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To cite this article: D Andriani *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **293** 012010

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# A review: Biomass-based fuel pellet usage in biomass gasifier-an optimization on non-wood material

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**Abstract.** Biomass gasifier is one of many trends in sustainable energy exploration to compete with solar and wind. The fuel was commonly dominated by wood-based pellet which has high-quality parameters such as pellet size, pellet durability, tar content, heating value, and ash content. However, non-wood fuel sources should also be considered since they have readability and no less quality parameter. This study was conducted to select and analyze the non-wood materials which are capable of fueling biomass gasifier. Shell pellet, wheat straw pellet, and miscanthus pellets were analyzed in this study to be attributed in a certain treatment. The treatments were included size reduction, gas heating, increasing durability, and ash content. The treatments have been proven to enhance the quality parameter of non-wood pellet. This result had ensured the improvement of biomass gasifier for no longer depending on wood pellet.

**Keywords:** Ash content, fuel pellet optimization, non-wood pellet, pellet durability, pellet quality parameter, size reduction.

## 1. Introduction

Renewable energy is becoming an inevitable need in the next decade since the depletion of fossil fuel has been the main concern along with environmental issue. Solar, wind, hydro, biomass, geothermal are the significant sources of renewable energy contributing about 19.3 % of global energy consumption [1]. Among those sources, biomass energy has shared the largest contribution up to 9 % of total primary energy supply in the world [2] and ranks as the fourth available source of energy in the world [3]. Biomass can be converted into commercial products via either biological or thermochemical processes [4, 5]. In thermochemical conversion, the entire biomass is converted into gases, which are then synthesized into chemicals or used directly. Production of thermal energy is the main objective where the gasification process should be in the form of combustion, pyrolysis, gasification, and liquefaction [6].



A. Sultana et al. [7] concluded that wood is the best sources for pelletization among other alternative biomass resources such as switchgrass, straw, poultry litter, and alfalfa pellets. Its superiority is covering almost all quality parameter such as its high bulk density, low friability, lower emission, and low deposit formation. Table 1 shows the ranking of pellets using PROMETHEE II without including qualitative criteria analysis [8].

**Table 1.** Pellets ranking [8].

Options	Base Case		Economic Scenario		Environmental Scenario	
	Net flow $\Phi$	Ranking	Net flow $\Phi$	Ranking	Net flow $\Phi$	Ranking
Wood pellet	0.46	1	0.41	1	0.45	1
Switchgrass pellet	0.08	2	0.04	2	-0.01	2
Straw pellet	-0.01	3	0.03	3	0.11	3
Alfalfa pellet	-0.30	5	-0.36	5	-0.25	4
Poultry litter pellet	-0.23	4	-0.11	4	-0.30	5

It is known that biomass material for gasification should have a recommended requirement to achieve optimum gas production. The standard should be varied and different in each region. European countries have developed various standard for their basic requirement, limit value, and application mode. That are French recommendations (for the use of pellets in stove and heating), German standards [9], the Austrian norm [10], and Italian standards (for A1 and A2 pellets). Pellet size, moisture content, heating value, and ash content are the quality parameters that appear most frequently in global standards and recommendations. However, pellet size (diameter, length and/or length/diameter ratio) is the only parameter that is appeared in all the norms [11].

This paper tried to review some biomass material which can be transformed into fuel pellets for biomass gasifier. Since the biomass material varies on many types, and some previous research has been focused on wood-based material, this review is focused on non-wood materials. With the competence of non-wood material, hopefully, biomass fuel pellet can emerge as the one sustainable enough replacing the fossil fuel.

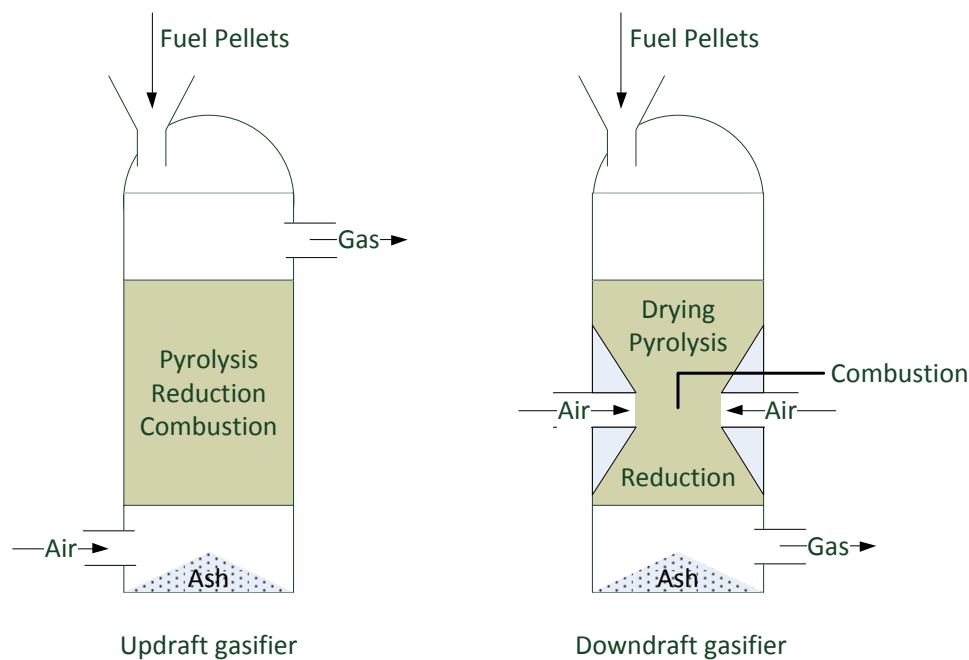
## 2. Biomass gasifier

The usage of biomass resource could be directly in the implementation of a biogas generator set [12]. However, biomass gasifier is also one of trending solution on using biomass to energy indirectly [13, 14]. There is two types of commonly used biomass gasifier, i.e. updraft gasifier and downdraft gasifier. Figure 1 shows the simplified schematic of the updraft and downdraft biomass gasifier [15].

Updraft gasifier (left) put the air inlet below the reactor while the biomass fuel inlet was in the top of the gasifier. The pyrolysis process was conducted in the middle of the reactor, and the ash will be collected at the bottom of the reactor. In this updraft type, the gas should be collected at the top side of the reactor.

As the opposite of the updraft, downdraft gasifier (right) put the gas collector in the bottom of the reactor. The biomass fuel still located on the top shelf but the air inlets are located in the middle of the reactor. The combustion was conducted in the throat at the middle of the reactor, and the ash would still be in the same collection at the bottom of the reactor.

Biomass gasifier can be fuelled by many forms of fuel. Fuel pellet is one of the forms that are in the increasing demand for the current year. Table 2 shows the commonly used fuel for gasification based on research by Molino et al. on biomass center [13].



**Figure 1.** Schematic diagram of updraft and downdraft fixed bed gasifiers

**Table 2.** Main fuel on the gasification process [13].

Fuel type	LHV (MJ kg <sup>-1</sup> )	Bulk density (kg m <sup>-3</sup> )	Energy density (MJ Nm <sup>-3</sup> )
Wood-based			
Woodchips (30 % MC)	12.5	250	3 100
Log wood (stacked-airdry: 20 % MC)	14.7	350 to 500	5 200 to 7 400
Wood (solid-ovendry)	19	400 to 600	7 600 to 11 400
Wood pellets	17	650	11 000
Non-wood based			
Miscanthus (bale-25 % MC)	13	140 to 180	1 800 to 2 300
House coal	27 to 31	850	23 000 to 26 000
Anthracite	33	1 100	36 300
Heating oil	42.5	845	36 000
Naturalgas (NTP)	38.1	0.9	35 200
LPG	46.3	510	23 600

### 3. Fuel pellet utilization

Some research have been conducted recently to study the usage of fuel pellet on gasification. The usage of biomass pellet has been proved more effective than using bulk biomass. For example, research by [16] calculated the difference between the using of rice husk and rice husk pellet on the gasification process. The result showed that the cold gas efficiency was calculated to be more than 60 % of rice husk and 70 % for rice husk pellet gasification [16]. Moreover, the power generation

result using synthetic gas produced from rice husk pellet gasification was about 10 kW. Therefore, pellet gasification showed higher stability in gas production as compared to the non-pellet gasification.

**Table 3.** Parameters of wood and wood shell pellet for biomass gasification [17].

Parameters	Wood	Shell pellet 11.5 mm diameter
Producer gas flow rate ( $\text{g s}^{-1}$ )	9.62	11.09
A mole of biomass ( $n$ )	9.30	6.90
A mole of air ( $\phi$ )	2.01	2.07
Air-Fuel ratio stoichiometric ( $A F^{-1}$ ) <sub>s</sub>	9.57	9.85
The calorific value of gas, $Q_{\text{CVg}}$ ( $\text{MJ N}^{-1} \text{m}^3$ )	4.48	4.66
Mass of gas generated, $mg$ (kg of gas/kg of biomass)	3.54	3.88
Molecular wt. of producer gas	25.82	26.77
The density of producer gas, $\rho_g$ ( $\text{kg N}^{-1} \text{m}^3$ )	1.16	1.13
The energy released per kg of biomass, $E_g$ ( $\text{MJ kg}^{-1}$ of biomass)	13.70	16.01
Gasification efficiency of the gasifier ( $\eta$ )	0.74	0.95

Research conducted by Susastriawan [18] concluded that produced gas flow rate from wood shell pellet was higher than wood gasification. The parameters were given in table 3 [17] were also show that the pellet usage in certain treatment should provide higher efficiency compared to the non-pellet efficiency.

It was also found that a 13 % overall moisture content and a glycerol addition of between 10 % and 20 % improve the pelletization properties of PIN and PINT, respectively, and increase their energy density when compared to the raw samples [19].

#### 4. Non-wood pellet optimization

This section will discuss the optimization process conducted to utilize non-wood pellet. Mostly, their quality will be judged by comparison with the quality of the wood-based pellet. The selected non-wood pellet are [20] sunflower seeds mix pellets, bagasse pellets, empty fruit bunch (EFB) pellets, Shell pellets (Pongamia shell residue), Alfalfa pellets, wheat straw pellets, Bioethanol production residue (DDGS pellets), miscanthus pellets, and rice husk pellet (mixture of husk and saw dust). The optimization process will be in the form of size reduction, pellet durability, ash content, gas heating, and tar content.

##### 4.1. Size reduction

Research by Prasad et al. [21, 22] investigate the size of the pellet should affect gasification quality. Table 4 shows the energy release per kg of fuel, calorific value and producer gas flow rate. All parameter was shown higher when the smaller diameter pellet was used compared to the larger pellet. The efficiency of successful thermal conversion can be seen as the ratio of energy release per kg of biomass to the energy contained in biomass. Pellet with a smaller diameter (11.5 mm) has shown higher gasification efficiency up to 0.95 while the larger diameter (17 mm) has 0.73 efficiencies. It was also found that the larger pellets were not gasified completely because there is still a high-pressure drop in the exit of the fine filter.

**Table 4.** Parameters of 11.5 mm pellet and 17 mm pellet for biomass gasification [17].

Parameters	Pellet 11.5 mm diameter	Pellet 17 mm diameter
Producer gas flow rate ( $\text{g s}^{-1}$ )	11.09	10.51
Mole of biomass ( $n$ )	6.90	7.26
Mole of air ( $\phi$ )	2.07	2.15
Air-Fuel ratio stoichiometric ( $A F^{-1}$ ) <sub>s</sub>	9.85	10.23
Calorific value of gas, $Q_{\text{CVg}}$ ( $\text{MJ N}^{-1} \text{m}^3$ )	4.66	3.98
Mass of gas generated, $mg$ (kg of gas/kg of biomass)	3.88	3.65
Molecular wt. of producer gas	26.77	26.48
Density of producer gas, $\rho_g$ ( $\text{kg N}^{-1} \text{m}^3$ )	1.13	1.19
Energy released per kg of biomass, $E_g$ ( $\text{MJ kg}^{-1}$ of biomass)	16.01	12.23
Gasification efficiency of the gasifier ( $\eta$ )	0.95	0.73

#### 4.2. Gas heating for tar reduction

A study by Robinson et al. [23] has explored that gas heating in specific treatment can affect the reactivity of the biomass. It was observed that wood-PET (polyethylene terephthalate) pellets emerged with 10 % lower producer gas heating value compared to wood pellets. This was because the gasification of wood-PET pellets yielded producer gas with high tar concentration ( $120 \text{ g Nm}^{-3}$ ) as compared to wood pellets ( $20 \text{ g Nm}^{-3}$ ). Ahrenfeldt et al. [24] observed that tar reduction could be achieved with an increasing of air ration for the partial oxidation of real gas from the pyrolysis of wood pellets.

#### 4.3. Higher pellet durability

Pellet durability was also concluded as one of the significant parameters to enhance the pellet. Research by Kalis et al. [25] compared miscanthus pellet and bioethanol production residues (distiller's dried grains with solubles (DDGS)) pellets. The pellets were made in similar size 6 mm to 8 mm with different durability level. The quality of the gas produced and the gasifier performance were assessed in terms of the gas composition, yield, heating value, cold gas efficiency, and carbon conversion efficiency. Pellet with higher durability resulted in higher cold gas efficiency as compared to DDGS pellets. Table 5 [25] express the comparison of performance result of miscanthus pellet vs DDGS pellets.

#### 4.4. Increase the ash content

Based on table 5, the quality and quantity ash content brought a significant role as well as pellet durability. Low pellet durability affects the ash content by increasing the surface area, so the mean combustion rate had been increased. This event was followed by the increasing temperature which led to melting the ash and finally effect on the quality and quantity of the gas produced. Higher temperatures in combination with better heat distribution would have increased syngas quantity.

**Table 5.** Comparison between DDGS pellet and Miscanthus pellet performance [25].

Parameter	DDGS Pellet	Miscanthus pellet
Durability (%)	91	96.5
K/Ca ratio	5.90	0.35
Gas yield ( $\text{m}^3 \text{kg}^{-1}$ biomass)	0.86	1.39
HHV ( $\text{MJ m}^{-3}$ )	2.06	4
LHV ( $\text{MJ m}^{-3}$ )	1.92	3.7
Cold gas efficiency (%)	9.5	30
Carbon conversion efficiency (%)	20.1	47

## 5. Conclusion

The investigation on biomass-based fuel pellet shows that non-wood pellet would still have higher efficiency compared to wood pellet. Non-wood pellet could be enhanced with certain treatment by reducing its size to increase the gasification efficiency. Another treatment, especially in pellet gas heating, could have reduced its tar concentration. Increasing pellet durability should also need to be considered as the higher the durability, the higher cold gas efficiency. This too will increase the ash content which will affect the temperature and later be combined with proper heat distribution to increase syngas quantity. Overall, non-wood pellet should be utilized in the biomass gasifier because of its higher quality within the same parameter compared with a wood pellet.

## Acknowledgement

The author would like to thank the researchers in the Research Centre for Electrical Power for the continuous data support on this study. The author also gratefully thanks to the Indonesian Institute of Science (LIPI) for providing equipment, facilities, and infrastructures in the completion of this study.

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