipalities. The integration of SDMSW with biomass in a downdraft gasifier has been suggested as a viable solution for waste management and renewable energy production.*
Materials and Methods*: The gasifier was designed, fabricated, and installed with the gas-cleaning system. The SDMSW and biomass blends were gasified at different operating conditions, and the results were analyzed.*
Results*: The study found that the gasification efficiency increased with increasing biomass blending ratio. The gas-cleaning system effectively removed tar from the producer gas. The study also demonstrated that the produced gas could be used for heating and power applications, indicating the potential for sustainable waste management and energy generation.*
Conclusion: *A gasification plant processed a blend of SDMSW and biomass, producing producer gas with an efficiency range of 24.83% to 68.78%. The 50/50 blend provided a relatively good efficiency of 48.09%.*
Keywords: *Downdraft gasifier, Co-gasification, producer gas, mechanical filtration, Syngas.*

Date of Submission: 20-02-2023 Date of Acceptance: 03-03-2023

I. INTRODUCTION

Access to water and energy is crucial for sustainable development, especially in the face of energy crises and increasing global population[1]. Alternative sources of clean and renewable energy are needed, and municipal solid waste (MSW) is a promising option for energy production[2,3]. Gasification technology, specifically Integrated Downdraft Gasifiers, can convert MSW and biomass into producer gas, clean and high-quality gaseous fuel for heating applications[4,5]. This paper provides an overview of gasification technology and the benefits of using MSW and biomass for heating purposes. The downdraft gasifier operates at low temperatures and pressures and converts organic matter into producer gas through pyrolysis and reduction[6,7,8].

Three stages of pyrolysis, combustion, and gasification result in the production of producer gas, which can be generated from MSW and any type of biomass regardless of its chemical composition[9,10,11,12]shown in Figure 1. With a 30 percent efficiency and minimal environmental impact, the proposed gasifier has shown potential. Researchers have suggested various design modifications to gasifiers to process SDMSW along with biomass, and several methods, including syngas cleaning systems, are available to limit tar formation and generate high-quality gas with the required composition[13,14,15]. A fixed bed downdraft gasifier is the most straightforward technique to construct and operate for the co-gasification of SDMSW and biomass, making it an attractive option for heat and power generation in remote rural communities[16,17,18,19,20].

Despite the potential benefits of using SDMSW as a feedstock for gasification, there are still some significant challenges that need to be addressed in order to optimize the efficiency of the process.

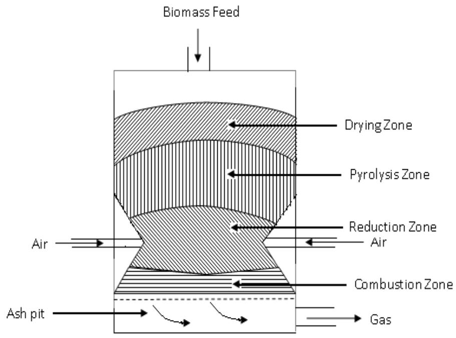


Figure 1. Downdraft gasifier with various zones

In this work, an experimental setup was designed and developed at MVSR Engineering College, Hyderabad, to investigate the performance of an integrated downdraft gasifier in processing segregated dry Municipal Solid Waste (SDMSW) and biomass blends[19]. The study focuses on the efficiency of a redesigned gasification plant that processes a blend of segregated dry municipal solid waste (SDMSW) and biomass to produce producer gas.The goal of this research is to optimize the operating parameters of the gasifier to achieve maximum gas production while ensuring high gas quality and efficiency.

II. Materials and Methods

The experimental setup was established on the college campus for the co-gasification of SDMSW and biomass. This approach is novel in its processing of dry leaves and carpentry wood waste through co-gasification. The experimental setup incorporates a cleaning system to purify the producer gas produced in the gasification process, shown in Figure 2.

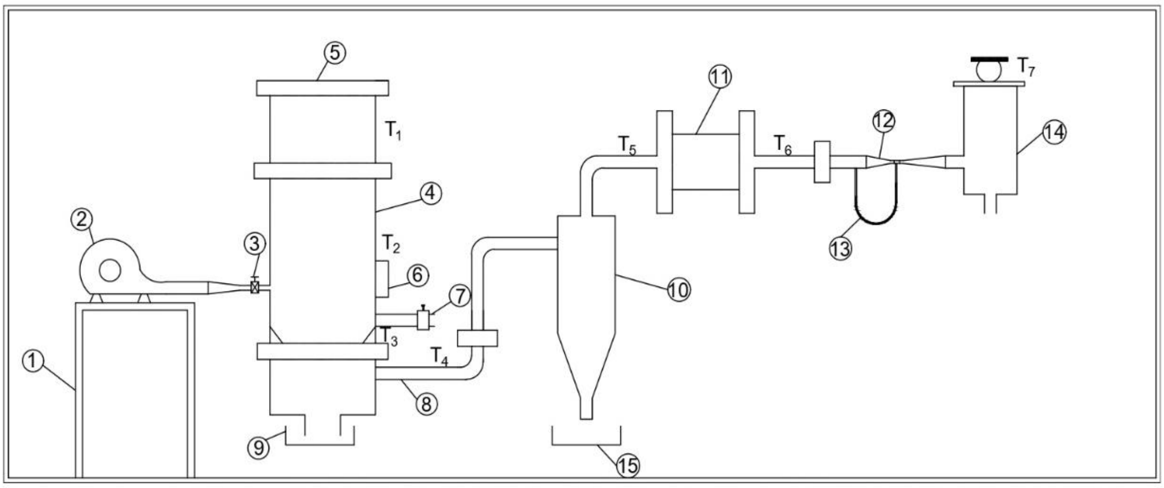


Figure 2. The schematic layout of the experimental setup with the cleaning system

Various parts of the experimental setup are (1) a support stand for the air blower, (2) the air blower, (3) the airflow regulator, (4) the gasifier, (5) feedstock, (6) the fire door, (7) gas blow-off pipe, (8) gas outlet pipe, (9) ash collection unit, (10) cyclone separator, (11) wet scrubber, (12) gas flow meter, (13) manometer, (14) gas burner.

The gasification process involves a Single Thorat Downdraft Gasifier fed from the top, that introduces SDMSW and biomass pellets. The process starts by igniting the pellets in a rich oxygen environment, with a blower providing air to enhance gasification. The pellets undergo thermochemical degradation in four stages, with drying occurring in the first stage, followed by pyrolysis in the second stage. The resulting producer gas is cooled and cleaned before being collected in balloons at the outlet vent. The third stage involves the combustion of the pellets, leading to a reduction in mass. Tar and ash are extracted as byproducts in the final stage. The calorific value of the collected producer gas is measured and tested for quality checks, with a flow meter installed at the outlet to measure the flow rate of producer gas.

One of the key components of the cleaning system is a cyclone separator. This device is used to remove particulate matter from the producer gas, thus ensuring that the gas is clean and safe for use in heating applications[21,22,23]. The design of a cyclone separator is a crucial aspect of the cleaning system, as it requires careful consideration of various factors such as the size and shape of the cyclone, the flow characteristics of the producer gas, and the type of particulate matter to be removed.

The wet scrubber is an important component in gas cleaning systems, as it effectively removes pollutants from exhaust streams. Its efficiency, low cost, and easy integration make it a popular solution for many industrial processes[24,25].

A. Design and fabrication of multi-fuel downdraft gasifier

A downdraft gasifier capable of processing both biomass and SDMSW at a rate of 30 kg/hour was developed, utilizing a multi-fuel processing design. The proposed gasifier's schematic layout is illustrated in Figure 2, and Table 1 outlines the modified gasifier's specifications.

The flow rate of the producer gas is calculated from the flow rate equation (1).

$$Qg=AV\ m^3/s \quad (1)$$

Where, Qg=Flow rate of gas, m^3/s

A= Cross-sectional area of the outlet pipe, m^2

V= velocity of producer gas, m/s

Mass of biomass/SDMSW pallet, M= Density of pallet x Volume of pallet, kg

Mass of the gas = Density of the gas x volume of the gas, kg

The Efficiency of the gasifier can be calculated from equation (2)

$$\eta = (\text{mass of gas} \times \text{calorific value of gas})/(\text{mass of pallet} \times \text{calorific value of pallet}) \quad (2)$$

Table 1: Design specifications of gasifier

Parameter	Dimension
Length (L)	1827 mm
The thickness of the gasifier (t)	3 mm
Flang dia (D_0)	342 mm
Shell external dia (D_1)	275.4 mm
Shell internal dia (D_2)	269.4 mm
The volume of gasifier (v)	0.154 m^3

B. Preparation and characterization of biomass/SDMSW pallets

High-quality producer gas production heavily relies on proper biomass/SDMSW pallets preparation. The process begins by collecting carpentry waste wood for use as biomass, which is then transformed into pallets. To prepare the desired raw materials, dry organic Municipal Solid Waste is collected from various locations on the college campus, separated, and left to sun-dry for 3-4 hours[26,27,28]. In accordance with ASTM D5231, eleven different compositions of biomass and SDMSW pallets are created, as listed in Table 5, and fed into the gasifier, as shown in Figure 3

Figure 3 combination of SDMSW and wood

A two-stage gas purification system has been implemented in the experimental setup of a downdraft gasifier to process SDMSW and biomass feedstocks as shown in Figure 4.

Figure 4 Photograph of the experimental setup

A 2D2D cyclone separator [15] is designed, fabricated, and employed in a downdraft gasifier for effective dust and tar cleaning from the producer gas[26]. Also, a wet scrubber is fitted after the cyclone separator to remove tar presented in the producer gas[30].

Figure 5. fabricated cyclone separator and wet scrubber for the experimental setup

C. Experimentation

The experiment was conducted using the setup shown in Figure 4. The process involved feeding individually composed pallets into the gasifier, which underwent the gasification process. Once the gasification process was completed, the producer gas was collected at the third stage and underwent cooling and cleaning. To determine the amount of producer gas produced for each sample composition, a venturi meter was utilized, and the speed of the producer gas was measured using an anemometer. The effectiveness of the gasifier was then calculated using equation (2), and the results were recorded in Table 5.

III. Results and discussions

The study investigated the effect of blending ratios on the generation of producer gas, and the results indicate that the amount and quality of the produced gas is significantly influenced by the blending ratio. The volume and mass of the gas decreases as the ratio of segregated dry municipal solid waste (SDMSW) increases as shown in Figure 6,7 respectively. The calorific value of the gas is also affected by the blending ratio, with higher SDMSW ratios resulting in a lower calorific value. However, the consistency of these trends depends on the quality of SDMSW and the calorific value of the biomass and SDMSW. The changes in the calorific value of the producer gas with different blending ratios are illustrated in Figure 8.

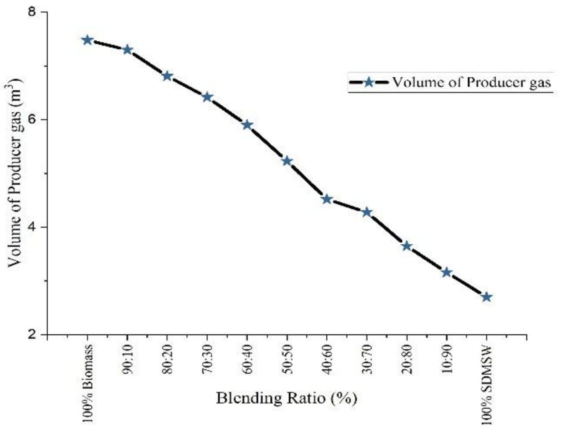
Table 2 Experimental Results for combinations of SDMSW and Biomass

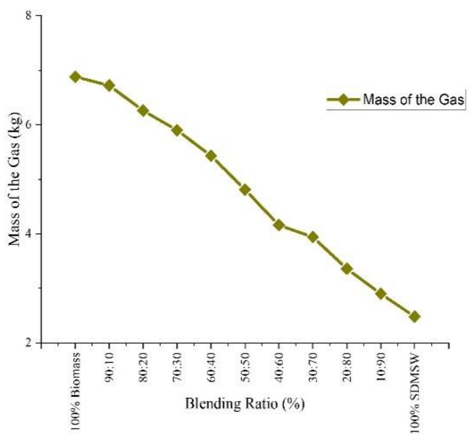
S. No.	Blending Ratio Biomass/SDMSW (w/w%)	Calorific Value of Pallets, Kcal/kg	Velocity, m/s	Flow Rate, 10^{-3} m^3/s	Time, s	Volume of gas, m^3	Mass of gas, kg	Calorific Value of Producer gas, Kcal/kg	Efficiency %
1	100% Biomass	3499.67	2.05	4.15	1800	7.48	6.88	3498.65	68.78
2	90:10	3479.72	2.22	4.51	1620	7.30	6.72	3478.68	67.18
3	80:20	3459.77	2.40	4.86	1400	6.81	6.26	3461.43	62.63
4	70:30	3439.83	2.57	5.22	1230	6.42	5.90	3442.16	59.04
5	60:40	3419.88	2.80	5.67	1040	5.90	5.43	3418.62	54.28
6	50:50	3399.93	3.00	6.08	860	5.23	4.81	3399.23	48.09
7	40:60	3379.99	3.10	6.28	720	4.52	4.16	3379.99	41.60
8	30:70	3360.04	3.30	6.69	640	4.28	3.94	3357.48	39.37
9	20:80	3340.09	3.40	6.89	530	3.65	3.36	3339.10	33.59
10	10:90	3320.15	3.50	7.09	445	3.16	2.90	3323.58	29.03
11	100% SDMSW	3300.20	3.70	7.50	360	2.70	2.48	3304.19	24.83

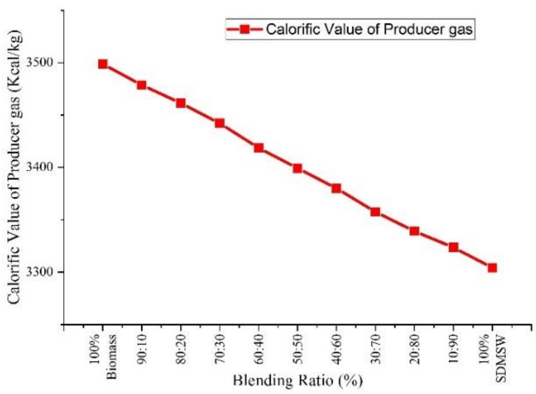
The gasification process time for 100% biomass blending is longer, taking around 1800 seconds, due to the higher density compared to the process time of 360 seconds for 100% SDMSW. This difference is a result of the greater amount of combustible components present in biomass compared to SDMSW, which plays a crucial role in producing producer gas during the pyrolysis process.

Figure 6.Volume of Producer gas vs Blending ratio Figure7. Mass of Producer gas vs Blending ratio

The decrease in producer gas mass as the proportion of SDMSW increases can be attributed to its lower density compared to biomass. The density and combustibility of the feedstock affect the thermochemical conversion of pallets during the pyrolysis process.







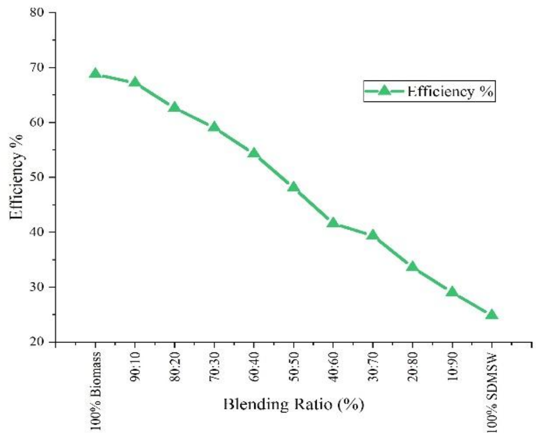


Fig. 8 Calorific value of Producer gas vs Blending ratioFig. 9 Efficiency of the gasifier vs blending ratio

This results in a decrease in the volume, mass, and calorific value of the producer gas as the SDMSW proportion increases. The gasification efficiency decreases with an increased blending ratio of SDMSW with biomass, shown in Figure 9. However, the flow rate and velocity of the producer gas increase as the SDMSW proportion increases due to the low density of SDMSW compared to biomass, which accelerates the pyrolysis process and reduces the time required to complete the gasification.These findings support trends reported by other authors[16,17,18,23,25]. however, these tendencies are not always consistent and it is dependent on the quality of SDMSW and the calorific value of biomass and SDMSW.

IV. Conclusions

The study used a redesigned gasification plant to process a blend of SDMSW and biomass, resulting in producer gas production with efficiency ranging from 68.78% to 24.83% depending on the blend ratio. The volume of producer gas decreased as the proportion of SDMSW increased, but the calorific value remained constant. A 50/50 blend of SDMSW and biomass provided a relatively good efficiency of 48.09%. The proposed gasification plant was effective in generating producer gas with satisfactory efficiency. A well-designed cyclone separator can improve the gasification process performance and ensure high-quality producer gas production.

Acknowledgments

The authors are grateful for the support given by MVSR Engineering College, Hyderabad.

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