INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
N.Nwokolo et al., Vol.10, No.2, June, 2020

# Gasification of Eucalyptus Wood Chips in a Downdraft Gasifier for Syngas Production in South Africa

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*Received: 12.03.2020 Accepted:11.04.2020*

**Abstract-** The present research article aims to study the gasification of *Eucalyptus* as wood chips for syngas production and its thermogravimetric analysis (TGA) in a nitrogen atmosphere. The eucalyptus wood chips were sourced from a sawmill industry, cut into desired sizes and subjected to gasification in a downdraft gasifier using air as the oxidizing agent. The compositions of the syngas were measured using non-dispersive infrared gas sensors and a palladium/nickel (Pd/Ni) gas sensor. Thermogravimetric analysis was carried out under 20 °C/min heating rate using a Perkin-Elmer TGA 7 and the gasification zones temperatures were monitored using thermocouples. An average higher heating value (HHV) of 6.08 $MJ/Nm^3$ containing predominantly of hydrogen, carbon monoxide and methane was obtained from the eucalyptus syngas. The volumetric compositions of the syngas produced varied from 22.3% - 22.5% for hydrogen, 22.3% – 24.3% for carbon monoxide, 1.9% - 2.1% for methane, 9.8% - 10.7% for carbon dioxide and 41.5% – 42.9% for nitrogen. Nitrogen composition was highest due to the use of air as the oxidizing agent. The study have successfully demonstrated gasification as an alternative technology for conversion of waste to energy.

**Keywords** Gasification, Eucalyptus wood, syngas, oxidizing agent, Thermogravimetric analysis, Temperature.

## 1. Introduction

South Africa is highly dependent on conventional fuels such as coal and oil due to its industrialized nature [1]. The country is endowed with plenty of biomass reserves that are considered as a potential for energy generation [2]. The gasification of these renewable biomass materials to produce syngas for heat and electricity can be a solution for South Africa's energy problems. Gasification is the thermochemical conversion of biomass material in the presence of an oxidizing agent to produce syngas, char, tars and some hydrocarbons of low molecular weight. The oxidizing agent, which comprises of oxygen, air, steam or a mixture of them, is usually provided in substoichiometric quantities to maintain partial oxidation of the biomass material. The oxidizing agent influences the quality of syngas produced particularly the heating value. This is attributed to the variation in the concentration of hydrogen and carbon monoxide [3]. The use of oxygen and steam as oxidizing agents results in higher heating value of syngas in the range of 9–10 $MJ/Nm^3$ for oxygen and 17–18 $MJ/Nm^3$ for steam. Although this is advantageous because of higher energy content of the syngas but it affect the cost of the gasification process. This is why air is one of the most used oxidizing agent because of low cost. However, air-blown gasification results in low heating value in the range of 4-6 $MJ/Nm^3$, which is attributed to higher concentration of nitrogen in the syngas [4].

Syngas is a mixture of gases that comprises of hydrogen ($H_2$), carbon monoxide (CO), methane ($CH_4$), carbon dioxide ($CO_2$), water vapour ($H_2O$), and nitrogen ($N_2$) in different proportions [5]. For these gases to be produced a series of chemical reactions are involved. These reactions occurs in a gasifier at temperature between 800 °C - 1000 °C. Inside the gasifier, the gasification process occurs in a set of four steps: drying, pyrolysis, oxidation and reduction process [6]. At the drying phase, the biomass moisture content vapourizes at a temperature of around 200 °C. While in the second step referred to as pyrolysis reaction, the cellulose, hemicellulose and lignin content of biomass material are decomposed into solid residue and volatile compounds at temperature between 200 – 600 °C. The volatile compounds and solid residue (chars) are oxidized into CO, $CO_2$ and $H_2O$ at the third step known as partial oxidation at a temperature above 700 °C. And lastly at the reduction step which occurs at a temperature above 800°C, the volatile compounds and char react with oxidizing agents to yield CO, $H_2$ and $CH_4$ [7]. These gasification reactions occur simultaneously within a gasifier.

Gasifiers are broadly divided into fixed bed, entrained flow and fluidized bed gasifiers. Fixed bed is further classified into downdraft, updraft and cross-draft gasifiers. Downdraft gasifier has been reported to be more suitable for small-scale heating and power applications usually within a capacity range of 10 kW – 1 MW [8]. It holds some advantages in terms of low tar production and fabrication ease. However, it is also faced with some challenges such as channeling, grate blocking and bridging [9, 10]. In a downdraft gasifier, biomass is introduce from the top and is allow to flow co-currently with the oxidizing agent that is introduce either from the top or through the side. The flow direction of the biomass and oxidizing agent allows the devolatilized products to reach the high temperature oxidation zone, hence resulting in a better quality of syngas with low tar content [7].

Syngas quality is influenced by many factors, which include biomass type, operating parameters, gasifier type and design. The operating parameters include gasification temperature, equivalence ratio and biomass consumption rate [9]. Among these parameters biomass type and temperature seems to have the most significant influence on syngas quality. Therefore, the aim of this study is to determine the quality of syngas that can be produced from gasification of eucalyptus wood waste in a downdraft gasifier as well as to determine the impact of temperature in thermal degradation of woody biomass. The Melani rural community in Eastern Cape Province of South Africa are currently using these wood wastes for direct heating through combustion. However, its gasification will result in a more valuable energy product for the South African community and will as well reduce the harmful emission resulting from its combustion. This study is equally providing solution on how to reduce the carbon footprint and over dependence on non-renewable energy resources.

## 2. Materials and Method

### *Biomass Characterization*

The biomass used in this study was eucalyptus wood sourced from a nearby saw mill industry. Theses wood chips were cut into a desired size of 7.5 x 6.8 x 4.3 cm for easy flow through the downdraft gasifier. The ultimate analysis to determine carbon, hydrogen, nitrogen and oxygen was carried out using CHNS/O, Model 2400, manufactured by Perkin Elmer while, the proximate analysis to determine volatile matter (VM), moisture content (MC), fixed carbon (FC) and ash content (AC) were carried out using Perkin-Elmer TGA 7 (Norwalk, CT, USA). These tests were carried out using ASTM standard. The energy value of the eucalyptus wood used was calculated using empirical formula given in Equation 1 and 2 [11, 22].

$$\text{HHV (MJ/kg)} = 0.3536\ \text{FC} + 0.1559\ \text{VM} - 0.0078\ \text{ASH} \quad (1)$$

$$\text{LHV (MJ/kg)} = \text{HHV} - 0.212\ (\text{H\%}) - 0.0245\ (\text{MC\%}) - 0.08\ (\text{O\%}) \quad (2)$$

Where HHV is Higher Heating Value, LHV is Lower Heating Value, H% is percentage of hydrogen, MC% is percentage of moisture content, O% is percentage of oxygen. Table 1 shows the ultimate and proximate analysis of the eucalyptus wood used in the gasification process.

**Table 1.** Ultimate and Proximate Analysis of Eucalyptus Wood

| Analysis | Content | Mass % |
|---|---|---:|
| Ultimate | Carbon | 48.21 |
| | Hydrogen | 6.36 |
| | Nitrogen | 0.08 |
| | Oxygen | 45.35 |
| Proximate | Moisture content | 7.52 |
| | Volatile Matter | 66.82 |
| | Fixed Carbon | 24.89 |
| | Ash Content | 0.77 |
| Heating Value (MJ/kg) | | 18.82 |

### *Experimental Set up for Gasification and Syngas Analysis*

The gasification system used in this study is made up of gasifier/reactor, cyclone, gas scrubber, sawdust filter, safety filter and gas engine and electric generator as shown in Figure 1.

The gasifier is a downdraft type hence; the wood chips were fed through the top of the gasifier. air was introduced through the air nozzle located at the side of the gasifier using a blower. The gasifier was ignited through the ignition sleeve and as the gasification process proceeds, it goes through four basic steps: drying, pyrolysis, oxidation and reduction. These steps involve some major chemical reactions as tabulated in Table 2.

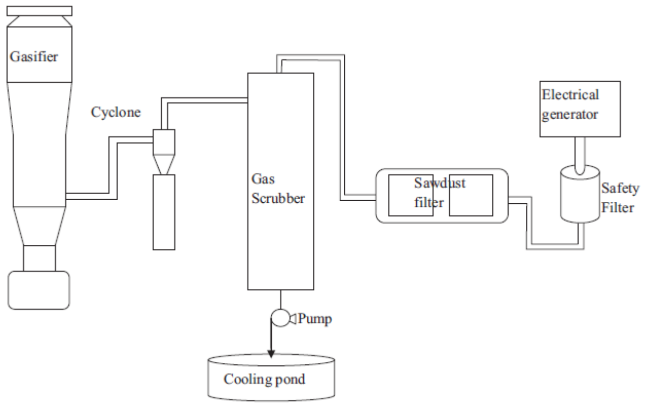

**Figure 1.** Schematic diagram of the gasification system

The major reactions presented in Table 2 are mainly affected by temperature and usually occur due to high operating temperature in the gasifier. A mixture of gases known as syngas emerges at the completion of these reactions through the lower chamber of the gasifier. As the syngas exit the gasifier it first goes through the cyclone separator for purification purpose where about 80% of the particulate matter was removed from the syngas. The gas scrubber and saw dust filter were not considered in the present study as the gas sampling point was located at the cyclone exit point.

The composition of the syngas was measured using a customized gas and temperature profiling system that uses non-dispersive infrared gas sensors for measurement of methane ($CH_4$), carbon monoxide (CO), carbon dioxide ($CO_2$) and a Palladium/Nickel (Pd/Ni) gas sensor for measurement of hydrogen. The gas profiling system gives its output as a differential voltage but this was converted to percentage composition. Finally, the energy value of the syngas was determined using Equation 3

$$CV_{syngas} = \frac{(CO_{vol} \times CO_{HV}) + (H_{2vol} \times H_{2HV}) + (CH_{4vol} \times CH_{4HV})}{100} \quad (3)$$

Where $CO_{vol}$, $H_{2vol}$ and $CH_{4vol}$ represents the volume concentration of carbon monoxide, hydrogen and methane present in the syngas respectively. $CO_{HV}$, $H_{2HV}$ and $CH_{4HV}$ represent the heating value of these gases as stated in the standard gas table.

## 3. Results and Discussions

### *Thermogravimetric Analysis*

The thermal degradation analysis of the eucalyptus wood was first studied using thermogravimetric method prior to the actual gasification. It measures the degree at which a biomass material degasses as a function of change in temperature. The thermogravimetric (TG) curve and its corresponding derivative (DTG) curve for the evaluated eucalyptus wood sample are presented in Figure 2.

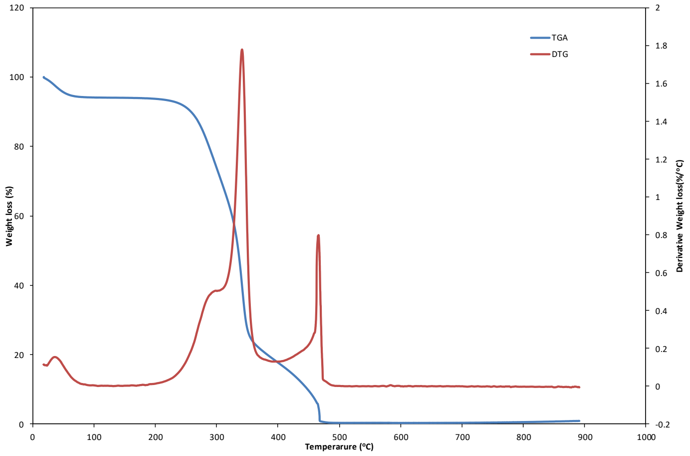

**Figure 2.** TGA and DTG plot of Eucalyptus wood sample in a nitrogen atmosphere

**Table 2.** Gasification Reaction [12, 13]

| Reaction | Heat of Reaction | Type of Reaction |
|---|---|---|
| $C + CO_2 \rightarrow 2CO$ | 172.5 kJ/mol | Boudouard |
| $C + H_2O \rightarrow CO + H_2$ | 131.3 kJ/mol | Water Gas Primary |
| $C + 2H_2O \rightarrow CO_2 + 2H_2$ | 90.2 kJ/mol | Water gas secondary |
| $C + 2H_2 \rightarrow CH_4$ | -74.9 kJ/mol | Methanation |
| $CO + H_2O \rightarrow CO_2 + H_2$ | -41.2 kJ/mol | Water gas shift |
| $CH_4 + H_2O \rightarrow CO + 3H_2$ | 206.2 kJ/mol | Steam Reforming |
| $CH_4 + CO_2 \rightarrow 2CO + 2H_2$ | 247.4 kJ/mol | Dry reforming |

As observed from Figure 2, the thermal degradation profiles can be divided into three stages. The first stage represents the drying phase in which the weight loss recorded corresponds to evaporation of moisture and light volatiles. This occurred within 11 mins while using 20 °C/min ramp and at a temperature range of 18 °C - 230 °C. The weight loss recorded at this first stage is low due to low moisture content of the eucalyptus wood samples. At the second stage, there was a rapid drop in weight between the temperature ranges of 250 °C – 360 °C. The pronounced weight loss at this stage corresponds to decomposition of cellulose and hemicellulose components and a part of the lignin component of the eucalyptus wood sample and is termed the active pyrolysis phase. From a temperature of around 370 °C – 900 °C a slight decrease in weight is recorded and this is caused by thermal degradation of the lignin content of the sample. This agrees with the report that lignin decomposes over a wider temperature range during TGA analyses compared to hemicellulose and cellulose that degrades over a shorter temperature range [14]. From the DTG curve, the first significant peak is associated with the degradation of hemicellulose and cellulose. This occurred at a temperature of 340 °C, while the second peak that occurred at a temperature of 470 °C is associated with lignin degradation. These peaks represent the reactivity of the fuel that determines the rate of reduction of carbon dioxide to carbon monoxide during gasification.

### *Gasifier Temperature Profile*

Temperature is the most significant parameter amongst the gasification operating parameters that influences the syngas final composition. It equally influences the thermodynamic behaviour of the reactions and the balance between endothermic and exothermic reactions. Figure 3 presents the temperature profile of the different gasification zones measured using thermocouples located inside the gasifier.

Figure 3 shows the drying, pyrolysis and reduction zone temperature profiles recorded from the start-up of the process to a stabilized condition. As observed, the drying zone reached its peak temperature of 120 °C later, compared to the pyrolysis and reduction zone temperature due to moisture removal. At the reduction zone where the syngas approach the exit point a peak reduction temperature of 543.5 °C was recorded at the mid of the gasification process. In literature, a similar temperature profile was obtained during the gasification of Eucalyptus wood using a two-stage air supply in downdraft gasifier [15].

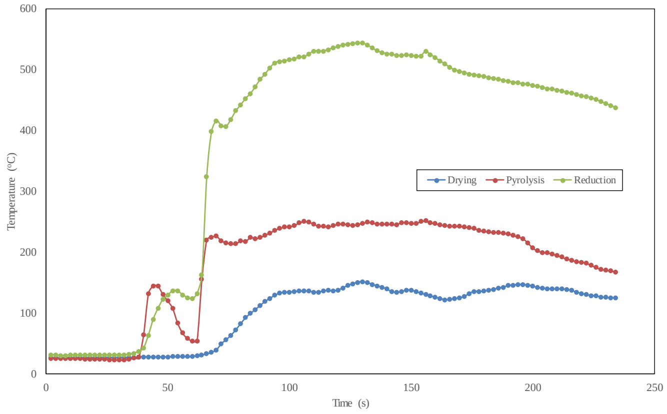

**Figure 3.** Temperature distribution of the gasification zones

The study also recorded a reduction zone maximum temperature of 550 °C. It was observed that at higher temperature more $H_2$ and CO were produced. This is attributed to an increase in the rate of primary water gas reaction, secondary water gas reaction, Boudouard and dry reformation reactions with increase in temperature because of their endothermic nature.

On the contrary, higher operating temperature caused a decrease in the concentration of methane due to consumption of methane in exothermic reactions at high temperature. In literature the decrease in methane is supported with the rationale that most exothermic reactions are inhibited to a certain rate at high temperatures [16] However, some other studies indicated that methane concentration remains almost constant both at low and high temperature due to the pyrolysis process through which methane is produced [12, 17]. More also, increase in temperature resulted in higher gas yield and can be explained by greater release of gases at the devolatilization stage of the eucalyptus wood in the gasifier. As much as high temperature gasification is recommended, it also causes slag formation through ash agglomeration, hence appropriate operating temperature must be maintained within the gasifier [18].

### *Syngas Composition and Properties*

Table 3 presents the composition of syngas produced from gasification of eucalyptus wood using air as the oxidizing agent.

The volumetric compositions of syngas produced from the gasification of eucalyptus wood varied from 22.3% - 22.5% for $H_2$, 22.3% – 24.3% for CO, 1.9% - 2.1% for $CH_4$, 9.8% - 10.7% for $CO_2$ and 41.5% – 42.9% for $N_2$. These gases were produced through the interaction of the eucalyptus water content and the oxygen content in the air that served as the oxidizing agent.

**Table 3.** Syngas Composition and Properties

| Item | $H_2$ | CO | $CH_4$ | $CO_2$ | $N_2$ | Total |
|---|---|---|---|---|---|---|
| % Composition of gas | 22.5 | 24.2 | 2.1 | 9.7 | 41.5 | 100 |
| Mass (g) | 2.02 | 30.26 | 1.50 | 19.06 | 51.89 | 104.75 |
| Molar Mass (g/mol) | 2.02 | 28.01 | 16.04 | 44.00 | 28.01 | 118.08 |
| Specific heat capacity | 10.16 | 0.72 | 1.70 | 0.65 | 0.74 | 13.97 |

As observed the syngas composition was predominated by CO followed by $H_2$. The dominancy of CO in the syngas composition is directly linked to enhancement in the rate of Boudouard reaction, which at high temperature has its chemical equilibrium directed to CO production. Similarly, higher volumetric percentage of hydrogen obtained could be explained by an increase in temperature, which promoted the endothermic reactions of water gas, dry and steam reformation reaction. Comparatively in Aydin et al [16] study, the average values of the syngas compositions obtained for wood pellet are 21.62% for $H_2$, 27.74% for CO, 2.30% $CH_4$, 9.43% for $CO_2$ while the remaining percentage is $N_2$. As observed, CO and $H_2$ equally dominated in concentration, which is typical of most downdraft gasifier systems.

The methane volumetric composition of 2.1% recorded in the current study was the least in the syngas composition mixture due to limited methanation reactions occurring during the gasification process. Similarly, Daniele et al [19] obtained a methane composition of 1.8% in an experimental investigation of air-$CO_2$ biomass gasification. While Susastriawana et al [9] got a methane composition that was less than 2% in the gasification of saw dust, rice husk and a mixture of the feedstock in a downdraft gasifier. An average HHV of 6.08 MJ/Nm$^3$ consisting mostly of $CH_4$, CO and $H_2$ was determined using Equation 3. This falls in the range of 4-6 MJ/Nm$^3$ usually recorded for air blown gasification [4]. In comparison with another study, an average HHV of 6.81 MJ/Nm$^3$ and 5.45 MJ/Nm$^3$ was reported for gasification of eucalyptus chips and Coffee wood respectively in an open source type of downdraft gasifier [20]. More also, an experimental study on the gasification of coffee husk using pure oxygen-steam blends obtained a HHV of syngas in the range of 7.71 - 8.84 MJ/Nm$^3$ [21]. The value obtained in the later study exceeded that of the present study because of the use of oxygen and steam as oxidizing agent. As reported in literature, the use of oxygen and steam increases the percentage composition of combustible gases that determines the HHV obtained [23, 24].

## 4. Conclusion

The present study have successfully evaluated the thermal degradation of eucalyptus wood chip in a thermogravimetric analyzer and downdraft biomass gasifier. From the TGA and DTG curves, it was found that the degradation proceeded through three stages of weight loss. The first stage occurred in a temperature range of 18 °C - 230 °C in the first 11 mins and this corresponded to the drying phase. At the second stage, a rapid drop in weight was observed between the temperature ranges of 250 °C – 360 °C. The pronounced weight loss is associated with decomposition of cellulose and hemicellulose component of the eucalyptus wood sample. The last stage represents a long and slow decomposition of lignin up to a temperature of 900 °C. The gasification of the eucalyptus wood chips in a downdraft gasifier further showed that a volumetric composition of syngas that varied from 22.3% - 22.5% for $H_2$, 22.3% – 24.3% for CO, 1.9% - 2.1% for $CH_4$, 9.8% - 10.7% for $CO_2$ and 41.5% – 42.9% for $N_2$. This gave an average HHV of 6.08 MJ/Nm$^3$ containing predominantly of hydrogen, carbon monoxide and methane. The higher concentration of $H_2$ and CO translates to better flammability of the syngas. Hence, the syngas produced in the present study is an ideal product for combustion in a combined heat and power plant using a diesel or compression ignition engines.

## 5. Recommendations

The study have successfully demonstrated gasification as an alternative technology for conversion of waste to energy. These wastes were previous combusted in open air for heating purposes, but its use as a feedstock in the downdraft gasifier have turned it to a more valuable energy product. More also, the higher heating value of the syngas produced showed its suitability as a fuel for combined heat and power plants. With the higher composition of CO and $H_2$ present, the produced syngas can be used as a fuel in diesel or compression ignition engines in dual fuel mode with the diesel serving as the principal fuel. This would not necessitate any change in the diesel properties; however, the properties of the fuel mixture of diesel and syngas would require further investigation. Prior to its adoption as an engine for heat and power production in South Africa.

## Acknowledgements

The authors’ wishes to acknowledge the financial support from Govan Mbeki Research and Development Centre of University of Fort Hare South Africa.

## References

[1] P. Mukumba, G. Makaka, S. Mamphweli, and P. Masukume, “Design, construction and mathematical modelling of the performance of a biogas digester for a family, Eastern Cape Province, South Africa”, AJSTID, vol. 11, pp. 391-398, 2019.

[2] P. Mukumba, G. Makaka, and S. Mamphweli, “Biogas technology in South Africa, problems, challenges

and solutions", Int. J. Renew. Energy Environ. Eng, vol. 5, pp. 58-69, 2016.

[3] J. Solarte-Toro, Y. Chacón-Pérez, and C. Cardona-Alzate, "Evaluation of biogas and syngas as energy vectors for heat and power generation using lignocellulosic biomass as raw material, Electron J. BiotechN., vol. 33, pp 52–62, 2018.

[4] F. Gallucci, R. Liberatore, L. Sapengo, E. Volponi, P. Venturini, F. Rispoli, E. Pris, M. Carnevale, and A. Colanttoni, "Influence of Oxidant Agent on Syngas Composition: Gasification of Hazelnut Shells through an Updraft Reactor", Energies, vol. 13, pp. 89-102 2020.

[5] N. Coutoa, A. Rouboa, V. Silva, E. Monteiro, and K. Bouziane, "Influence of the biomass gasification processes on the final composition of syngas", Energy Procedia, vol. 36, pp. 596–606, 2013.

[6] R. Bain, and K. Broer, Gasification. In: Brown RC, editor. Thermochemical processing of biomass: Conversion into fuels, chemicals and power, Wiley, pp. 47–77, 2011

[7] Y. Situmorang, Z. Zhao, A. Yoshida, A. Abudula, G. Guan, "Small-scale biomass gasification systems for power generation (<200 kW class): A review", Renew. Sust. Energ., vol. 117, pp. 109486, 2020.

[8] N. Mahinpey, and A. Gomez, "Review of Gasification fundamentals and new findings: reactors, feedstock, and kinetic studies", Chem. Eng. Sci., vol. 48, pp. 14-31, 2016.

[9] A. Susastriawana, H. Saptoadi, and Purnomo, "Small-scale downdraft gasifiers for biomass gasification: A review", Renew. Sust. Energ., vol. 76, pp. 989–1003, 2017.

[10] A. Saleh, B. Sudarmanta, H. Fansuri, and O. Muraza, "Syngas production from municipal solid waste with a reduced tar yield by three-stages of air inlet to a downdraft gasifier", Fuel, vol. 263, pp. 116509, 2020

[11] P. Sheth, and B. Babu, "Production of hydrogen energy through biomass (waste wood) gasification", Int. J. Hydrog. Energy, vol. 35, pp. 10803 – 10810, 2010.

[12] L. Emami Taba, M. Irfan, W. Wan Daud, and M. Chakrabarti, "The effect of temperature on various parameters in coal, biomass and CO-gasification: A review", Renew. Sust. Energ., vol. 16, pp. 5584–5596, 2012.

[13] N. Nwokolo, S. Mamphweli, and G. Makaka, "An investigation into heat recovery from the surface of a cyclone dust collector attached to a downdraft biomass gasifier", Appl. Therm. Eng., vol. 98, pp. 1158–1164, 2016.

[14] M. Protić, A. Miltojević, M. Raos, A. Đorđević, and Golubović T, "Thermogravimetric analysis of biomass and sub-bituminous Coal", International Conference Industrial Engineering and Environmental Protection, Sebia, 2018.

[15] A. Galindo, E. Lora, R. Andrade, S. Giraldo, R. Jaen, and V. Cobas, "Biomass gasification in a downdraft gasifier with a two-stage air supply: Effect of operating conditions on gas quality", Biomass & Bioenergy, vol. 61, pp. 236–244, 2014.

[16] E. Aydin, O. Yucel, and H. Sadikoglu, "Experimental study on hydrogen-rich syngas production via gasification of pine cone particles and wood pellets in a fixed bed downdraft gasifier", Int. J. Hydrog. Energy, vol. 44, pp. 17389–17396, 2019.

[17] J. Fermoso, B. Arias, M. Plaza, C. Pevida, F. Rubiera, and J. Pis, "High-pressure CO-gasification of coal with biomass and petroleum coke", Fuel Process. Technol., vol. 90, pp. 926–32, 2009.

[18] J. Bermudez, and B. Fidalgo, Production of bio-syngas and bio-hydrogen via gasification, Handbook of Biofuels Production Second Edition, Processes and Technologies, 2016.

[19] A. Daniele, S. Ail, F. Patuzzi, M. Grigiante, and M. Baratieri, "Experimental investigations of air-CO2 biomass gasification in reversed downdraft gasifier", Fuel, vol. 253, pp. 1473–1481, 2019.

[20] J. de Oliveira, J. da Silva, M. Martins, E. Pereira, M. da Conceicao, and T. Oliveira, "Gasification of waste from coffee and eucalyptus production as an alternative source of bioenergy in Brazil", Sustainable Energy Technologies and Assessments, vol. 27, pp. 159–166, 2018.

[21] J. Bonilla, G. Gordillo, C. Cantor, "Experimental Gasification of Coffee Husk Using Pure Oxygen-Steam Blends", Frontier in Energy Research, vol. 7, pp. 1-11, 2019.

[22] J. Thiagarajan, P.K. Srividya, P. Balasubramanian, "Thermal Kinetics and Syngas Production on Co Gasification of Deoiled Jatropha Seed Cake Residues with Wood Chips", IJRER, vol. 8, pp. 1105 - 1111, 2018.

[23] O. J. Reátegui, H. L. Cárdenas, D. G. Peña, V. J. Castro, R. F. Roque, N. F. Mejía, M. M. Ponce, R. S. Mestas, "Biogas production in batch in anaerobic conditions using cattle manure enriched with waste from slaughterhouse", 6th International Conference on Renewable Energy Research and Applications, San Diego, 2017.

[24] G. Mutani Carlucci, and M. Martino, "Assessment of potential energy producible from agricultural biomass in the municipalities of the Novara plain", 2015 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Palermo, pp. 1394-1398, 22- 25, 2015