

Thermodynamic Study and Improving Efficiency of Biomass Gasifier

Alpana Singh¹, Nishant Kr Srivastava², Vinod Yadav³, Devesh Kumar⁴

¹Student, MMMUT Gorakhpur
singhalpana.14@gmail.com

²Student, SSET, SHAITIS Allahabad

³Assistant Professor, RRSIMT, Amethi

⁴Assistant Professor
MMMUT, Gorakhpur

Abstract : Gasification of solid biomass is a thermo-chemical process which converts it into a mixture of combustible gases for further usage in various applications. In this project, an attempt is made to study the thermal behavior of an existing 60 KW downdraft biomass gasifier. Rice husk is used as a feedstock in the gasifier unit. Gasifying medium is changed from air to steam (keeping all other parameters unchanged) which has led to an increase in hydrogen content of producer gas. Composition of producer gas is predicted using stoichiometric approach. Efficiency of gasifier has been evaluated by calculating volume flow rate of producer gas and fuel feed rate. It was observed that the steam gasification is best for higher yield of hydrogen gas, which further results in improved efficiency. This study will lead to improvement in efficiency of biomass gasifier by changing gasification medium.

1. INTRODUCTION

At present, the entire world is facing huge crises of fossil fuels. Further this is not the only one; degradation of environment is another major issue. According to an estimate, the petroleum reserve is depleting at such an alarming rate that it will not be available more than 218 years for coal, 41 years for oil, and sixty 63 years for natural gas, under a business cum usual scenario [1]. Due to this higher depletion rate and exponential increase in demand, prices of fossil fuel have also been increasing for the last few decades. Use of fossil fuel results in liberation of billions of tons of carbon dioxide and other allied gases, and this stimulates the Green house effect. These problems are inevitable against use of conventional fossil fuels. Hence finding alternate source of energy is the need of hour for reducing emission of green house gases and to meet sustainable power generation.

Direct use of biomass has been seen since starting of mankind but its engineering application includes thermo-chemical conversion to generate product gas. The conversion into gas makes it more cleaner source of energy either for heating or further production of electricity. This conversion takes place

in a specially designed gasifier. Here biomass is heated with a limited amount of air to produce CO₂, H₂, traces of CH₄ and some non useful products like tar and dust. The chemical reaction of biomass with limited amount of air produces carbon monoxide, hydrogen and traces of methane and non-useful products like tar and dust [2].

Purpose of biomass gasification is the production of product gas (combustible gas of low or medium heating value) for further use in power production or an internal combustion engine [3]. Major part of crop residue in developing nation such as India is either burnt due to space constraints or remains underutilized due to various reasons. This crop residue can be utilized in a cleaner way for power generation at improved efficiencies in the form of product gas [4]. Negligible cost of biomass further provides financial benefits for biomass gasification [5]. Moreover, biomass gasification through this thermo-chemical conversion process also assists in protecting environment and ecology [6, 9]. Biomass gasification is still in its nascent stages and there has been no such design which can be influenced yet. Market study shows that it is unable to compete with other technologies due to lesser efficiencies [7]. In the present study, gasification experiments have been carried out with rice husk as a biomass material in the downdraft biomass gasifier. The purpose of this study is to evaluate the performance of gasifier in terms of gasification efficiency. This study gives a thorough analysis of thermal behavior of various stages along the downdraft biomass gasifier. Present study will be helpful for us in enhancing performance of existing downdraft biomass gasifier.

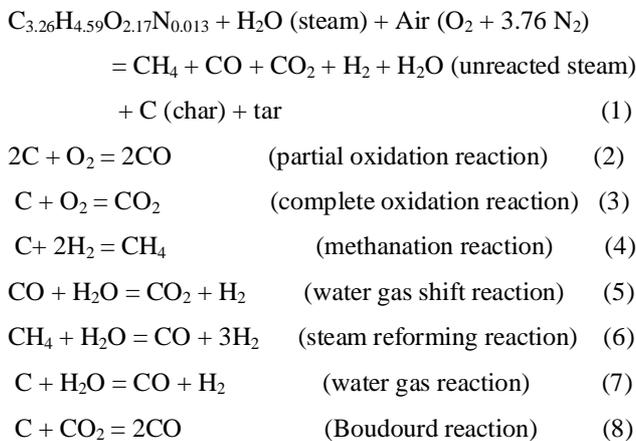
2. Theory of gasification

Gasification is a thermo-chemical process in which carbonaceous (hydrocarbon) materials (coal, petroleum coke,

biomass, etc.) are converted to a synthesis gas (syngas) or producer gas by means of partial oxidation with air, oxygen, and/or steam. Gasifier is a chemical reactor where various complex thermo-chemical and physical processes take place. A hydrocarbon feedstock (biomass i.e. rice husk) is fed into a high-pressure, high-temperature chemical reactor (gasifier) containing steam and a limited amount of air. As biomass flows through the reactor it gets dried, heated, pyrolysed, oxidized and simultaneously reduced. Under these “reducing” conditions, the chemical bonds in the feedstock are weakened by the extreme heat and pressure resulting in production of producer gas. The main constituents of resulting producer gas are hydrogen (H₂) and carbon monoxide (CO). In short, the task of gasifier is to pyrolyze the biomass to produce volatile matter, gas and carbon and further convert the volatile matter into CO, H₂ and CH₄.

3. REACTION CHEMISTRY OF GASIFICATION

In present work, the estimated molecular formula for rice husk is C_{3.26}H_{4.59}O_{2.17}N_{0.013}. It is assumed that rice husk is rapidly mixed with bed material and almost instantaneously heated up to bed temperature. Hence, the pyrolysis occurs rapidly and results in a component mix with a relative large amount of gaseous material. In equilibrium state, no solid char is produced and the main composition of product gases is CO, CO₂, CH₄, H₂ and N₂; the involved intermediate reactions takes place during the process are as follows:



Equation (5) and (6) i.e. water gas shift reaction and steam reforming reaction occur only if steam gasification is used in place of air gasification.

4. DESIGN SPECIFICATION

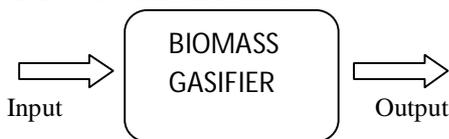


Fig 1. Biomass Gasifier

For any design, specification of plant plays the major role.

4.1 Input includes

4.1.1 Specification of fuel: Rice Husk is used as a fuel which is fed to the gasifier unit. The ultimate analysis of rice husk is shown in Table 1.

4.1.2 Gasification medium: Steam followed by air is used as a mode of gasifying medium.

Table 1. Ultimate analysis of Rice Husk [10]

Carbon %	Nitrogen %	Sulphur %	Chlorine %	Hydrogen %	Oxygen %	Moisture %	Ash %
39.1	0.18	0.04	0.09	4.59	34.7	8.20	13.2

4.1.3 Product gas: Specification of product gas includes-

- Desired gas composition.
- Desired gas heating value.
- Desired gas production rate.
- Yield of product gas per unit fuel consumed.

4.2 Output includes

The design output of process design includes geometry, operating and performance parameters.

4.2.1 Basic size: It includes calculation for reactor configuration, cross-sectional area and height.

4.2.2 Important operating parameter: It includes calculation of steam flow rate, fuel feed rate.

4.2.3 Performance parameter: It includes calculation for gasification efficiency.

5. GAS PREDICTION METHOD

Producer gas is predicted using stoichiometric approach [8] and steam followed by air is taken as a mode of gasifying medium. Thus, composition of producer gas is predicted on volume basis is:

$$CO = 28.9\% \quad CH_4 = 3.61\% \quad N_2 = 20.42\%$$

$$CO_2 = 7.2\% \quad H_2 = 39.78\%$$

The lower heating value of gas (LHV_{gas}) is calculated using formula:

$$LHV_{gas} = \sum(\text{volume \% of component} \times \text{LHV of component})$$

$$= 9232.104 \text{ KJ/m}^3$$

Calorific value of producer gas is mentioned in the table below.

TABLE 2. Calorific value of components of producer gas

Component	#Calorific value (KJ/m ³)
H ₂	10788
N ₂	----
CH ₄	35814
CO	12622
CO ₂	----

Source: Waldheim & Nilsson, 2001

6. MASS BALANCE

Process design for gasifier starts with a mass balance followed by an energy balance. The points discussed below gives the explanation for the calculation procedures for these. Basic mass and energy balance is common to all types of gasifiers. In this calculation is made to obtain product gas flow rate and fuel feed rate.

6.1 Product gas flow rate

The required power output, P (say 60KW), is an important parameter. Based on this, amount of fuel to be fed and gasifying medium required are estimated. The volume flow rate of the product gas, Q_{gas} (m³/s), from its desired lower heating value, LHV (KJ/m³), is found by

$$Q_{\text{gas}} = \frac{P}{\text{LHV}} \quad (\text{m}^3/\text{sec}) \quad [8]$$

$$= 0.0065 \text{ m}^3/\text{sec}$$

6.2 Fuel feed rate

For estimating biomass feed rate, B_f, the required power output is divided by the lower heating value of the biomass (LHV) by the gasifier efficiency, η_{gasf}.

$$B_f = \frac{P}{\text{LHV of biomass} \times \eta_{\text{gasf}}} \quad [8]$$

$$= 0.00454 \text{ kg/s}$$

LHV of rice husk can be calculated using ultimate analysis of rice husk by formula;

$$\text{HHV}_{\text{dry}} = 0.3491C + 1.1783H + 0.1005S - 0.0151N - 0.1034O - 0.0211 \text{ Ash}$$

$$= 15.913 \text{ MJ/Kg}$$

$$\text{HHV} = \text{HHV}_{\text{dry}} \left[\frac{1 - M}{1 - \text{Ash} - M} \right]$$

$$= 17.744 \text{ MJ/Kg}$$

$$\text{LHV}_{\text{Rice Husk}} = \text{HHV} - 20300H - 2260M$$

$$= 16.513 \text{ MJ/Kg}$$

where HHV_{dry} and HHV are high heating value on dry basis and moisture free basis respectively. C, H, S, N, O is the percentage of carbon, hydrogen, sulphur, nitrogen and oxygen in rice husk on dry basis respectively.

6.3. Flow rate of gasifying medium

The amount of gasification medium in addition to its composition has a major influence on yield and composition of producer gas.

6.3.1. Air: The amount of theoretical air required for complete combustion of unit mass of a fuel, air_{th}, is an important parameter. It is known as the stoichiometric air requirement, that is,

$$\text{air}_{\text{th}} = .1153C + .3434 \left[\frac{H}{8} - \frac{O}{8} \right] + .0434S \quad (\text{Kg/Kg of dry fuel})$$

$$= 4.596 \text{ Kg/Kg of dry fuel}$$

The quantity of air required, air_{gasif}, for gasification of unit mass of biomass is calculated by multiplying it by another parameter ER (Equivalence Ratio):

$$\text{air}_{\text{gasif}} = \text{air}_{\text{th}} \times \text{E.R.}$$

$$= 1.149 \text{ Kg/Kg of dry fuel}$$

For fuel feed rate, B_f, the air required of gasification is:

$$B_{\text{fa}} = \text{air}_{\text{th}} \times \text{E.R.} \times B_f \quad [8]$$

$$= 18.77 \text{ Kg/hr}$$

6.3.2. Steam: Steam (preferably superheated) is used as a gasifying medium along with air. It contributes to generation of hydrogen. The quantity of steam is known from molar ratio of steam-to-carbon (S/C).

$$\text{Steam flow rate} = \frac{B_f C}{12} \text{ (S/C)} \quad [8]$$

$$= 40.77 \text{ kg/hr}$$

7. ENERGY BALANCE

Most gasification reactions are endothermic, unlike most combustion reactions. Hence, heat must be supplied to the gasifier for these reactions to take place at the desired temperature. In commercial units, it is a major issue, and it must be calculated and provided, since it is one of major running costs. The amount of external heat supplied to the

gasifier depends on the heat requirement of the endothermic reactions as well as on the gasification temperature.

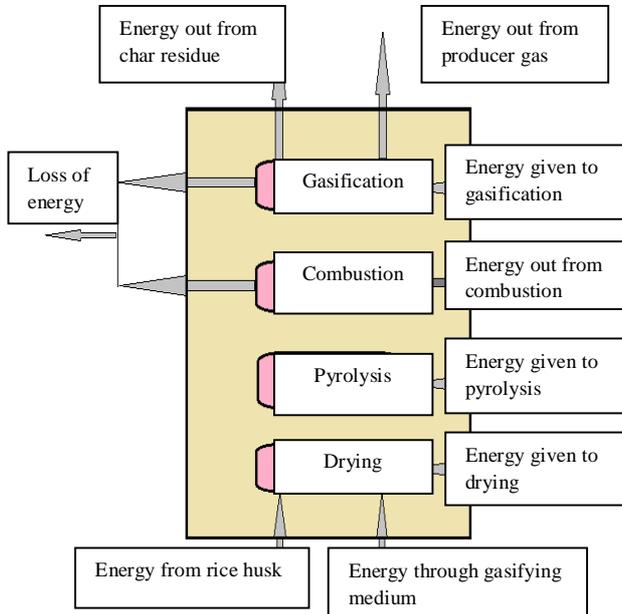


Fig 2. Energy supplied in and out of the gasifier

7.1. Gasification temperature

Since lignin, a refractory component of biomass does not gasify well at lower temperatures, because thermal gasification of lingo-cellulosic biomass prefers a minimum gasification temperature in the range 800 to 900°C. The exit gas temperature of a downdraft gasifier is about 700°C, but its peak gasifier temperature at the throat is 1000°C.

8. CALCULATIONS

This section involves the calculation of gasification efficiency and amount of gas produced in 1 kg of rice husk.

8.1. Gasification efficiency

Gasification efficiency is calculated using formula, that is,

$$\eta = \frac{LHV_{gas} \times Q_{gas}}{LHV_{rice\ husk} \times B_f}$$

$$= 80.04\%$$

8.2. Amount of gas produced in 1 kg of rice husk

Mass fraction of nitrogen and oxygen in air is 0.755 and 0.232 respectively. Nitrogen supply from air

$$= .755 \times 1.149 \text{ kg N}_2/\text{kg feed}$$

$$= 0.867 \text{ kg N}_2/\text{kg feed}$$

Total nitrogen supplied by feed air and fuel feed, which carry 0.18% nitrogen is

$$= 0.867 + 0.0018 \text{ kg N}_2/\text{kg feed}$$

$$= 0.03104 \text{ kmol N}_2/\text{kg feed}$$

Since product gas contains 20.42% of nitrogen by volume, amount of gas produced per kg of feed is

$$= 0.03104/0.2042 \text{ kmol gas/kg feed}$$

$$= 0.152 \text{ kmol gas/kg feed}$$

$$= 3.2 \text{ Nm}^3$$

Thus, amount of gas produced in 1 kg of rice husk is 3.2 Nm³.

9. RESULT

Rice husk is used as a feed material in downdraft gasifier, which produces the required power output of 60KW. Steam gasification is used as a mode of gasifying medium along with air. Its biomass feed rate is 16.34 kg/hr, steam flow rate is 40.77 kg/hr and air flow rate is 18.77 kg/hr. The outcome of study is listed in the table below.

TABLE 3. Result Analysis

Sr. No.	Particulars	Existing gasifier	Modified gasifier
1.	Gasification efficiency	70%	80.04%
2.	Amount of gas produced per kg of feed	2.5 Nm ³	3.2Nm ³
3.	Volume % of H ₂ produced	18±2%	39.78%
4.	Mode of gasifying medium	Air	Steam
5.	Typical gas composition	CO=19±3% H ₂ =18±2% N ₂ =50±2% CH ₄ =3±1% CO ₂ =10±3%	CO=28.9% H ₂ =39.78% N ₂ =20.42% CH ₄ =3.61% CO ₂ =7.2%

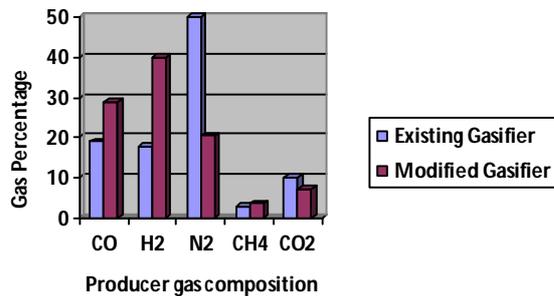


Fig 3. Gas composition analysis

10. CONCLUSION

In this work, an existing rice husk based downdraft gasifier is studied whose power output is 60KW. The efficiency of this gasifier is improved from 70% to 80.04%. It was found that steam followed by air should be used as a gasifying medium in place of air gasification. It is because steam gasification increases the partial pressure of H₂O inside gasification chamber which favors water gas reaction, water-gas shift reaction and steam reforming reaction leading to increased H₂ production. As H₂ production is increased the final gas produced is 3.2 Nm³ per kg of rice husk. This leads to further increase in efficiency of the gasifier.

11. REFERENCES

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Our study showed the improvement in thermal efficiency and emission reduction potential of micro-gasifier. A prototype micro-gasifier was built and tested using the water boiling test protocol. The test results gave a thermal efficiency of 39.6% and a specific fuel consumption of 57 g of fuel/ liter of water. The only improved biomass cookstove selected for dissemination in Ethiopia is Tikikil which has a thermal efficiency of 28% [3]. This cookstove saved on average 1.07 tons of CO₂ per stove where it is used in kaficho zone, Ethiopia [4]. Based on our study, a gasifier stove is worth promoting rather than biomass cookstoves and open-fire stoves. This is due to its thermal efficiency and less indoor air pollution and emission reduction. Biomass gasification allows the conversion of different biomass feedstocks to a more convenient gaseous fuel that can then be used in conventional equipment (e.g., boilers, engines, and turbines) or advanced equipment (e.g., fuel cells) for the generation of heat and electricity. The conversion to a gaseous fuel provides a wider choice of technologies for heat and electricity generation for small- to large-scale applications. Furthermore, electricity generation from gaseous fuels is likely to be more efficient compared to the direct combustion of solid fuels. This article provides an overview of the state-of-the-art of biomass gasification with a focus on heat and electricity generation. The product gas, however, could also be used for the production of a range of transport fuels. Gasification is the process in which biomass is converted into clean and combustible gas in the presence of limited amount of air. Maximizing the efficiency of the gasifier can be done through optimization of the operating parameters such as temperature, () and equivalence ratio (ER). The design study of a downdraft gasifier includes a gas cleaning system (cyclone and filter) and gas engine for power generation as presented in Figure 1. To minimize the formation of char and improve gasification efficiency, the gasifier employs a high-temperature air gasification (HTAG) technique. During the gasification process, highly preheated air is produced by means of an air preheater including a pair of ceramic honeycomb heat storage beds.

4.2.4 Chemistry of Biomass Gasification

4.2.5 Thermodynamics of Gasification

1 1 2 3 3 3 3 4 4 4 4. 6 6 6 6 7 7. However, more extensive biomass use still waits for the application of improved conversion methods, such as gasification, that match biomass energy to processes currently requiring liquid and gaseous fuels. The article by Schlapfer and Tobler, "Theoretical and Practical Studies of Operation of Motorcars on Wood Gas," (Schlapfer 1937) is the best practical and scientific discussion of small gasifiers to appear during that period. H. LaFontaine of the Biomass Energy Foundation to build a prototype gasifier that could be made with readily available parts and to write a "craftsman. manual" description of gasifier construction and. operation (LaFontaine 1987). 3 Exergetic efficiency of biomass gasification. Current gasifiers, such as fluidized bed and downdraft, are applied to gasify various biomass feedstocks as well as coal. The exergetic efficiency of gasification depends on the chemical composition of a fuel and in this section the efficiency of different feedstocks is compared and benchmarked against gasification of coal. The properties of biomass and biowastes can be improved by a process known as torrefaction, which comprises thermal pre-treatment in an inert gas at temperatures 230 to 300oC, Bourgois et al [4]. The torrefied biomass has a lower O/C and H/C ratio due to removal of water and carbon dioxide, as shown for beach wood in Figure 3, so.