Journal of AgriSearch, 12 (4) : 245-252
An Open Access International Peer Reviewed Quaterly

ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v12i04.15263

Design and Performance Evaluation of a Cyclone Gasifier for the Thermochemical Conversion of Sugarcane Bagasse

Manvendra Bhardwaj[1*], Rajesh Soni[1], Mahesh Chand Singh[2], Rupinder Chandel[1], Rishi Richa[3] and Yogesh Pandey[3]

ABSTRACT

The global reliance on fossil fuels has led to serious environmental challenges, driving the search for sustainable alternatives such as biomass-based energy. This study focuses on the design, development, and evaluation of a cyclone gasifier optimized for the use of torrefied and powdered sugarcane bagasse. A 1D1.5D cyclone configuration was selected to accommodate the fine particle size range (0.18–0.70 mm) produced through torrefaction and grinding. Experimental trials were conducted with a feed rate of 40 kg/h and an inlet air velocity of 12 m/s at an equivalence ratio of 0.25. The resulting producer gas had a heating value of approximately 5.0 MJ/Nm³, with carbon monoxide and hydrogen concentrations of 18% and 9%, respectively. Theoretical modeling, including pressure drop and effective turn calculations, aligned closely with observed performance. These results confirm the suitability of the proposed cyclone gasifier design for efficient biomass conversion and support its potential for decentralized energy applications.

Keywords: Cyclone separator, Gasifier, Producer gas

ARTICLE INFO

Received on	:	16/10/2025
Accepted on	:	05/12/2025
Published online	:	18/12/2025

INTRODUCTION

The global energy crisis and growing concerns about climate change have accelerated the transition towards renewable and eco-friendly energy resources to reduce dependence on conventional fossil fuels. In this context, lignocellulosic biomass is gaining attention as a sustainable, cost-effective, and cleaner alternative due to its widespread availability and low environmental impact. Biomass is a carbon-neutral energy source with environmental benefits, as the CO_2 emitted during combustion is offset by the carbon absorbed during its growth. While the potential competition between food and fuel remains a challenge, surplus agricultural biomass could serve as a viable energy source for future generations, provided appropriate conversion technologies are employed. The extensive reliance on fossil fuels has raised critical concerns globally, not only about energy security but also about the adverse environmental effects of their use. Biomass residues from food and agricultural industries contribute significantly to solid and liquid waste loads, which require proper mitigation before energy conversion applications (Richa et al., 2022). To address these issues, there is an urgent need to transition to green energy by developing advanced technologies that harness renewable resources, such as agro-forestry biomass, for bioenergy production. This shift is essential to meet the rising energy demands while ensuring sustainable development.

Agricultural biomass, a plentiful and renewable resource, can be converted into liquid biofuels and alternative biofuels, making it a promising substitute for fossil fuels. Lignocellulosic biomass, a natural polymer composed of cellulose, hemicellulose, and lignin, is particularly well-suited for these applications. Fibrous biomass materials are ideal feedstocks for thermochemical conversion processes such as pyrolysis and gasification (Mohan et al., 2006).

Cyclone gasifiers, for instance, enable the utilization of powdered bagasse, offering an efficient pathway to enhance energy recovery (Gabra et al., 1997). Torrefaction is a vital pre-treatment for biomass conversion technologies, such as gasification and co-firing. It retains about 70% of the biomass mass as a solid product while preserving 90% of its original energy content. This process not only improves energy density but also enhances the uniformity and quality of the final product (Stelt et al., 2011; Tumuluru et al., 2011). Such advancements underscore the potential of lignocellulosic biomass as a reliable and sustainable energy resource for the future. The study was conducted for cyclone design and operational parameters, particularly body height and air stream travel distance, in determining the efficiency of cyclone gasifiers. The new theoretical method was developed for predicting cyclone performance, including air stream travel distance, number of turns, and pressure drop, provides a comprehensive framework for optimizing cyclone operation in biomass gasification systems.

MATERIALS AND METHODS

This study was conducted to evaluate the performance of a cyclone gasifier specifically designed for torrefied sugarcane

[1] Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India
[2] Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India
[3] Sher-e Kashmir University of Agriculture Sciences and Technology of Kashmir, Shalimar, 190025 Srinagar Jammu and Kashmir
[*] Corresponding Author E-mail: manvendrabhardwaj19@gmail.com

bagasse. The methodology included the preparation of biomass feedstock through drying, torrefaction, grinding, and sieving to achieve a consistent particle size distribution suitable for cyclone gasification. A 1D1.5D cyclone gasifier was fabricated based on design principles tailored to handle fine biomass particles efficiently. Experiments were performed to assess gasification performance under controlled air flow and feed conditions, and theoretical modeling was used to predict key parameters such as pressure drop, number of effective turns, and overall efficiency.

Evaluation procedure

Sieving was performed on both torrefied and raw bagasse to analyze the particle size distribution. For torrefied bagasse, with torrefaction durations ranging from 30 to 60 minutes, approximately 78–89% of the particles fell within the size range of 0.18 to 0.70 mm. In contrast, the particle size of raw bagasse was irregular and inconsistent. Based on these observations, a torrefaction duration of 30 minutes is recommended to reduce power consumption while achieving favorable grinding characteristics (Bhardwaj and Soni, 2016). The choice between 30 and 60 minutes of torrefaction depends on weighing the energy required for each duration against the additional sieving effort needed for bagasse torrefied for 30 minutes. The final decision should consider the scale of the operation and its associated requirements (Bhardwaj et al., 2019).

Torrefaction and Particle Size Distribution

The bagasse was air-dried to achieve a moisture content of approximately 10%. For each trial, 400 g of raw bagasse was used, and torrefaction was carried out at a temperature of 230°C for durations of 0, 20, 30, 40, 50, and 60 minutes. Each treatment was replicated three times. A locally manufactured bakery oven was employed for the torrefaction process.

Following torrefaction, the bagasse was ground using a locally made 3 HP single-phase grinder, equipped with a 3 mm sieve. The torrefied and raw bagasse samples were then sieved to determine their particle size distribution. Sieving was performed using five sieve sizes: 0.18 mm, 0.35 mm, 0.70 mm, 1.4 mm, and 2.8 mm. The sieving process was conducted using the Macro Rotap Sieve Shaker (Model MSW-323), which operates with both oscillating and reciprocating motions. Each sieving operation was run for 5 minutes to ensure proper separation of particle sizes (Bhardwaj et al., 2019).

Experimental Setup and Operating Conditions

The fabricated cyclone includes a 150 mm diameter barrel, a cone with top and bottom diameters of 150 mm and 75 mm, a tangential inlet duct (38 x 75 mm), a 93.7 mm diameter cleaned gas outlet, and a 78 mm diameter dust outlet that is 50 mm in length. During operation, the cyclone gasifier achieved an inlet air velocity of approximately 12 m/s. Biomass with the specified particle size range was fed at a rate of 40 kg/h. At an equivalence ratio of 0.25, the producer gas generated had a heating value of approximately 5.0 MJ/Nm^3. The gas composition analysis revealed carbon monoxide (CO) and hydrogen (H_2) concentrations of 18% and 9%, respectively.

For efficient cyclone gasifier operation, continuous fuel feeding is essential. The cyclone also acts as a particle separator. Bagasse powder was gasified in a cyclone gasifier at a relatively low temperature of 950°C and at atmospheric pressure. The gasification process remains stable within certain ranges of conditions, ensuring the system runs smoothly. A side view and top view of the cyclone gasifier are shown in Fig. 4. The complete experimental setup is shown in Fig. 5.

Cyclone Design and Modeling

Cyclone designs

In agricultural processing sector, the 2D2D (Shepherd and Lapple, 1939) and 1D3D (Parnell and Davis, 1979) cyclone designs are commonly used to control particulate matter emissions. In cyclone designations, "D" stands for barrel diameter. A 2D2D cyclone has barrel and cone lengths twice the barrel diameter, while a 1D3D cyclone has a barrel length equal to the barrel diameter and a cone length three times the barrel diameter. These two cyclone configurations, illustrated in Fig. 1, have been extensively studied. Research by Wang et al. (2006) highlighted that 1D3D and 2D2D designs are particularly effective at capturing fine dust particles with diameters smaller than 100 μm, making them highly efficient options compared to other cyclone designs.

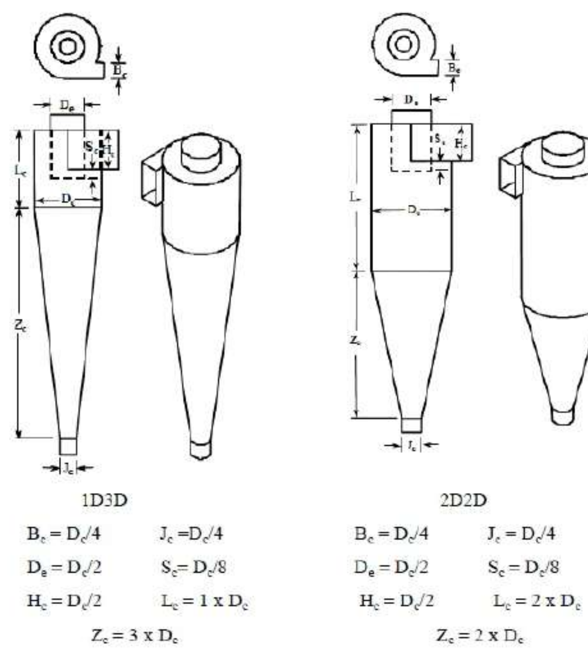

Fig. 1: 1D3D and 2D2D cyclone configurations

Mihalski et al. (1993) observed that "cycling lint" near the trash outlet was a notable issue in the 1D3D and 2D2D cyclone designs when particulate matter (PM) in the incoming air stream contained lint fibers. This phenomenon resulted in a significant increase in PM concentrations at the clean air exit. Mihalski attributed this to small lint fiber balls that cycled near the trash exit, diverting fine particles—normally collected—towards the clean air stream. To address this issue in the cotton ginning industry, Simpson and Parnell (1995) introduced the 1D2D cyclone, a new low-pressure cyclone design specifically aimed at resolving the cycling-lint problem. Subsequently, Wang et al. (1999) reported that the 1D2D cyclone performed more effectively for trash with high lint content compared to the 1D3D and 2D2D cyclone designs. The configuration of the 1D2D cyclone is depicted in Figure 2.

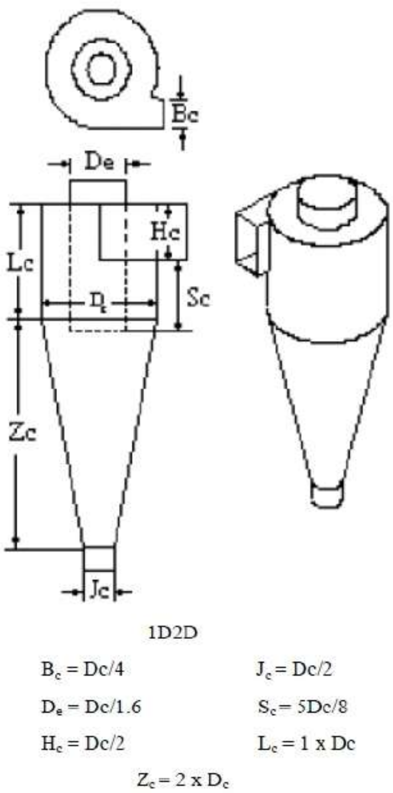

Fig. 2: 1D3D and 2D2D cyclone configurations

Theoretical considerations in Classical Cyclone Design (CCD)

The classical cyclone design process requires the engineer to know flow conditions, particulate matter concentrations with particle size distribution, and the intended cyclone type (high efficiency, conventional performance, or high throughput).

Number of Effective Turns (Ne)

The first step in classical cyclone design is determining the number of effective turns, which refers to the gas revolutions in the outer vortex. More effective turns improve collection efficiency of cyclone. The Lapple model provides the formula for calculating the number of effective turns (Ne) as follows:

$$Ne = 1/Hc\,[Lc + Zc/2] \qquad (1)$$

where,

Ne = Number of effective turns
Hc = Height of tangential inlet duct
Lc = Length of cyclone barrel
Zc = Height of cyclone cone section

Using equation 1, the predicted number of effective turns (Ne) for the 1D1.5D cyclone design was calculated and compared with those of the 1D2D, 2D2D, and 1D3D cyclone configurations, as illustrated in fig. 1 & 2. These cyclone designs share identical inlet dimensions (Hc and Bc), commonly referred to as the 2D2D inlet. In the case of the 1D3D cyclone, the inlet height equals the barrel diameter (Hc = Dc), while the inlet width is one-eighth of the barrel diameter (Bc = Dc/8). A comparison of the predicted Ne values with the observed Ne values is presented in Table 1. It is important to note that the Ne model, originally developed by Shepherd and Lapple (1939), is specifically applicable to 2D2D cyclone designs.

Table 1: Number of effective turns (Ne)

Cyclone	Lapple	Observed
1D1.5D	3.5	N/A
1D2D	.0	N/A
2D2D	6 .0	6.0
1D3D	5 .0	6.0

Cut-Point (d_{50})

The cut-point of a cyclone refers to the aerodynamic equivalent diameter (AED) of particles that are collected with 50% efficiency. A higher cut-point corresponds to a lower collection efficiency. The cut-point can be calculated using the following Lapple model equation:

$$dpc = [9\mu W/2\pi Ne\, Vi]1/2 \text{ (in AED)} \qquad (2)$$

where, Dpc = Cut-point diameter (AED)
μ = Dynamic viscosity of air
W = Width of cyclone inlet duct
Ne = Number of effective turns
Vi = Inlet air velocity

This equation (2) demonstrates that the cut-point is independent of the characteristics of the inlet particulate matter. However, the cut-point shifts when there is a change in the inlet particle size distribution. Therefore, the Lapple model for the cut-point needs to be adjusted to account for the particle characteristics of the inlet particulate matter.

Fractional Efficiency Curve (FEC – ηj)

Building on the cut-point, Lapple developed an empirical model (equation 3) to predict the collection efficiency for any particle size, commonly referred to as the fractional efficiency curve:

$$\eta j = 1/\, 1 + (dpc/dpj)2 \qquad (3)$$

where, Hj = Fractional efficiency for particle size j
Dpc= Cut-point diameter (AED)
Dpj = Particle diameter for size class j

Overall Efficiency (η_o)

When the particle size distribution at the inlet is known, the overall collection efficiency of a cyclone can be calculated based on the fractional efficiency curve of the cyclone. The overall collection efficiency is the weighted average of the collection efficiencies for various particle size ranges, as given by:

$\eta o=\Sigma\eta j m j$ (4)

where, ηo = Overall collection efficiency
ηj = Fractional efficiency for particle size j
mj = Mass fraction of particle size j

Table 2 compares the cyclone overall efficiencies predicted by the Lapple model and those measured experimentally by Wang (2000). This comparison indicates that the Lapple model significantly underestimates the actual cyclone collection efficiency. Consequently, the Lapple model for the fractional efficiency curve (equation 3) requires correction to improve its accuracy.

Table 2: Overall Efficiency of cyclone

Cyclone	Lapple Model (%)	Measured (%)(Wang et. al, 2000)
1D1.5D	77.2	94
1D2D	78.9	95
2D2D	86.6	96
1D3D	85.2	97

Pressure Drop (ΔP)
Cyclone pressure drop is a crucial parameter to consider when designing a cyclone system. The first step in this approach is to calculate the pressure drop in terms of the number of inlet velocity heads (Hv) using equation 5. The second step is to convert the number of inlet velocity heads to a static pressure drop (ΔP) using equation 6:

Hv = K * HW/De2 (5)

ΔP = ½ * ϱg Vi2 Hv (6)

where, Hv = Number of inlet velocity heads
K = Empirical constant (depends on design)
HW = Inlet duct height or width (undefined in manuscript)
De = Diameter of cleaned gas outlet
ΔP = Cyclone pressure drop
ϱg = Density of gas (typically air)
Vi = Inlet air velocity
Hv = Inlet velocity heads

Leith and Mehta (1973) noted that the Lapple pressure drop equation does not account for any vertical dimensions contributing to pressure drop. It has been observed that cyclone efficiency increases with the increase in vertical dimensions. Therefore, a new scientific approach is necessary to accurately predict cyclone pressure drop, considering the vertical dimensions of the cyclone.

Texas A&M Cyclone Design (TCD)

Sizing Cyclone

The TCD approach for designing cyclones involves determining optimum inlet velocities (design velocities) for different cyclone designs. The design inlet velocities for 1D3D, 2D2D, 1D2D, and 1D1.5D cyclones are 16 m/s ± 2 m/s, 15 m/s ± 2 m/s, 12 m/s ± 2 m/s, and 12 m/s ± 2 m/s, respectively. With the design inlet velocities known, a cyclone's dimensions can be easily determined using the following formula:

Dc=(8Q/Vi)1/2=Dc=(8*12/4.5)1/2=16±1cm= 15cm= 150mm (for 2 inch dia) (7)

- The average freely flowing bagasse feed rate is 42.66 kg/h.
- Kaupp and Goss (1984) indicated that for dry density medium dust, a carrying velocity of 15 m/s is required. Given the cyclone gasifier was operated with particles in the range of 0.18 to 0.70 mm, a slightly lower velocity of 12 m/s was selected.
- The calculations are based on the following design parameters:

Equivalence ratio (ER) = 0.25

The actual flow rate of bagasse powder used in the system is 40.0 kg/h.

Pressure Drop (ΔP)

The TCD process provides an empirical model for cyclone pressure drop calculation. In this model, K is a dimensionless empirical constant, with values of 5.1, 4.7, 3.4, and 3.4 for the 1D3D, 2D2D, 1D2D, and 1D1.5D cyclones, respectively:

ΔP = K* (VPi + VPo) (8)

where, ΔP = Cyclone pressure drop
K = Empirical constant (TCD approach)
VPi = Inlet velocity pressure
VPo = Outlet velocity pressure

Fractional Efficiency Curve

The cyclone fractional efficiency curve (FEC) relates the percent efficiency to the particle diameter, which can be derived from test data that include inlet and outlet concentrations and particle size distributions (PSDs). The sharpness-of-cut (slope of FEC) is defined as:

Slope = d84.1/d50 = d50/d15.9 (9)

where, d84.1 = Particle size with 84.1% collection efficiency
d50 = Cut-point diameter (50% efficiency)
d15.9 = Particle size with 15.9% efficiency

Mathematical Model for Number of Effective Turns

The air stream travel distance in the outer vortex and the cyclone dimensions determine the number of effective turns in a cyclone. In the barrel part of the cyclone, the number of turns is defined by:

Ne1 = L1/ʌ* Dc (10)

where, L1 = Travel length in barrel
Dc = Barrel diameter

In the cone part of a cyclone, the number of turns is determined by

Ne2 = L2/ʌ* (Dc+Do/2) (11)

Do= Dust outlet diameter

Table 3 summarizes the calculation of air stream travel distance and number of effective turns for 1D3D, 2D2D, 1D2D and 1D1.5D cyclones with different sizes.

Table 3: Air stream travel distance and number of effective turns

Cyclone Design	Barrel Part	Cone Part	Total			
	L_1	N_{e1}	L_2	N_{e2}	L	N_e
1D3D	4.8 D_c	1.53	10.83 D_c	4.60	15.63 D_c	6.13
2D2D	9.6 D_c	3.06	7.22 D_c	3.07	16.82 D_c	6.13
1D2D	5.2 D_c	1.66	2.57 D_c	1.01	7.77 D_c	2.67
1D1.5D	1 D_c	0.31	1.50 D_c	0.63	2.50 D_c	0.94

Theoretical Analysis of Pressure Drop

Cyclone pressure loss is typically calculated by summing all individual pressure loss components:

Cyclone Entry Loss (ΔP_e)

A cyclone entry loss is the dynamic pressure loss in the inlet duct and can be determined by the appropriate equations, taking into account the specific conditions and design parameters of the system.

$$\Delta P_e = C_5 * VP_{in} \quad (12)$$

In this equation, C_5 is the dynamic loss constant and VP_{in} is the inlet velocity pressure.

Kinetic Energy Loss (ΔP_k)

This portion of energy loss results from the area change (and corresponding velocity change) between the inlet and outlet tubes. It can be calculated using specific equations tailored to the system's conditions and design parameters.

$$\Delta P_k = VP_{in} - VP_{out} \quad (13)$$

where VP_{in} is the inlet velocity pressure and VP_{out} is the outlet velocity pressure.

Frictional Loss in the Outer Vortex (ΔP_f)

Frictional pressure loss in the cyclone's outer vortex, caused by air-surface wall friction, can be calculated using Darcy's equation.

$$d\Delta P_f = f * (VPs/Ds) * dL \quad (14)$$

where D_s is the diameter and L is the length (travel distance in the outer vortex).

In the barrel part (ΔP_{f1})

The frictional pressure loss in the barrel section can be calculated as follows:

$$\Delta Pf1 = \int_0^{L1} f * \frac{VPs1}{Ds1} dL = \int_0^{Z1} f * \frac{VPs1}{Ds1} * V1 * \frac{dZ}{Vz1} \quad (15)$$

where, $D_{s1} = 0.395\ D_c$ (for 1D3D, 2D2D,1D2D and 1D1.5D)

In this equation, VP_{s1} is the stream velocity pressure determined by stream velocity V_{s1}. f is the friction factor and is a function of Reynolds number (R_e) and the degree of roughness of imaginary spiral tube surface.

$$Re = D^* V^* \varrho / \mu \quad (16)$$

The following results were obtained from equation 15 for predicting friction loss in the barrel part of a cyclone:

$$\Delta P_{f1} = 0.13 * VP_{s1} = 0.14 * VP_{in} \quad \text{(For 1D3D)}$$
$$\Delta P_{f1} = 0.27 * VP_{s1} = 0.28 * VP_{in} \quad \text{(For 2D2D)}$$
$$\Delta P_{f1} = 0.14 * VP_{s1} = 0.15 * VP_{in} \quad \text{(For 1D2D)}$$
$$\Delta P_{f1} = 0.14 * VP_{s1} = 0.15 * Vp_{in} \quad \text{(For 1D1.5D)} \quad (17)$$

<u>In the cone part (ΔP_{f2})</u>

In the cone part, the equivalent stream diameter (D_{s2}) is determined by:

$$V_{s2} * \pi * D^2_{s2} / 4 = V_{in} * D^2_c / 8 * Z / Z_{o2} \quad (18)$$

The friction pressure loss in the cone part can be determined as follows:

$$\Delta Pf2 = \int_0^{L2} f * \frac{VPs2}{Ds2} dL = \int_{Z02}^{0} f * \frac{VPs2}{Ds2} * V2 * \frac{dZ}{Vz2} \quad (19)$$

Kinetic Energy Loss Caused by the Rotational Field (ΔP_r)

Rotational loss is the pressure change in the pressure field from the cyclone cone wall to the vortex interface. This pressure change has been determined through the theoretical analysis of tangential velocity.

$$dP = \varrho * V^2_t / r * dr \quad (20)$$

Solving equation 21, the rotational loss can be obtained as follows:

$$\Delta P_r = \varrho * V^2_{in} * (R/r_o - 1) \quad (21)$$

Then, $\Delta P_r = 2\ VP_{in}$ (For 1D3D and 2D2D)

$\Delta P_r = 1.22\ VP_{in}$ (For 1D2D and 1D1.5D)

Pressure Loss in the Inner Vortex and Exit Tube (ΔP_o)

The inner vortex is assumed to have a constant spiral height and a constant angle of inclination to the horizontal. It maintains the same rotational velocity at the same radius at any vertical position. To calculate the pressure component for this part, the average pressure loss in the inner vortex and the exit tube is determined as follows:

$$\Delta P_o = C_6 * VP_{out} \quad (22)$$

In this equation, C_6 is the dynamic loss constant and VP_{out} is the outlet velocity pressure.

Cyclone Total Pressure Loss (ΔP_{total})

The total pressure drop in a cyclone is calculated by summing up the five pressure drop components:

$$\Delta P_{total} = \Delta P_e + \Delta P_k + \Delta P_f + \Delta P_r + \Delta P_o \quad (23)$$

RESULTS AND DISCUSSION

Air Flow Rate Calculations

Based on the design parameters of the 1D1.5D cyclone gasifier, the airflow and pressure-drop calculations confirm that the system operates efficiently under the selected conditions. For a target inlet velocity of 12 m/s, the corresponding inlet-pipe velocity was calculated as 4.50 m/s using continuity equations, considering the circular inlet area of 20.26 cm² and the rectangular inlet duct area of 7.6 cm². The predicted pressure-drop components including entry loss, kinetic-energy loss, frictional loss in both barrel and cone sections, rotational loss, and exit pressure loss were computed individually and summed to determine total pressure drop. For the 1D1.5D configuration at Vin = 12 m/s, the combined pressure drop was 392 Pa, consistent across all evaluated cyclone sizes due to geometric similarity. This demonstrates that the cyclone maintains an acceptable pressure requirement while delivering stable gasification performance.

Additionally, pressure-drop predictions at varying inlet velocities (4.5–20 m/s) showed a clear increasing trend, with total ΔP ranging from 42 Pa at 4.5 m/s to 1089 Pa at 20 m/s, confirming that operational efficiency strongly depends on inlet velocity selection. These calculated results validate the suitability of 12 m/s as the design velocity, balancing energy demand and separation efficiency. Overall, the computational analysis aligns well with experimental observations, supporting the effectiveness of the 1D1.5D cyclone geometry for biomass gasification applications. Calculation of results shown below

Earlier for a particle size in the range of 0.18 to 0.70 mm, velocity of 12 m/s was selected.

Area of inlet pipe, A_1 = 2 inch diameter = 20.26 cm^2

Area of rectangular cross-section of inlet to gasifier, A_2 = (3.8x2) cm^2 = 7.6 cm^2

From equation of continuity, $A_1 \times V_1 = A_2 \times V_2$

Taking velocity of rectangular cross-section (inlet to gasifier), V_2 = 12 m/s

Velocity of inlet pipe, $V_1 = (A_2/A_1) \times V_2 = (7.6/20.26) \times 12 = 4.50$ m/s

Therefore, velocity of inlet pipe is 4.50 m/s.

All the parameters i.e., A_1, A_2, and V_2 are calculated either by knowing the formula for area of circular pipe i.e., A=πr^2, area of rectangular cross-section i.e., A = l x w, velocity of outlet pipe is already known i.e., 12 m/s. By substituting all the values we know the inlet velocity of pipe.

Table 4: Predicted pressure drop for 1D1.5D at Vin = 12 m/s (2362.2 ft/min)

Cyclone Size	ΔP_e	ΔP_k	ΔP_f		ΔP_r	ΔP_o	Total ΔP
			ΔPf1	ΔPf2			
0.1 (4)	89 (0.36)	75 (0.30)	12 (0.05)	80 (0.32)	107 (0.43)	27 (0.11)	392 (1.57)
0.15 (2)	89 (0.36)	75 (0.30)	12 (0.05)	80 (0.32)	107 (0.43)	27 (0.11)	392 (1.57)
0.2 (6)	89 (0.36)	75 (0.30)	12 (0.05)	80 (0.32)	107 (0.43)	27 (0.11)	392 (1.57)
0.3 (12)	89 (0.36)	75 (0.30)	12 (0.05)	80 (0.32)	107 (0.43)	27 (0.11)	392 (1.57)
0.6 (24)	89 (0.36)	75 (0.30)	12 (0.05)	80 (0.32)	107 (0.43)	27 (0.11)	392 (1.57)
0.9 (36)	89 (0.36)	75 (0.30)	12 (0.05)	80 (0.32)	107 (0.43)	27 (0.11)	392 (1.57)

Cyclone size: metre (inch) and pressure drop: Pa (inch H_2O)

Table 5: Predicted pressure drop for 1D1.5D with Dc = 0.15 m (5.906 inch)

Velocity	ΔP_e	ΔP_k	ΔP_f	ΔP_r	ΔP_o	Total ΔP
4.5	9	6	10	14	3	42
5	16	13	17	19	5	69
8	35	29	37	42	11	153
10	62	52	64	75	19	271
12	89	75	94	107	27	392
15	140	117	146	168	42	611
16	159	133	168	191	47	697
18	190	159	200	228	57	834
20	248	207	261	298	74	1089

Velocity: m/s and pressure drop: Pa

1D1.5D Cyclone Configuration and its Calculations

The design calculations have been used to figure out the 1D1.5D design configurations.

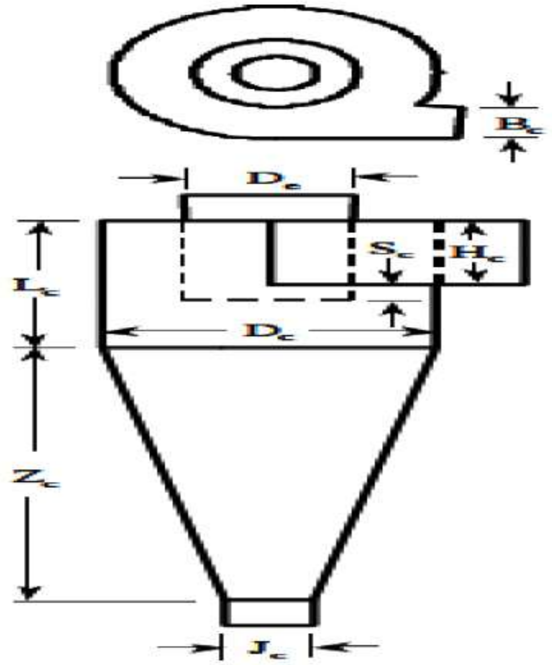

Fig. 3: 1D1.5D Cyclone Configuration

Table 6: Calculation of 1D1.5D Cyclone Gasifier

Parameters	Formula	Dimension (mm)
Diameter of blower, B_c	$B_c = D_c/4$	37.50
Diameter of dust outlet, J_c	$J_c = D_c/2$	75.00
Diameter of cleaned gas outlet, D_e	$D_e = D_c/1.6$	93.70
Distance between cleaned gas outlet bottom and tangential inlet dust base, S_c	$S_c = 5D_c/8$	93.70
Height of tangential inlet duct, H_c	$H_c = D_c/2$	75.00
Length of barrel, L_c	$L_c = 1 \times D_c$	150.00
Distance between the top and bottom of the cone, Z_c	$Z_c = 1.5 \times D_c$	225.00

Experimental Setup and Observations

For efficient cyclone gasifier operation, continuous fuel feeding is essential. The cyclone also acts as a particle separator. Bagasse powder was gasified in a cyclone gasifier at a relatively low temperature of 950°C and at atmospheric pressure. The gasification process remains stable within certain ranges of conditions, ensuring the system runs smoothly. A side view and top view of the cyclone gasifier are shown in Fig. 4.

Gasifier Performance and Gas Composition

The cyclone gasifier was evaluated using torrefied bagasse particles in the range of 0.18–0.70 mm, which were found suitable for stable gasification in a 1D1.5D configuration. The producer gas generated had a heating value of approximately 5.0 MJ/Nm^3, with carbon monoxide (CO) and hydrogen (H_2) concentrations of 18% and 9%, respectively. A bright, stable flame observed in the combustion chamber further confirmed effective gasification performance.

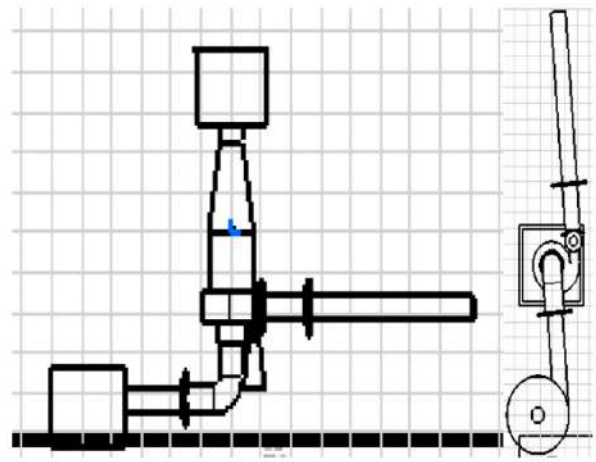

Fig. 4: Side and top view of a Cyclone Gasifier

Fig. 5: Experimental set up of Cyclone Gasifier

CONCLUSION

The study emphasizes the significant role of cyclone design and operational parameters, particularly body height and air stream travel distance, in determining the efficiency of cyclone gasifiers. The new theoretical method developed for predicting cyclone performance, including air stream travel distance, number of turns, and pressure drop, provides a comprehensive framework for optimizing cyclone operation in biomass gasification systems. Experimental results confirm the validity of these theoretical models, showing strong agreement with actual performance. Furthermore, the design parameters, including the barrel diameter and the geometry of the cyclone's inlet and outlet ducts, contribute to the overall effectiveness of the system. The biomass feeding rate of 40 kg/h, along with the measured heating value of 5.0 MJ/Nm^3 for the producer gas at an equivalence ratio of 0.25, indicates the potential for efficient gasification at the selected particle size range. The gas composition, with CO and H_2 concentrations of 18% and 9%, respectively, further supports the suitability of the cyclone gasifier for biomass conversion. These findings provide a solid foundation for optimizing cyclone design and enhancing the efficiency of gasification processes in industrial applications.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

REFERENCES

Bhardwaj M and Soni R. 2016 Torrefaction of bagasse for improving its usability as a fuel in cyclone gasifier. *Ind J Ecol*. 43: 610-612.

Bhardwaj M, Soni R and Singh M C. 2019. Fabrication of a cyclone gasifier for gasification of sugarcane bagasse. *Intl J Chemical Studies*. 7: 10072-10075.

Gabra M, Salaman H and Kjellstrom. 1997. Development of a sugar cane residue feeding system for a cyclone gasifier. *Biomass Bioenergy* 15: 143-153.

Kaupp A and Goss J R. 1984. State of the art for small (2-50 kW) gas producer engine systems, Final report to USDA, Forest service, Contact No. 53-39R-0-141, Vieweg, Wiesbaden.

Leith D and Mehta D. 1973. Cyclone performance and design. *Atmospheric Env*. **7**: 527-549.

Mihalski K, Kaspar P and Parnell C B. 1993. Design of pre-separators for cyclone collectors. In Proc. Beltwide Cotton Production Conferences, 1561-68. Memphis, Tenn.: National Cotton Council.

Mohan D, Pittman C U and Steele P H. 2006. Pyrolysis of Wood/Biomass for Bio-oil: A Critical review. *Energy Fuels* 20: 848-889.

Parnell C B and Davis D D. 1979. Predicted effects of the use of new cyclone designs on agricultural processing particle emissions. ASAE Paper No. SWR-79040. St. Joseph, Michhigan. ASAE.

Richa R, Singh A, Mahapara S, Richa S, Kumar R, Ali M and Khan K. 2022. Mitigation strategies for environmental hazards generated by food industries. *SKUAST Journal of Research* 24(1): 1-11.

Shepherd C B and Lapple C E. 1939. Flow pattern and pressure drop in cyclone dust collectors. *Industrial and Eng. Chemistry* 31: 972-84.

Simpson S and Parnell C B. 1995. New low-pressure cyclone design for cotton gins. In Proc. Beltwide Cotton Production Conferences, 680-687. Memphis, Tenn.: National Cotton Council.

Stelt Van der M J C, Gerhauser H, Kiel J H A and Ptasinski K J. 2011. Biomass upgrading by torrefaction for the production of biofuels: A review. *Biomass Bioenergy* 35: 3748-3762.

Tumuluru J S, Sokhansanj S, Hess J R, Wright C T and Boardman R D. 2011. A review on biomass torrefaction process and product properties for energy applications. *Industrial Biotechnol* **7**: 384-401.

Wang L. 2000. A new engineering approach to cyclone design for cotton gins. M S thesis. College Station, Texas: Texas A&M University, Department of Agricultural Engineering.

Wang L, Parnell C B, Shaw B W. 1999. Performance characteristics for the 1D2D, 2D2D,1D3D and barrel cyclones. ASAE Paper No. 994195. St. Joseph, Michhigan. ASAE.

Wang L, Parnell C B, Shaw B W and Lacey R E. 2006. A theoretical approach for predicting number of turns and cyclone pressure drop. *Trans ASABE* 49: 491-503.

Citation:

Bhardwaj M, Soni R, Singh M C, Chandel R, Richa R and Pandey Y.2025. Design and performance evaluation of a cyclone gasifier for the thermochemical conversion of sugarcane bagasse. Journal of AgriSearch 12(4): 245-252