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Thermodynamic Study and Improving Efficiency of Biomass Gasifier

Alpana Singh[1], Nishant Kr Srivastava[2] , Vinod Yadav[3] , Devesh Kumar[4]

[1]*Student, MMMUT Gorakhpur*
singhalpana.14@gmail.com
[2]*Student, SSET, SHAITS Allahabad*
[3]*Assistant Professor, RRSIMT, Amethi*
[4]*Assistant 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 CO_2, H_2, traces of CH_4 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 (H_2) 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, H_2 and CH_4.

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, CO_2, CH_4, H_2 and N_2; the involved intermediate reactions takes place during the process are as follows:

$$C_{3.26}H_{4.59}O_{2.17}N_{0.013} + H_2O \text{ (steam)} + \text{Air } (O_2 + 3.76\,N_2)$$
$$= CH_4 + CO + CO_2 + H_2 + H_2O \text{ (unreacted steam)}$$
$$+ C \text{ (char)} + \text{tar} \quad (1)$$

$$2C + O_2 = 2CO \quad \text{(partial oxidation reaction)} \quad (2)$$

$$C + O_2 = CO_2 \quad \text{(complete oxidation reaction)} \quad (3)$$

$$C + 2H_2 = CH_4 \quad \text{(methanation reaction)} \quad (4)$$

$$CO + H_2O = CO_2 + H_2 \quad \text{(water gas shift reaction)} \quad (5)$$

$$CH_4 + H_2O = CO + 3H_2 \quad \text{(steam reforming reaction)} \quad (6)$$

$$C + H_2O = CO + H_2 \quad \text{(water gas reaction)} \quad (7)$$

$$C + CO_2 = 2CO \quad \text{(Boudourd reaction)} \quad (8)$$

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

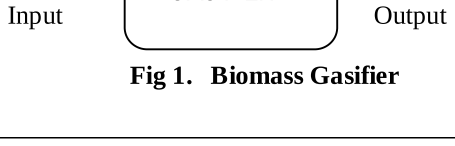

Fig 1. Biomass Gasifier

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:

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

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

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 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} (m^3/s), from its desired lower heating value, LHV (KJ/m^3), is found by

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

$$= 0.0065\ m^3/sec$$

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}.

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

$$= 0.00454\ kg/s$$

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

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

$$= 15.913\ MJ/Kg$$

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

$$= 17.744\ MJ/Kg$$

$$LHV_{Rice\ Husk} = HHV - 20300\ H - 2260M$$

$$= 16.513\ MJ/Kg$$

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 stoichiometeric air requirement, that is,

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

$$= 4.596\ Kg/Kg\ of\ dry\ fuel$$

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):

$$air_{gasif.} = air_{th} \times E.R.$$
$$= 1.149\ Kg/Kg\ of\ dry\ fuel$$

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

$$B_{fa} = air_{th} \times E.R. \times B_f \qquad [8]$$

$$= 18.77\ Kg/hr$$

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).

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

$$= 40.77\ kg/hr$$

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.

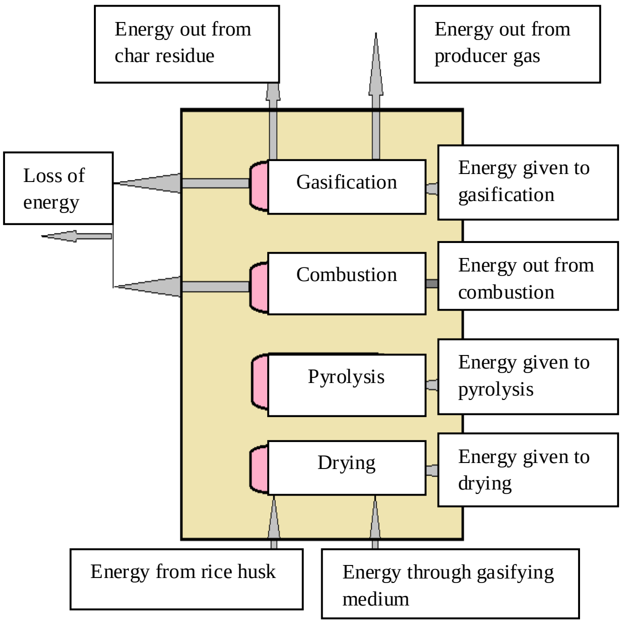

Fig 2. Energy supplied in and out of the gasifier

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

$= .755 \times 1.149$ kg N_2/kg feed

$= 0.867$ kg N_2/kg feed

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

$= 0.867 + 0.0018$ kg N_2/kg feed

$= 0.03104$ kmol N_2/kg feed

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

$= 0.03104/0.2042$ kmol gas/kg feed

$= 0.152$ kmol gas/kg feed

$= 3.2\ Nm^3$

Thus, amount of gas produced in 1 kg of rice husk is 3.2 Nm^3.

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$\pm$2%	39.78%
4.	Mode of gasifying medium	Air	Steam
5.	Typical gas composition	CO=19$\pm$3% H_2=18$\pm$2% N_2=50$\pm$2% CH_4=3$\pm$1% CO_2=10$\pm$3%	CO=28.9% H_2=39.78% N_2=20.42% CH_4=3.61% CO_2=7.2%

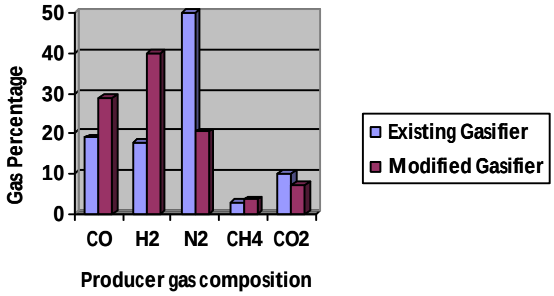

Fig 3. Gas composition analysis

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 H_2O inside gasification chamber which favors water gas reaction, water-gas shift reaction and steam reforming reaction leading to increased H_2 production. As H_2 production is increased the final gas produced is 3.2 Nm^3 per kg of rice husk. This leads to further increase in efficiency of the gasifier.

11. REFERENCES

[1] Agarwal Avinash Kumar "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines" *Progress in Energy and Combustion Science* 33(2007) 233-271.

[2] Rajvanshi Anil K; "Biomass gasification," published as a Chapter (No. 4) in book *Alternative Energy in Agriculture*, Vol. II, Ed. D. Yogi Goswami, CRC Press, 1986, pgs. 83-102.

[3] Balat Mustafa, Mehmet Balat, Elif Kirty, Havva Balat; "Main routes for the thermo-conversion of biomass into fuels and chemicals. Part 2 Gasification systems," *Energy Conversion and Management*50 (2009)3158-68.

[4] Varshney Rajiv, Bhagolia J L, Mehta C R; "Small biomass gasification technology in India-an overview," Journal of Engineering, Science and Management Education, Vol. 3, 2010/33-40.

[5] Suresh P. Basu, "Observation of the current status of biomass gasification," IEA Bioenergy Report, 2005.

[6] Panwara N.L. Kothari Richa, Tyagi V V; "Thermo chemical conversion of biomass- Eco friendly energy routes," *Renewable and Sustainable Energy Reviews* 16 (2012) 1801-1816.

[7] Kirkels Arjan F, Geert P J Verbong; "Biomass gasification: Still promising? A 30-year global overview," *Renewable and Sustainable Energy Reviews* 15 (2011) 471-481

[8] Dr. Prabir Basu, "Biomass Gasification and Pyrolysis: Practical Design" Chap-6 Design of Biomass Gasifiers, 12 May 2010, pg 167-228.

[9] Buljit Burgahain, Pinakeswar Mahanta and Vijayanand S. Moholkar, "Investigations in gasification of biomass mixtures using thermodynamic equilibrium and semi- equilibrium models" *International Journal of Energy and Environment (IJEE)*, Volume 2, Issue 3, 2011, pp.551-578.

[10] www.efe.or.th/download/BiomassAnalysis.pdf,p.1 (ultimate analysis).