

Producer Gas Generation by Utilizing Paddy Straw as a Biomass Feedstock in an Open Core Downdraft Gasifier

Mohit Sharma^{1*}, Rajneesh Kaushal², Naveen Rana³, Mohit Bhargva⁴, N.K. Batra⁵, Anukriti Sharma⁶

Abstract

In present day scenario, the burning of paddy straw seriously affects the environment in India. This paper research work is utilized to solve the above-mentioned problem. In this research work, a downdraft gasifier is used for the gasification process of paddy straw for generating Producer gas (PG). The process is carried out with air as gasifying agent. The gas composition, calorific value, temperature, and efficiency are taken as performance characteristics whereas equivalence ratio (ϕ) and feedstock are considered as input parameters. It is concluded from experiments that consumption of feedstock (Kg/hr) increased to 64 from 48 with the increase in equivalence ratio (ϕ) from 0.227 to 0.295 the feedstock consumption rate is increased from 48 to 64 kg/hr. Moreover, the values of cold gas efficiency (87.29%) and calorific value (5.32 MJ/Nm³) are observed maximum at 0.286 value of ϕ . In addition, the concentration of carbon monoxide (CO) (i.e., 17.87%) is found to be maximum at 0.248 value of ϕ . Besides this, the oxidation zone temperature is also changed from 700 - 1000°C.

Keywords: Gasification, Paddy Straw, Producer Gas, Equivalence Ratio, Calorific Value, Cold Gas Efficiency

INTRODUCTION

All over the world, energy as an input parameter plays indispensable role in economics as well as technological progress. It has been aptly alleged “life blood of modern economy” as every human operate it every day in one form or the other. The policy maker and economists around the earth noted affirmative association among its application and economic development. India holds fourth position for (PPP) Purchasing Power Parity in comparison to other nations. Additionally, Indians are

the fifth largest consumers too. The input energy could be represented with a ramp graph for analyzing different growing fields like agriculture, transport. The conservative sources which meet power demands are losing ground daily due to their exhausting nature.

Furthermore, the population sizes over the world getting two-fold by middle of the 21st century. As a result, each state must switch its emphasis from traditional energy sources to cutting-edge renewable energy technologies, which have been copiously available and non-polluting in nature for better accomplishment of their applications by the next generation.

Biomass emerged as new renewable source of energy other than existing conservative resources likewise oil, natural gas and coal (1). Energy can

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be obtained from bio waste when gasification process is led over squander from industries, irrigation and human/ fauna bio wastes (2). The following four feasible processes of producing biomass can be listed as Biochemical, Direct combustion, agrochemical and thermochemical methods (3, 4). The two prominent methods of biochemical and thermochemical are adopted for extracting power from bio waste (5). Thermochemical method is classified such as Gasification, Combustion and pyrolysis. The Gasification is the modest technique for generating energy from biomass. Though fossil fuel contains carbon neutralizing impact on environment yet the outcome of biomass as energy produced is in the renewable form (6). Thus, this is how it becomes identical from other eco- friendly resources. It finds application in vast areas of transport, generating power, and thermal appliances like heating via furnace, cook stove, many more. In India, MNRE reported a huge figure that for generating energy, biomass has been easily accessible in quantities of 500 million metric tonnes annually. Unfortunately, amount of generation of energy from bio waste is null when compared to existing resources (7, 8).

G. Venkatesh et al. (9) generated PG via. sugar cane bagasse and coconut shells in updraft gasifier. It has been reported that gasification efficiency of 52.86% and 46.96% was achieved for sugar cane bagasse and coconut shells, respectively. Fanbin Meng et al. (10) explored the consequence of gasifying agent on gasification performance utilizing sawdust as feedstock in bubbling fluidized bed gasifier. Results reported that gasifying agent has a noteworthy impact on gasifier performance. The peak value of hydrogen to carbon monoxide ratio (1.44) has been achieved when gasification was done at $\phi = 0.30$ with oxygen – steam and air – steam. Narasimhan Kodandna Ram et al. (11) performed gasification using air-steam gasifying agent in order to reduce fraction of non-combustible gases in PG. Results revealed that via. air-steam gasifying agent, H_2 fraction in producer gas increased up to 27.24% vol. Sharma and Kaushal (12, 13) utilized bio wastes such as pistachio shells and walnut shells for gasification purpose and the PG thus produced is then utilized in dual fuel diesel engine for predicting the engine performance. Laura V. Martínez et al. (14) performed gasification on corncobs by considering 18kW fixed bed gasifier to study the effect of corncob and gasifying agent mixture on system performance. It was revealed that with corncob below 10 mm size and increase in engine load the process temperature increases and consequently specific fuel consumption decreases. Jignesh P. Makwana et al. (15) enhanced PG properties while doing rice-husk gasification in fluidized bed gasifier at elevated temperature. Yash Raj et al. (16) developed producer gas by utilizing coir pitch and supplied as a dual-fuel with diesel and biodiesel for predicting performance analysis of single cylinder diesel engine. It is concluded from the experiments that a marginal increase in fraction of CO, CO₂ and hydrocarbon was observed with dual fuel mode. M. Shahabuddin et al. (17) analyzed pore diffusion effect on kinetic parameters and other gasification characteristics using coal char at 700-1200°C temperature at atmospheric conditions. The results showed the activation energy of 178 kJ/mol at a temperature range (700-900°C) in the chemically regulated region and 69 kJ/mol in the diffusion region.

Rice is considered as the primary food of nearly the world's half population (i.e., around 3.5 billion). Around 91% of rice is consumed and cultivated in Asia. According to sources for the year 2015-2016, 104.32 million ton of rice is produced in India. Apart from this 1.5 ton of paddy straw is produced for each ton of rice (18). Presently paddy straw is considered as a waste product and it is buried in open fields, causing airborne emission which is perilous for the ecosystem.

The present study has been categorized in two fragments. Firstly, gasification of bio wastes, named as paddy straw has been performed with air as gasifying agent for generating a combustible gas that is prevalently recognized as PG. Further, several parameters have been computed for assessing the gasifier's performance.

EXPERIMENTAL MODEL

A downdraft gasifier having an open core (capacity-418400 kJ/hr) installed at NIT Kurukshetra, India is used in the current experimental work to generate PG. The gasifier is designed to operate with

other accessible feed-stocks. The mild steel cylinder shell of the gasifier reactor, where thermochemical processes take place, is insulated with a 50 mm thick refractory lining. Ash removal has been accomplished using an SS-310 grate that has been operated manually. The experimental test rig is equipped with starting mechanism (i.e. blower), venturi scrubber and coarse filter (for PG cleaning and cooling) and filters (i.e. fine and fabric) for further cleaning of PG. Gasifier specifications have been presented in Table 1. The equivalency ratio (ϕ) has been changed during the experiment from 0.227 to 0.295. Additionally, the PG produced by gasifying paddy straw has been rich in components and has various uses in the production of fuel and power.

Table 1. Gasifier Specifications.

Item	Specification
Category	Downdraft
Starting mechanism	Electric blower
Temperature range	>1000°C
Conversion efficiency	>75%
Capacity (rated)	418400 kJ/hr
Storage	120 kg

EXPERIMENTAL METHODOLOGY

Initially, gasification process is commenced with 48 kg paddy straw (feedstock) and 15 kg charcoal that have been packed inside a downdraft gasifier. Due to blower action vacuum is created in gasifier. Further, air from the surrounding is imbibed inside the gasifier via an open core positioned on its upper side. Anemometer is used to measure the air velocity. Diesel (approx. 30 ml) is poured for initiation of feedstock combustion. Within a short time, interval whole of the diesel is combusted because of its poor explosive characteristics at higher temperature values. This period has been taken into consideration as the experiment's start time. Biomass has been added to the gasifier every hour or whenever its level drops below a certain threshold. Here, a coarse filter has been used to remove contaminants from the producer gas that was produced in the gasifier.

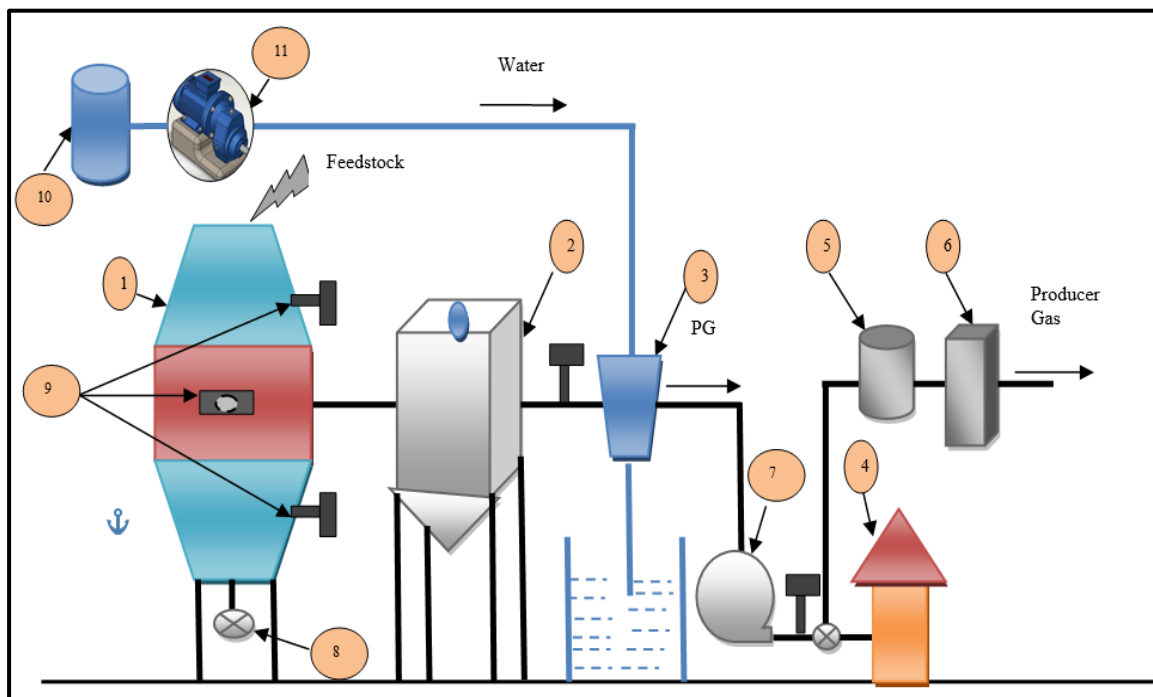


Figure 1. Schematics of Test-Rig. 1. Gasifier, 2. Coarse filter, 3. Venturi, 4. Test flare, 5. Fine filter, 6. Fabric filter, 7. Blower, 8. Grate, 9. Thermocouples, 10. Water tank, 11. Motor.

As the gas passes through the venturi, water has also been sprayed on via a jet for cooling and cleaning purposes. The reason being, water itself possess the tendency to soak hydrogen sulphide, Sulphur dioxide presents in the PG. Additionally, there has been a provision for test flare for investigating the combustion potential of the producer gas. After obtaining stable colorless flame PG is then passed through two filters (fine and fabric) so as to remove particulates and moisture, respectively. For each set of testing, an augmentation in air flow rate for subsequent observations with duration of 25 minutes in order to limit the variations. ATS206A (gas analyzer) is installed at fabric filter end to determine PG composition. Thermocouples (K type) are used to predict the temperature at different locations. The charcoal and ash have been removed via. a manually rotated grate. Figure 1. depicts the schematics of experiment test-rig.

MEASURING DEVICES SPECIFICATIONS

To measure the temperatures at distinct locations of the set-up, K-type thermocouples ($\pm 2.2\text{ }^\circ\text{C}$ accuracy) are used. Anemometer ($\pm 0.1\text{ m/s}$ accuracy) is used to measure the air velocity and the flow rate is measured using a rotameter ($\pm 2\text{ m}^3/\text{h}$ accuracy). The composition of PG and weight are measured with PG analyzer ($\pm 2\%$ accuracy) and a weighing machine ($\pm 3\text{ g}$ accuracy). To measure the time, a stopwatch ($\pm 0.01\text{ s}$ accuracy) is used during the experimentation. The uncertainty related to the measurement of air velocity and flow rate are ± 2.263 and ± 0.172 respectively. The uncertainty in measuring PG composition, temperature, time, and weight are ± 2.384 , ± 2.621 , ± 0.038 , and ± 3.800 respectively.

RESULTS AND DISCUSSION

Paddy Straw Gasification

In current research work, the gasification is carried out in downdraft gasifier (*i.e., open core*) with paddy straw (Figure 2.). It is used because of high CV. Moreover, CV of paddy straw is calculated by Equation 1. (19). Furthermore, a proximate analysis is carried out for calculating the properties of paddy straw. In addition, these calculated properties are compared with properties of different bio mass feedstock as depicted in Table 2.

$$\text{HHV} = 0.3536 \times \text{FC \%} + 0.1599 \times \text{VM \%} - 0.0078 \times \text{Ash \%} \tag{1}$$



Figure 2. Paddy Straw.

Table 2. Paddy Straw Characteristics comparison with other feedstocks (12, 13, 20).

Biomass feedstock	Parameters					
	Moisture content (% wet basis)	Volatile matter (% dry basis)	Fixed carbon (% dry basis)	Ash (% dry basis)	Density (kg/m ³)	HHV calculated (MJ/kg)
Walnut shells	9.53	75.49	14.05	0.91	255.00	16.72
Rice Husk	3.60	60.00	20.10	16.30	86.00	16.33
Pistachio shells	8.18	79.23	10.60	1.97	248.35	15.93
Paddy straw	10.21	66.94	9.08	13.75	54.00	13.53

It is observed that during gasification, air flow rate and bio mass consumption are varied with time. These variables have significant influence on gasification performance. Moreover, these parameters' effects are calculated by ϕ . It is obtained by Equation 2. (21). The final values of (ϕ) at different runs are depicted in Table 3.

$$\phi = \frac{(A/F)_{\text{actual}}}{(A/F)_{\text{stoichiometric}}} \quad (2)$$

where, A/F denotes air-fuel ratio

Table 3. Equivalence ratio (ϕ) Values at Different Runs.

Test run	Air discharge (m ³ /h)	Paddy straw feed rate (kg/hr)	Equivalence ratio (ϕ)
1	49.73	48	0.227
2	58.78	52	0.248
3	63.30	55	0.253
4	76.86	59	0.286
5	85.91	64	0.295

Feedstock Consumption Rate

The impact of ϕ on feedstock consumption rate is shown in Figure 3. With an increase in the equivalency ratio (ϕ) from 0.227 to 0.295, it has been shown that the feedstock (paddy straw) consumption increased from 48 to 64 kg/h. It has been owing to presence of higher amount of oxygen at higher values of ϕ . Another reason of increased feed stock consumption is increasing rate of Pyrolysis and drying process.

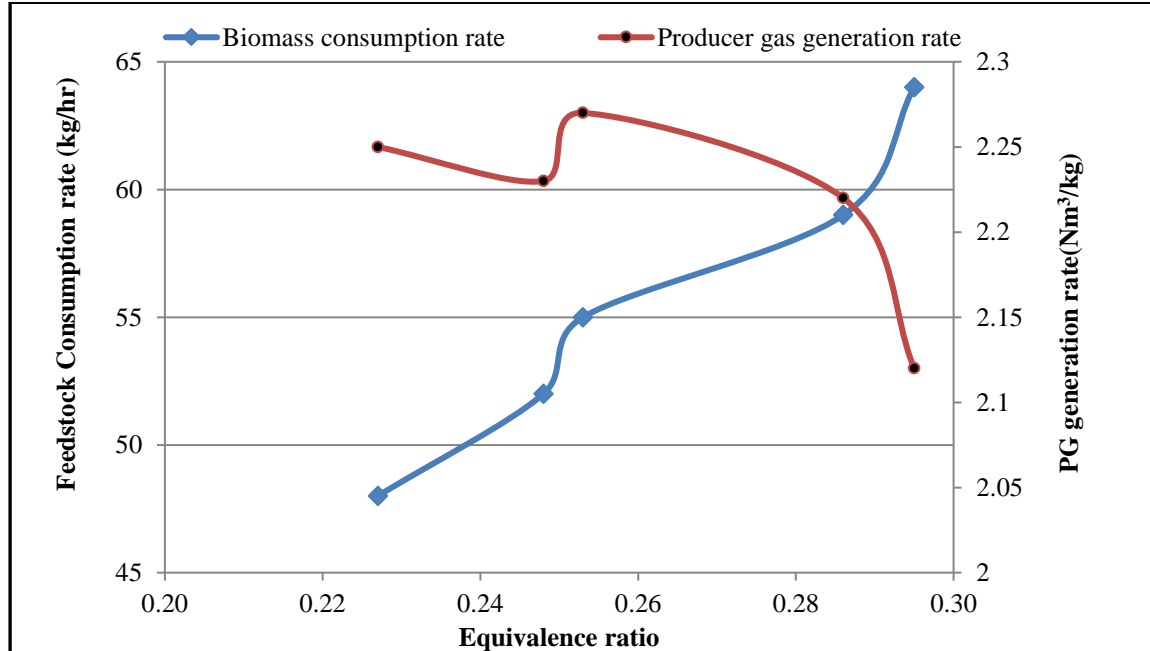


Figure 3. Feedstock consumption rate and PG production Rate Variation with ϕ .

PG Generation Rate

Equation 3. (13) has been utilized for obtaining the values of (PG) generation rate. The values of PG generation rate have presented in Table 4.

$$\text{PG generation rate} = \frac{\text{PG flow rate}}{\text{Feedstock consumption rate}} \quad (3)$$

Table 4. Producer gas (PG) Generation Rate.

Test run	Equivalence ratio	Producer gas flow rate (Nm ³ /hr)	Producer gas production rate (Nm ³ /kg)
1	0.227	108	2.25
2	0.248	116	2.23
3	0.253	125	2.27
4	0.286	131	2.22
5	0.295	136	2.12

Additionally, it has been inferred that the improvement in the equivalency ratio (ϕ) caused the feedstock consumption and producer gas flow rate to rise. Figure 3. gives the variation of PG production rate and equivalency ratio. It is abundantly evident from Figure 3. that the PG generation rate has been at its maximum value i.e. 2.27 m³/kg, when the equivalency ratio (ϕ) is equal to 0.253.

Thermal Profile

In regard to the equivalency ratio (ϕ), Figure 4 shows the temperature variation at various stages of gasification. The combustion phase temperature ($T_2 = 257^\circ\text{C}$) and pyrolysis phase temperature ($T_3 = 912^\circ\text{C}$), as shown in Table 5. reached their peak values at $\phi = 0.248$.

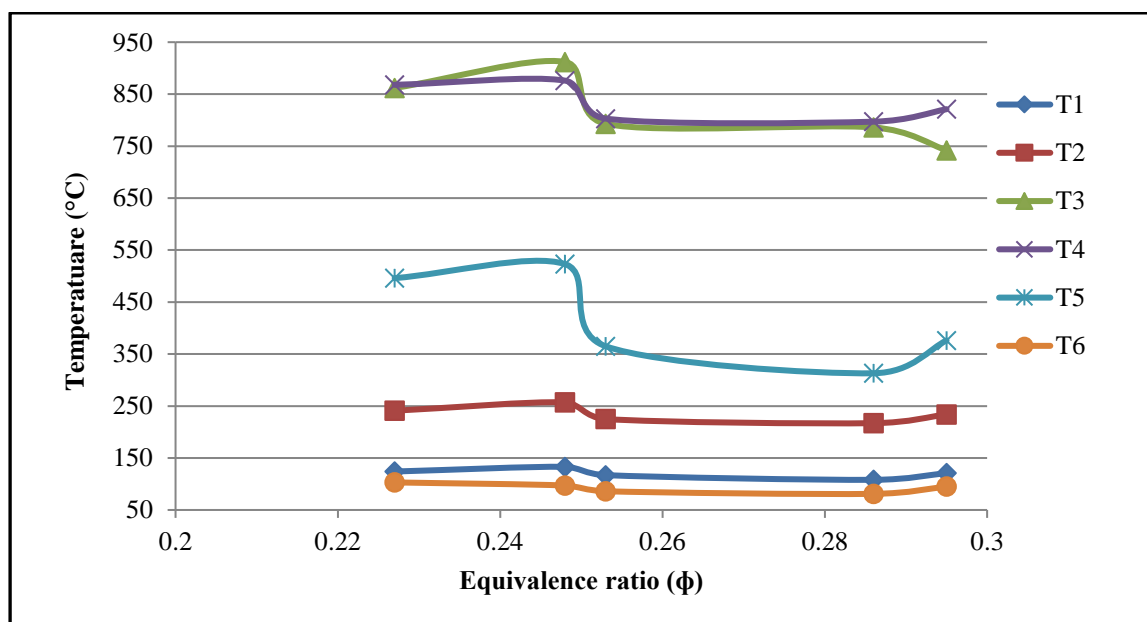


Figure 4. Temperature Variation with (ϕ).

The combustion chamber temperature is influenced the most by the thermal energy of feedstock combustion and air velocity. Increased airflow increases the amount of O₂ reaching the oxidation zone, this also enhanced the fraction of nitrogen which works as a heat energy carrier. As a result, temperature recorded for combustion and pyrolysis zones drops at higher (ϕ) values. Table 5 depicted how the temperatures varied throughout the gasification system.

Table 5. Temperature Distribution in Gasification System.

(φ)	Temperature (°C)					
	Drying (T_1)	Pyrolysis (T_2)	Combustion (T_3)	Reduction (T_4)	PGTACF (T_5)	PGTAV (T_6)
0.227	124	241	862	868	496	102
0.248	133	257	912	876	523	97
0.253	117	225	793	803	365	86

0.286	108	217	786	797	313	81
0.295	121	234	742	821	376	95
PGTACF: PG temperature after course filter PGTAV: PG temperature after venturi						

Producer Gas (PG) Composition

During Gasification, gas analyzer (Applied Techno System ATS 206A) is used for measuring the PG composition. Figure 5. depicts the variation of PG composition with equivalence ratio (ϕ). Experimental results revealed that maximum 13.67% of H₂ gas is available in PG at (ϕ) value of 0.227. Furthermore, as (ϕ) value changes to 0.248 the fraction of CO₂ in PG reduces because CO₂ starts converting into CO in reduction zone during this equivalence ratio (ϕ) range. Further rise in (ϕ) value beyond 0.248 shows a reverse trend. The reason being, at higher (ϕ) values the amount of CO₂ produced in oxidation zone is comparatively higher than quantity of CO produced in reduction zone.

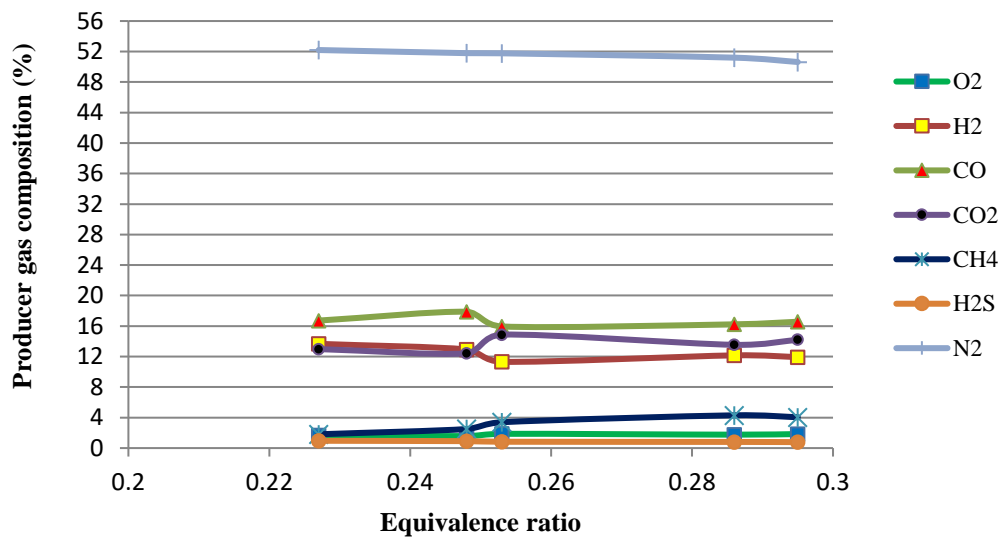


Figure 5. Producer Gas (PG) w.r.t. (ϕ).

PG Calorific Value

CV of PG is determined by Eq.4. (3). PG constituents calorific value is given in Table 6 (22).

$$CV = \frac{(a * CV)_{H_2} + (b * CV)_{CO} + (c * CV)_{CH_4}}{100} \quad (4)$$

Here, fraction of PG constituents (H₂, CO and CH₄) are measured with (ATS, model 206A) gas analyzer.

Table 6. PG Constituents CV.

Constituents	CV (MJ/Nm ³)
Methane	39.80
Carbon Monoxide	12.70
Hydrogen	12.80

Figure 6 illustrates the upshot of equivalence ratio (ϕ) on PG heating value. The fraction of CO and H₂ significantly defines the PG heating value. At (ϕ) equals 0.227, PG heating value was found to be at a minimum of 4.59 MJ/Nm³. The heating value rises continuously as the (ϕ) value increases, reaching a maximum of 5.32 MJ/Nm³ at (ϕ) equals 0.286. Similarly, to H₂ and CO, calorific value exhibits an increasing and decreasing trend with equivalency ratio (ϕ).

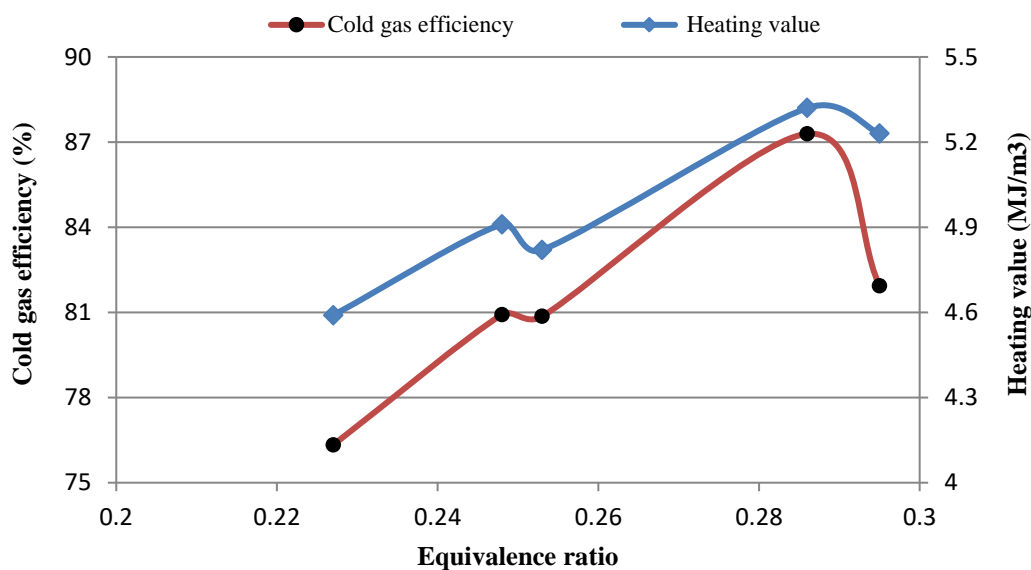


Figure 6. Impact of φ on Heating Value and Cold Gas Efficiency.

Cold Gas Efficiency

Any system's efficiency determines its acceptability. The term CGE is used in the gasification system to pronounce performance criterion. The cold gas efficiency has been calculated mathematically as per Equation 5 (23).

$$\text{Cold gas efficiency} = \frac{(\text{Yield} \times \text{CV})_{PG}}{(\text{CV})_{\text{Feedstock}}} \times 100 \tag{5}$$

Figure 6 depicts the impact of the equivalency ratio (φ) on cold gas efficiency. CGE is clearly dependent on PG output, its CV, and the fixed feedstock calorific value of 13.53MJ/kg, as revealed in Equation 5. There is an inconsequential change in cold gas efficiency as φ rises from 0.248 to 0.253. CGE ranges from 76.33% at an equivalency ratio (φ) of 0.227 to 87.29% at (φ) equal 0.286.

EVALUATION OF PERFORMANCE

Comparison of the proposed study results to those formerly presented in the literature is shown in Table 7. The findings of walnut shell gasification established that at φ equals 0.251, the CV and CGE achieved its highest values of 7.59 MJ/Nm³ and 83.07%, respectively (12). In addition, Sharma and Kaushal (13) utilized pistachio shells for experimentation. At φ = 0.378, maximum CGE (65.62%) and CV (7.35 MJ/m³) of PG were obtained. Lastly, present study findings suggested highest value of CGE and CV of PG as 87.29% and 5.32 MJ/Nm³ obtained at 0.286 value of φ respectively.

Table 7. Experimental Outcomes vs Previous Research Findings.

Investigators	Feedstock	(φ)	CV (MJ/Nm ³)	CGE (%)	PG production (Nm ³ /kg)
Sharma and Kaushal (2020)	Walnut shells	0.25	7.60	83.06	1.831
Sharma and Kaushal (2020)	Pistachio shells	0.378	7.40	65.60	1.423
Present Study	Paddy Straw	0.286	5.32	87.29	2.22

The test rig used to conduct gasification in this experimental work is capable of handling a variety of agricultural leftovers (in pellets or briquettes form). As a result, different bio wastes may be used in the future to complete the gasification process. During the testing, no distinct strategies for removing tar from PG were used. In order to obtain producer gas with lowest tar, oil scrubbers could be used during gasification. Some other methods include catalytic cracking and multi-stage gasification.

CONCLUSIONS

1. The Paddy straw consumption rate has been found to be increase from 48kg/hr to 64kg/hr with increase in equivalence ratio (ϕ) value from 0.227 - 0.295.
2. The maximum rate of producer gas generation (i.e., 2.27 m³/kg) has been observed at an equivalence ratio (ϕ) of 0.253.
3. It has been concluded that the maximum fraction of CO in producer gas (i.e., 17.87) is obtained at ϕ value of 0.248.
4. The segment of CO₂ has been increased after 0.248 value of equivalence ratio (ϕ). Conversely, CO is decreased.
5. The maximum values of temperature have been obtained at 0.248 value of equivalence ratio (ϕ) for combustion (i.e., 912°C) and pyrolysis zone (i.e., 257 °C).
6. The heating value has been seen to alter gradually when the equivalent ratio changes. The maximum value (i.e., 5.32 MJ/m³) has been obtained at 0.286 value of (ϕ).
7. At (ϕ) of 0.286, the CGE has its maximum value (87.29%).

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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