An Energy Generation Opportunity from Biomass by Thermochemical Gasification Techniques

Waste management with Energy generation Approach

[1]Smit Patel, [2]Rishit Sharma, [3]Dharmendra Sapariya, [4]Umang Patdiwala,
[1]Research Student, [2]Research Student, [3]Assitant Professor, [4]Assitant Professor
[1,2,3,4] Mechanical Engineering Department, Indus University, Ahmedabad, Gujarat

Abstract: The biomass thermochemical gasification has been carried out using a fluidized bed gasifier. This work focuses on the production and analysis of syngas from biomass. In the present work four samples namely, rice husk, wood chips, sugarcane and bagasse have been studied. The effect of different parameters viz. temperature, steam to biomass ratio and equivalence ratio on syngas composition has been studied. It is observed that with the increase in steam to biomass ratio yield of hydrogen increases while equivalence ratio and temperature of fluidized bed are fixed. By experimental work it has been observed that Bioenergy generated from biomass materials

Keywords: Biomass, Gasification, Fluidized bed gasifier, Equivalence ration, thermochemical techniques, Energy Generation

I. Introduction

The traditional fossil fuels (oil, coal and natural gas) continue to be the major sources of energy in the world. The increasing energy demands will speed up the exhaustion of the finite fossil fuel. Depending of fossil fuels has led to serious energy crisis and environmental problems, i.e. fossil fuel exhaustion and pollutant emission. Carbon dioxide is the main greenhouse gas, and a major part of CO_2 emissions is due to combustion of fossil fuels. Also combustion of fossil fuel produces toxic gases, such as SO_2, NOx and other pollutants, causing global warming and acid rain. Several researches have been made to explore clean, renewable alternatives. As synthesis gas is clean and renewable source of energy it can replace the conventional fossil fuels.

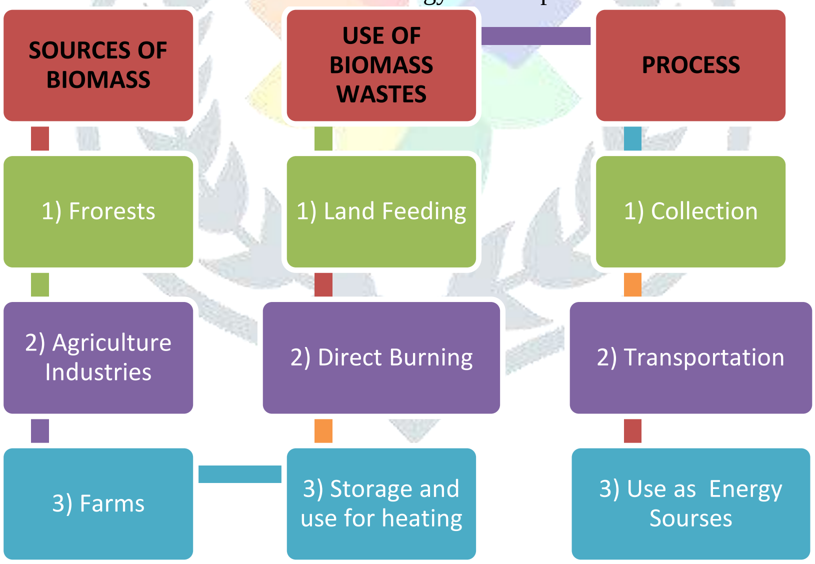


Fig. 1 Sources of Biomass and its Process

Biomass as a product of photosynthesis is one of the most abundant renewable resource that can be used for sustainable production of hydrogen. Figure 1 shows Biomass Sources its utilization and process for utilization. Gasification is a process that converts organic or fossil based carbonaceous material into a combustible gas by reacting the material at high temperature with a controlled amount of air/oxygen often in combination with steam. Biomass gasification differs from coal gasification. Biomass is a carbon-neutral and sustainable energy source unlike coal. Because biomass is more reactive and has higher volatiles content than coal, biomass gasification occurs at a lower temperature. Lower temperature reduces the extent of heat loss, emissions and material problems associated with high temperatures. Biomass also has low sulfur content, which results in lower SO_x emission. But the high alkali contents in biomass, like sodium and potassium, cause slugging and fouling problems in gasification equipment [4-5]

Figure 2 shows gasification process takes place in path of upstream processing, gasification and downstream processing. Fig.1 Indicate sources of biomass and outcome of biomass gasification [3].

The syngas generated in the process of gasification is used to produce electricity and effective mechanical power[6]. or they can potentially be used in the synthesis of liquid transportation fuels [7], H_2 or chemicals [8].

As compared to the solid fuels, gaseous fuel is believed to be more environments friendly. The process of gasification does not emit greenhouse gases in the air. The electric power generated in this process is much cheaper than the steam cycle.

Fluidized bed gasifiers are advantageous for gasification of biomass because of their flexibility in feedstock size and better contact between gases and solid. Currently, the utilization of agriculture residues like rice husk, rice straw and sugar cane bagasse for thermal energy and/or electricity generation has received tremendous attention as it do not interfere in the matter of ‘‘food/fuel’’ controversy[1].

While focusing fluidized bed gasification and its different operating conditions like equivalence ratio (ER) can be chosen as primary factors which influence the operation quite severely. The ER is defined as the ratio of the amount of oxygen (air) supplied and the amount of oxygen (air) needed for stoichiometric combustion of the fuel or biomass feedstock[2].

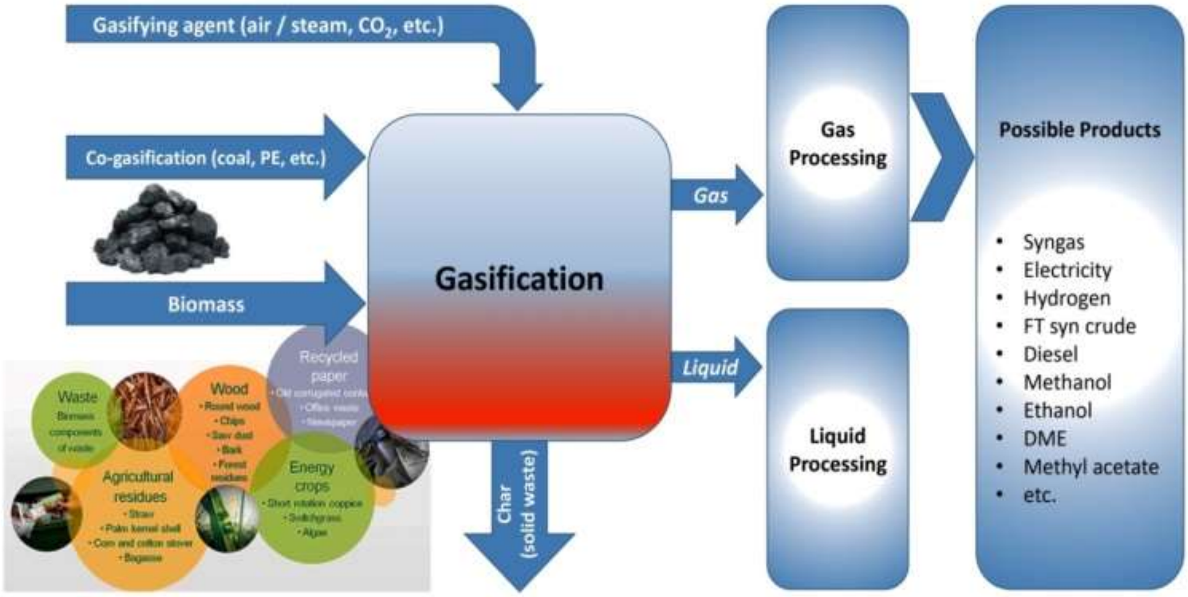


Fig. 2 Biomass gasification [3]

II. THERMOCHEMICAL GASIFICATION

Thermochemical pathways have an edge over the other routes, as commercialized biochemical processes currently have issues treating biomass rich in lignocelluloses[9]. Figure 3 shows gasification conversion zone for feed stock material

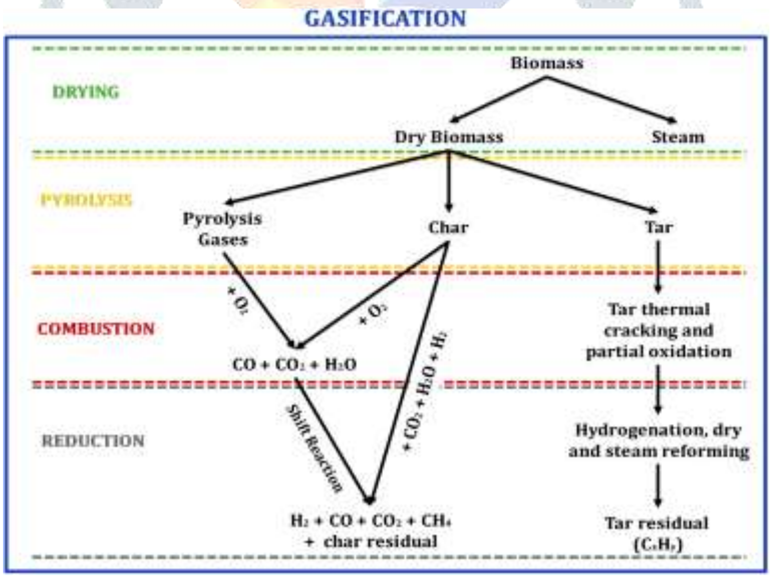


Fig. 3 Thermal cracking zone of gasification process for Biomass feedstock material [6]

Steps in gasification are listed below and are illustrated by the prevailing physical and chemical reactions.

- Drying: evaporation of the fuel moisture;

$$Fuel_{\text{raw}} \rightarrow Fuel_{\text{dry}} + H_2O(g) \quad (1)$$

- Pyrolysis (devolatilization):

The volatile fraction of fuel constituents is released into the gas phase; the remaining solid is called char, *i.e.*, fixed carbon and ash;

$$fuel_{\text{dry}} \rightarrow gases + vapors(tar) + char \quad (2)$$

- Oxidation: the products of the pyrolysis step react with an externally supplied oxidant. The most common oxidant is the O_2 molecule itself, either from the (enriched) air or in the pure form, but also steam and CO2 can act as oxidants;

Partial oxidation reaction

$$C(s) + 1/2O_2 \rightarrow CO \quad (3)$$

Combustion reaction

$$CO + 1/2O_2 \rightarrow CO_2 \quad (4)$$

Combustion reaction

$$H_2 + 1/2O_2 \rightarrow H_2O \quad (5)$$

III. Parameter impact on Gasification process

3.1 Biomass Feed stock material properties:

The cellulose to lignin ratio varies from 0.5 to 2.7 and hemicelluloses to lignin ratio ranges from 0.5 to 2.0 Thermochemical conversion processes such as BG. For every kilogram of moisture in biomass, at least 2260 kJ of extra energy is needed to evaporate the water and that spent energy is not readily recoverable [8]

3.2 Biomass partial size and Density:

Heat transfer is excellent in the particles of smaller dimensions. More controlled gasification is achieved if temperatures remain uniform throughout the feedstock particle. In addition, rate of gasification is enhanced exponentially, according to the Arrhenius rate law, with increasing temperature only when internal kinetics controls the gasification process [10].

3.3 Rate of Air Flow:

3.3.1 Equivalence ratio (ER):

Ratio of air flow to the airflow required for stoichiometric combustion of the biomass, which indicates extent of partial combustion.

3.3.2 Superficial Velocity (SV):

Ratio of air flow to the cross-sectional area of the gasifier which removes the influence of gasifier dimension by normalization [11].

3.4 Temperature:

During steam gasification, at high temperature, the H_2 yield is more pronounced than the increase in gas yield which results in an increase in H_2 content.

3.5 Catalyst:

Dolomite, limestone, olivine, alkali carbonates, Ni-based catalysts, metal-oxide catalysts, zeolite or char in the gasifier bed, either with or without sand along with the biomass feed, help reduce tar and increase the extent of reforming reactions in the gasifier, thereby increasing overall carbon conversion efficiency[12].

IV Thermochemical Gasifier techniques (TCG)

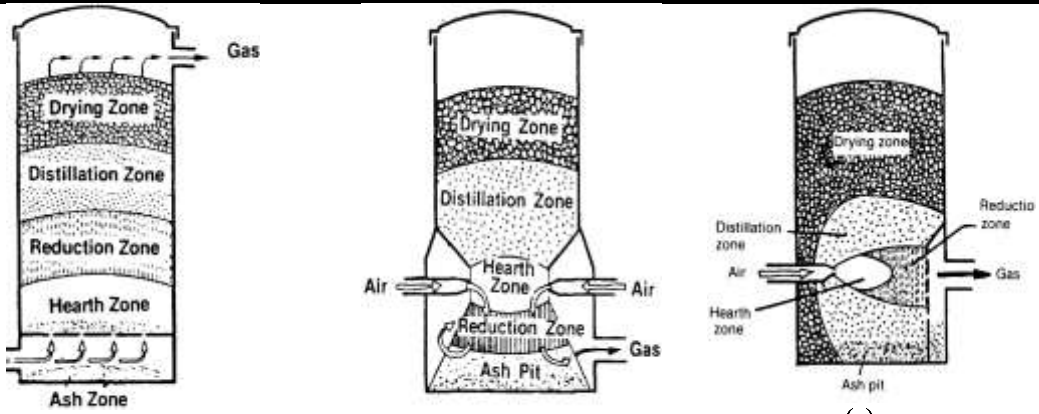
Processes of thermochemical convert solid degradable wastage into bio-power and bio-fuel. Bioenergy is an energy available from biological sources from natural materials. There are various thermochemical gasification techniques implements for face mask gasification.

4.1 Fixed Bed Thermochemical Gasification Techniques

Fixed bed gasifiers are defined as the basis of a fuel and oxygen (air/steam) path that is either concurrently or counterflow. Because of the simple mechanism, biomass gasification using fixed bed type gasifier is advantageous. Biomass can be feed by pushing into or moving as a plug, with gases flowing between particles[13]. In both updraft and downdraft fixed-bed gasifiers, feedstock is a feed from the top of the gasifier reactor. Gasifier agents such as O_2 or ambient air rise and pass from the heated reaction zone to the gasifier base in the opposite direction of solid raw material advancement[14]. The produced gas contains tar components, and it must be cleaned out; otherwise, it destroys a substantial portion of the gasifier. Fixed bed gasifiers require well-defined fuel qualities due to the inflexibility of feedstock. [15]. Figure 4 (a) Updraft in which Air enters the updraft gasifier from below the grate and flows upward through the bed to produce a combustible gas. High temperatures at the air inlet can easily cause slugging or destruction of the grate, and often some steam or CO_2 is added to the inlet air to moderate the grate temperature. Charcoal updraft gasifier is characterized by comparatively long (b) In down draft air is introduced at or above the oxidation zone in the gasifier. The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction, as schematically shown in Figure 4 (b). On their way down the acid and tar distillation products from the fuel must pass through a glowing bed of charcoal and therefore are converted into permanent gas like hydrogen, carbon dioxide, carbon monoxide and methane. Figure 4 (c) Crossdraft types Fixed Bed Gasifier, The load following ability of cross-draft gasifier is quite good due to concentrated partial zones, which operate at temperatures up to 2000°C. Cross-draft gasifier is an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500°C and higher) in the oxidation zone that can lead to material problems. In cross-draft gasifier the fuel (charcoal) itself provides insulation property against high temperatures. The relatively higher temperature in cross-draft gas producer has an obvious effect on gas composition such as high carbon monoxide, and low hydrogen and methane content when dry fuel such as charcoal is used. Cross-draft gasifier operates well on dry air blast and dry fuel.

4.2 Fluidized Bed Thermochemical Gasification Techniques

The gas flow entering the reactor (air, oxidant, steam, and reused syngas) must be adequate, but not too heavy to float feedstock particles onto the bed. The reactor will get lighter and smaller as the feedstock particles are gasified. To minimize particle agglomeration, the bed temperature must be kept between 800-1000 C lower than the initial ash fusion temperature of the biomass. Such features are present in FBG type reactors[]. When pyrolysis products come into contact with hot solids, they disintegrate into non-condensable gases. FBG has a flexible biomass fuel supply, a constant fuel combination, equal biomass heating, and a variety of reactive gasify mediums such as atmospheric air, steam, O_2, and CO_2[15]. FBG reactors are classed according on their medium fluidization velocity. BFB normally operates at low gas speeds of less than 1 m/s, whereas CFB operates at higher gas speeds of 3-10 m/s.



(c)

(a) (b)

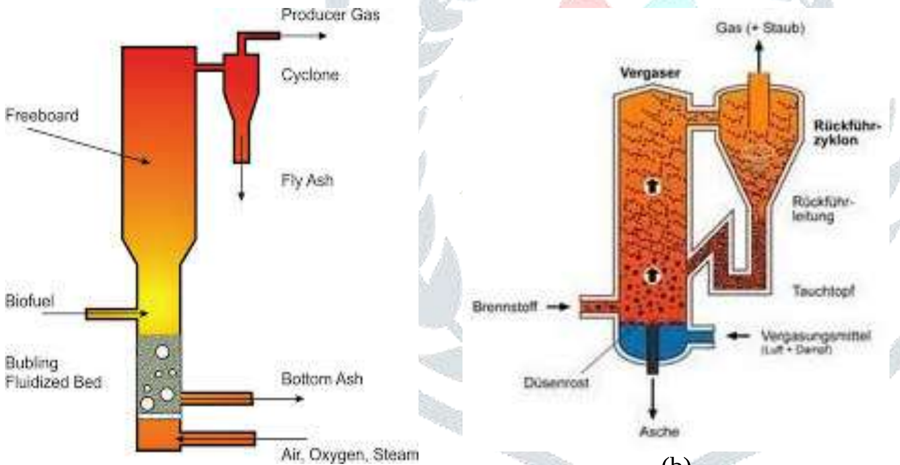
Fig. 4 shows (a) Updraft (b) Down Draft (c) Crossdraft types Fixed Bed Gasifier [22]

3.2.1 Bubbling Fluidized Bed Gasifier (BFBG)

In BFBG, the feedstock is heated to a high temperature before being introduced into the bed. To ensure efficient heat transmission. Inert bed materials include sand, ash, and char. Figure 8 (a) displays a schematic diagram of the BFB gasifierAir, O_2, or steam is forced through the bed's inert material until friction forces between feedstock materials and gas counterbalance. Gas velocity at which minimal fluidization occurs and bed material bubbling begins, with the objective that feedstock elements remain in gasifier chamber and seem to be nearing boiling state. Through allowing heat transfer through the reactor to be successful, feedstock particles separate by fluidization from the bed. Imported bad material reacts as a catalyst or as a gas cleansing procedure[16].

3.2.2 Circular Fluidized Bed Gasifier (CFBG)

CFBG functions at a greater gas velocity than the needed fluidization stage and exhibits feedstock element dissipation with the generated syngas stream. Figure 8 (b) displays a schematic diagram of the CFB gasifier[17]. The cyclone separator removes dissipated particles from generated gas as it exits the reactor's top and returns to the reactor's bed. Continues the process of recirculating fugitive feedstock elements to bed until it is light and tiny enough to occur with the generated gas leaving the cyclone separator[17].



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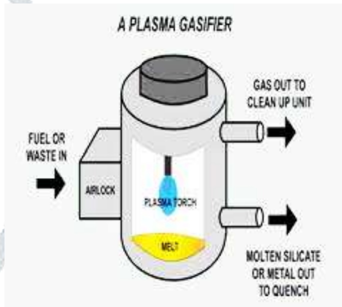


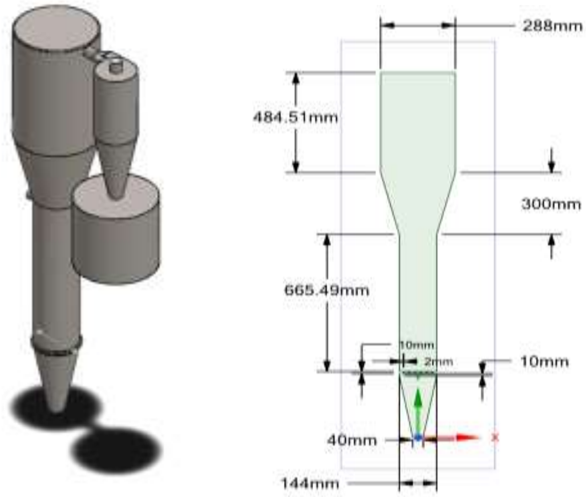
Fig. 5 schematic diagram of (a) BFB gasifier (b) CFB gasifier [18] Fig. 6 Plasma gasifier [19]

3.3 Plasma Thermochemical Gasification Techniques

Two ways can produce the plasma stage "thermal or equilibrium" by atmospheric pressure along with "cold or non-equilibrium" by negative (vacuum) pressure. By plasma gasification, thermal way produced gas with components like Ar, N_2, H_2, H_2O vapor or mixture of gases has a temperature of 4700˚C-20000˚C. This method benefits non-ionizing radiation, high energy density, high intensity, and high temperature[2-22]. Figure 9 Shows a schematic working diagram of a plasma gasifier[19]. Biomedical waste with radioactive compounds gasify in a plasma gasifier at high temperatures. A high-temperature plasma gasifier working environment of about 1500K removes highly toxic dioxins, benzopyrene, furans and destroys thermally stable bacteria with no harmful impurities. Plasma gasifier is economically disadvantaged as an electricity source that contributes to high building, operating, and maintenance costs [23, 24].

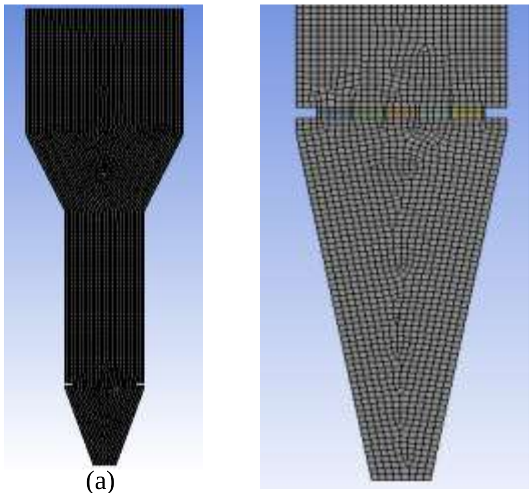
III. Biomass Gasification using Bubbling Fluidized Bed Gasifier

BFBG System for various types of biomass with 10 kg/hr feed stock rate designed and developed. CAD model analyses for three different velocities 0.19, 0.22 and 0.30 m/s air velocity. Figure 7 (a) (b) shows CAD model based on designed BFBG calculation. Figure 8 (a) and (b) shows mesh geometry distribution. Table 3.1 shows analysis messing details. Analyses carried out in ANSYS FLUENT software[25]. Table 3.2 Sand and Bagasse physical properties



(a) (b)

Fig. 7 Designed CAD BFBG Model[30]



(a) (b)

Fig. 8 Mesh geometry and Closer View[30]

Table 3.1. Mesh Details[30]

Element Size (mm)	4
Number of Elements	12930
Number of Nodes	13380

Table 4.2 Sand and Baggase physical properties

Property	Sand	Bagasse
Particle Size (µm)	360	846
Density (kg/m^3)	2590	343
Porosity (ε)	0.44	0.57
Sphericity (ø)	0.72	0.43

Figure 12 shows sand as bed material and Bagasse as Feed stock material particle distribution during three inlet velocities 0.19 m/s, 0.22 m/s and 0.30 m/s using the Syamlal and O'Brien drag model. Sand particles were found to combine in the middle and under the bed. Bagasse particles tend to be mostly located in the left and middle regions of the bed. Bagasse movement across the bed was predominantly upwards at the reactor's centre-line and downwards in the near-wall region. This distribution showed a close relationship with the size of the structure and the size of the particles Small temperature variation occur because simulation time was 2s only. In next study will built a lab-scale model of BFBG according to design parameters and perform experiments and compare the result with CFD data[30].

CFD Work Observation:

- The behavior of the bed expands in response to changes in gas velocity.
- The model can quantitatively represent the buildup of solid at the wall. Solid concentrations are flat in the center and rise toward the wall.
- The fluidized bed exhibits back-mixing behavior or particle buildup.
- The velocity in the core region is observed to be in the upward flow direction and substantially higher than that in the annulus region, while solid and gas velocities near the wall are decreasing.
- The CFD simulation shows a solid circulation pattern for all operating parameters and all biomass samples, which is consistent with the literature published by other researchers.
- The contours for sugarcane bagasse and sand show that the bed is fluidized. The air contour shows that the volume percentage of the gas is less in the fluidized portion than the solid particles.

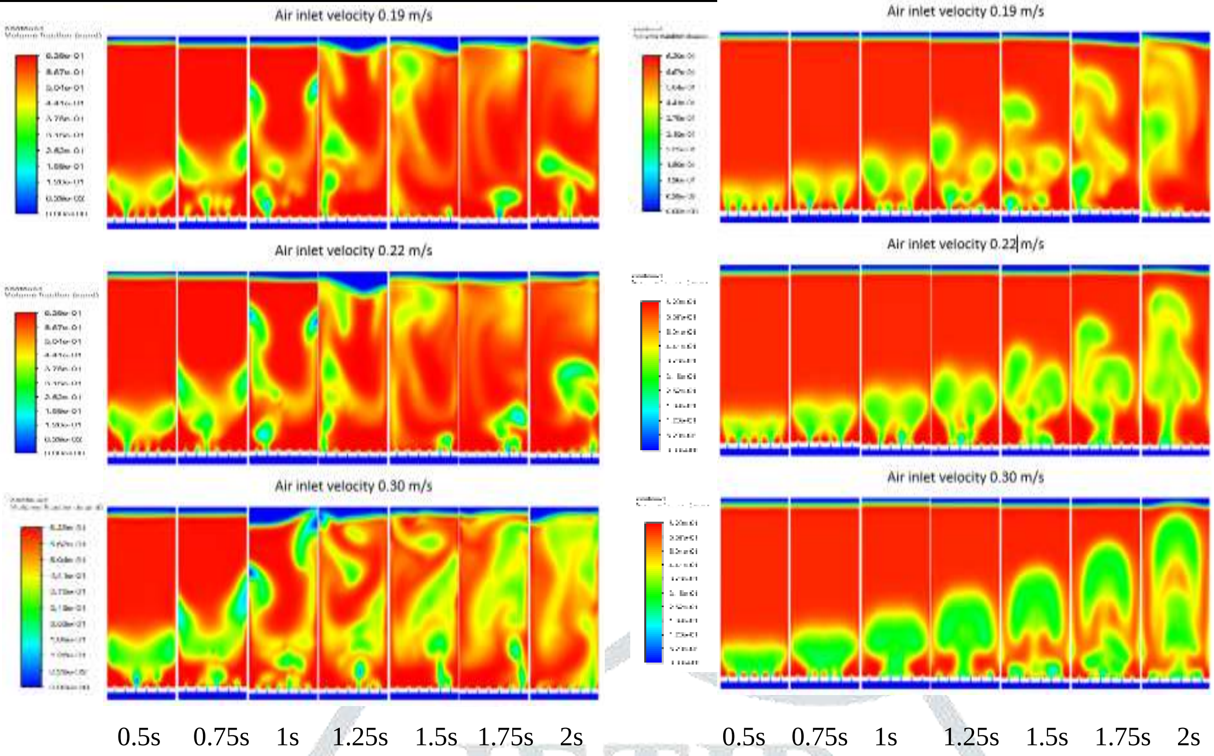


Fig 12. Volume fraction distribution for (a) the Sand (b) Bagasse Particles using the Syamlal and O'Brien drag model with three inlet velocities 0.19 m/s, 0.22 m/s and 0.30 m/s [30]

IV. Experimental on BFBG for Selected Biomass Gasification

Figure 13 shows schematic diagram of Face mask to syngas conversion methodology.

4.1 Experimental Procedure:

For experimental work following procedure are followed

- Selection of Biomass materials
- Sizing of biomass as per feed stock size requirement
- Prepare the fluidized bed by sizing it on sand using a messing procedure and feeding it into the BFBG reactor.
- Start Supply of Air as gasify agent at 0.35 m/s speed as per 0.35 Equivalent Ratio requirement
- Reach BFBG Reactor Temperature up to 650-750 ºC
- Feed Biomass in to the reactor, Produced syngas leave reactor from top portion of the BFBG reactor
- Feed stock article leave with syngas separated at Cyclone separator
- Syngas go to Cleaning and cooling device for separation of further particles and cooling of syngas.
- Syngas come out from the burner by proving spark at burner, ignition of flame can be observed

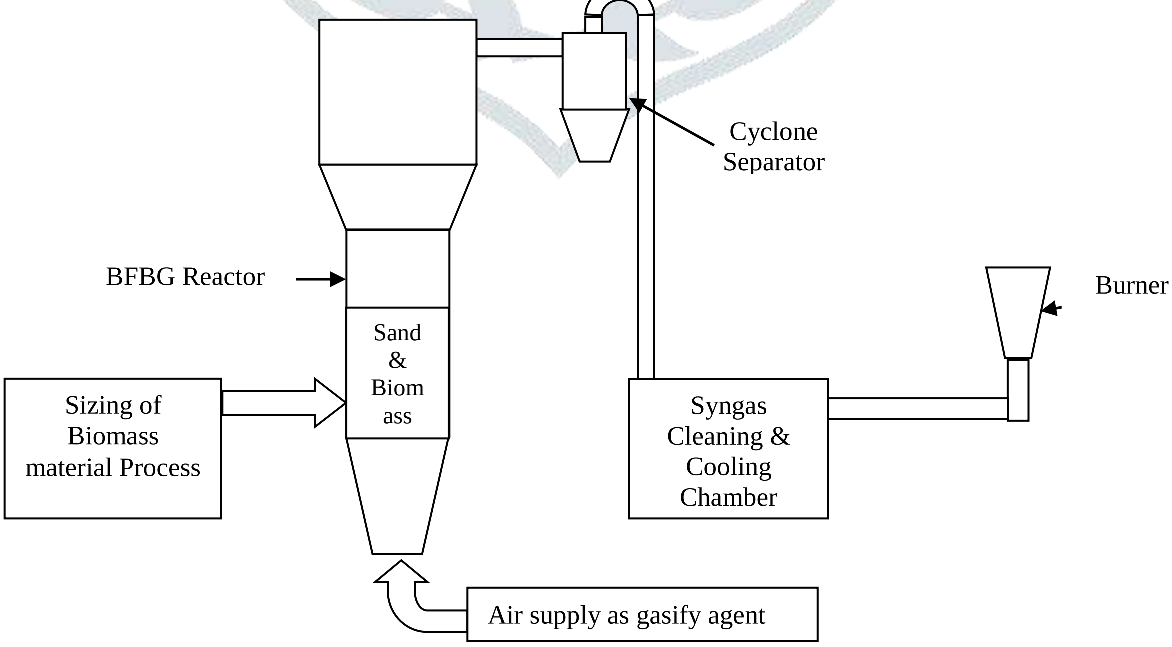


Fig. 13 Line Diagram of Experimental Setup

V. RESULTS AND DISCUSSION

5.1 Results of Feed Stock Material

Table 5.1: Proximate analysis of Face Mask

	Bagasse	Groundnut Shell	Rice Husk	Wooden Shavings
Moisture (%)	4.8	4.2	4.43	6.7
Volatile Matters (%)	76.24	68.4	59.6	74.8
Ash (%)	4.2	4.1	20.13	2.8
Fixed Carbon (%)	14.2	23.17	15.5	14.9
Sulphur (%)	0.56	0.13	0.34	0.8
Calorific Value (Kcal/kg)	4137	4324	3648	4264

Table 5.2: Ultimate Analysis of Biomass Materials

Biomass	Bagasse	Groundnut Shell	Rice Husk	Wooden Shaving
Carbon %	43.87	44.87	36.9	45.26
Hydrogen %	5.2	6.53	6.4	6.04
Nitrogen %	1.98	0.48	0.79	0.64
Sulfur %	0.09	0.02	0.01	0.02
Oxygen %	48.86	48.1	55.9	48.04

Table 5.1 displayed face mask Proximate analysis biomass material used for feed stock material for gasification, which shows Ground nut shell having highest Hydrogen element and also having highest Calorific values with 4324 Kcal/kg .

Table 5.2 displayed Ultimate analysis which shows Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen content present in selected face mask feed stock material.

5.2 Discussion on Experiment work

By observing flame of syngas generated from various biomass as heating application of gasification, it can say that groundnut shell flame can be used for thermal or heating applications. Analysis of the produced syngas will be carried out by testing it in laboratory.

CONCLUSION

As Waste to energy Approach, Thermochemical Gasification techniques give valuable outcome as a solution of handling of wastes. Experiment work was done with a selected Biomass material as the feed stock material, sand as the bed material, and air as the gasify agent. The syngas produced by the BFBG reactor was used to generate heating flame. As thermal applications, this syngas flame was noticed. Produced syngas will be sent to lab for tests its elements and identify other compositions. Waste generated from woody biomass and agriculture industries might be viewed as energy generating waste. TGT might become waste management with the use of an energy generating approach. Energy generated from biomass called as Bio energy.

REFERENCES

[1] LIM, J.S., MANAN, Z.A., WAN, A.S.R., HASHIM, H., 2012. A REVIEW ON UTILISATION OF BIOMASS FROM RICE INDUSTRY AS A SOURCE OF RENEWABLE ENERGY. RENEWABLE SUSTAINABLE ENERGY REV. 16, 3084–3094.

[2] NARVÁEZ, I., ORÍO, A., AZNAR, M.P., CORELLA, J., 1996. *BIOMASS GASIFICATION WITH AIR IN AN ATMOSPHERIC BUBBLING FLUIDIZED BED: EFFECT OF SIX OPERATIONAL VARIABLES ON THE QUALITY OF THE PRODUCED RAW GAS*. IND. ENG. CHEM. RES. 35, 2110–2120.

[3] FLETCHER, D.F.,B.S. HYNES, F.C. CHRISTO ,S.D. JOSEPH, 1997, *COMBUSTION MODEL OF AN ENTRAINED FLOW BIOMASS GASIFIER* ,CONFERENCE CFD IN MINERAL & METAL PROCESSING AND POWER GENERATION.

[4] HUBER, G.W.; IBORRA, S.; CORMA, A. SYNTHESIS OF TRANSPORTATION FUELS FROM BIOMASS: CHEMISTRY, CATALYSTS, AND ENGINEERING. CHEM. REV 2006, VOL. 106: 4044 - 4098.

[5] ARTICAL BY ADITYA HANDA 2018, *INDIA LIKELY TO REACH BIOMASS POWER GENERATION CAPACITY TARGET BEFORE 2022*, HTTPS://YOURSTORY.COM/2018/09/INDIA-BIOMASS-POWER-GENERATION.

[6] BOERRIGTER H, DEN UIL H, CALIS HP, 2003, *GREEN DIESEL FROM BIOMASS BY FISCHER– TROPSCH SYNTHESIS: NEW INSIGHTS IN GAS CLEANING AND PROCESS DESIGN. IN: BRIDGEWATER AV, EDITOR. PYROLYSIS AND GASIfiCATION OF BIOMASS AND WASTE*. NEWBURY, UNITED KINGDOM: CPL PRESS: 371–83.

[7] BOERRIGTER H, VAN DER DRIFT A., 2003, *LIQUID FUELS FROM SOLID BIOMASS: THE ECN CONCEPT(S) FOR INTEGRATED FT-DIESEL PRODUCTION SYSTEMS. ENERGY RESEARCH CENTRE OF THE NETHERLANDS REPORT, RX–03-060*, PETTEN, THE NETHERLANDS; OCTOBER 2003: 18.

[8] WU W, KAWAMOTO K, KURAMOCHI H., 2006, *HYDROGEN-RICH SYNTHESIS GAS PRODUCTION FROM WASTE WOOD VIA GASIfiCATION AND REFORMING TECHNOLOGY FOR FUEL CELL APPLICATION*. J MATER CYCLES WASTE MANAGE 8:70–7

[9] P. BASU, *A BOOK ON BIOMASS GASIFICATION AND PYROLYSIS*, ELSEVIER 2010, OXFORD

[10] B. Xiao, S. Luo, and X. Guo, 2009, *Hydrogen-rich gas from catalytic steam gasification of biomass in a fixed bed reactor: Influence of particle size on gasification performance* Int. Journal. Hydrogen Energy, 2009, Vol.34:1260–1264.

[11] Yamazaki, T.; Kozu, H.; Yamagata, 2005. *Effect of superficial velocity on tar from downdraft gasification of biomass*. Energy Fuels, 19: 1186–1191.

[12] Schnurr, R.E.J., Alboiu, V., Chaudhary, M., 2018. *Reducing marine pollution from single-use plastics (SUPs): a review.* Mar. Pollut. Bull. 137: 157–171.

[13] Schmidt, N., Thibault, D., Galgani, F., Paluselli, A., Sempéré, R., 2018. *Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea).* Prog. Oceanogr. 163, 214–220.

[14] Zhang, W., Shi, Z., Zhang, F., Liu, X., Jin, J., Jiang, L., 2013. *Superhydrophobic and superoleophilic PVDF membranes for effective separation of water-in-oil emulsions with high flux*. Adv. Mater. 25: 2071–2076.

[15] Shrestha, S., Ali, B.S. and Hamid, *Cold Flow Model of Dual Fluidized Bed: A Review.* Renewable Sustainable Energy Rev. Vol.53: 1529-1548.

[16] Jurgen Kel and Tobias Proll, *Steam Gasification of Biomass in Dual Fluidized Bed Gasification: A Review, Renewable & Sustainable Eng. Reviews 2018*, Vol.98: 64-78

[17] Dharmendra Sapariya, Umang Patdiwal Hiitesh Panchal, 2021. *A review on thermochemical biomass gasification techniques for bioenergy production*., Energy Sources Part A : Recovery, Utilization and Environmental effects: *doi.org/10.1080/15567036.2021.2000521*

[18] Ilkka Hannula and Esa Kurkela, 2013, *Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass*, VTT Technical Research Centre of Finland 91

[19] Plasma gasifier image *http://titan-machinery.com/en/waste-management/plasma-gasification-waste-to-energy*

[20] Shrestha, S., Ali, B.S. and Hamid, *Cold Flow Model of Dual Fluidized Bed: A Review.* Renewable Sustainable Energy Rev. Vol.53: 1529-1548.

[21] Jurgen Kel and Tobias Proll, *Steam Gasification of Biomass in Dual Fluidized Bed Gasification: A Review, Renewable & Sustainable Eng. Reviews 2018*, Vol.98: 64-78.

[22] Pfender E., *Thermal Plasma Technology: Where do we stand and where are we going?* Plasma Chem. 1999, Vol. 19: 1-31.

[23] Daniel Pedro and E Machin, Experimental Study of Bottom Feed Updraft Gasifier, Renewable Eng. 2013, Vol.57 : 311-316

[24] Sikarwar, V.S., Zhao, M., Clough, P., Yao, 2016 *An overview of Advances in Biomass Gasification, Energy Environment*, Sci. Vol.9: 2939-2977.

[25] Dharmendra sapariya, Umang Patdiwala, Jay Makwana 2021, *CFD Analysis of Biomass Gasification Using Bubbling Fluidized Bed Gasification Technique*, Journal of Emerging Technologies and Innovative Research Vol. 8 Issue 5