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Waste-to-Energy: Producer Gas Production from Fuel Briquette of Energy Crop in Thailand

Kittikorn Sasujit*, Natthawud Dussadee*[1], Nigran Homdoung*, Rameshprabu Ramaraj*, and Tanongkiat Kiatsiriroat[+]

Abstract – *Biomass is a renewable source of energy with environment-friendly carbon neutral characteristics. World-wide, a considerable amount of biomass is available in the form of wastes whose economy is primarily dependent on agricultural production. In the present work, an experimental investigation has been conducted using briquette of oil palm and tung tree wastes through downdraft gasification process. The effect of the low heating value of producer gas, gasification efficiency, producer gas yields and tar concentration by variation equivalence ratio were presented. The experimental results showed that gasification performance was the optimum value of equivalence ratio is 0.385 and 0.372. The optimum low heating value of producer gas containing 3.20 MJ/Nm3 and 3.23 MJ/Nm3, gas yield was 4.46 Nm3/kg and 3.72 Nm3/kg, gasification efficiency was 76.24% and 70.15%, furthermore, tar concentration was 89.90 g/Nm3 and 71.71 g/Nm3, respectively. Finally, briquette from oil palm and tung tree waste can be converted to producer gas production and utilized for internal combustion engine for electricity.*

Keywords – Biomass, briquette, gasification, oil palm wastes, producer gas, tung tree wastes.

1. INTRODUCTION

Biomass is potentially an attractive feedstock for producing fuel gas as its useful contributes little or no net carbon dioxide to the atmosphere which is derived from plant sources such as wood from natural forests, waste from agricultural and forestry processes along with industrial, human or animal wastes. Of all the renewable energy sources, biomass is unique in that it effectively stores solid, liquid and gaseous fuels [1]. Currently, agricultural wastes make up a major part of biomass source; however, biomass energy is very small as compared to the conventional energy. In Asian nation, Thailand is one of the biggest producer and exporters of oil palm which has significantly large plantation areas in the country. Wastes from oil palm plantation and palm oil frond, empty fruit bunch, palm kernel cake, palm fiber, which has potential about 17.162 ton per hectare. Tung tree is the popular plant and grown large agricultural area in the Laos (Lao People's Democratic Republic). Since Northern Thailand has similar weather with Laos, so tung plantation process and yields were almost comparable. The high content of oil is derived from the seeds of the tung tree. Tung oil, also called china wood oil or nut oil, has traditionally been used in lamps in the People Republic of China. Recently, tung tree and oil were used as an ingredient in paint, varnish, and caulk. It is also used as a wood finish for furniture and other wooden objects. After processing to removes gums in the oil, it was also used as a motor fuel. Currently, many research to studies used tung oil for biodiesel production and used in a diesel engine as well [2]-[4]. There are several tung trees waste materials from plantation such as left and branch, tung kernel cake, tung seed shell which is potential of waste about 8.083 ton per hectare. Using biomass sources from agricultural wastes are having highest energy content; together the highest efficiency conversion methods would add a significant amount of energy. The conversion technologies for biomass conversion into four basic categories: direct combustion processes, thermochemical processes, biochemical processes and agrochemical processes [5]. The thermochemical conversions of biomass are pyrolysis, gasification and combustion. Combustion is one of the promising routes among the renewable energy options for future energy. Since biomass gasification has attracted the highest interest as it offers higher efficiencies compared to combustion and pyrolysis. It is a process of conversion of solid fuel into combustible gas by partial combustion [6]. The producer gas is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. It is burnt to produce process heat and steam or used in gas turbines to produce electricity [7], [8].

The main benefit of downdraft gasifiers is the lower tar concentration in the producer gas, which is significant for the permanence of combustion engines. The lower tar concentration is because of gas passing through the combustion zone, which enables the cracking of the tars formed during the gasification process. Besides that, the downdraft gasifier is the high char conversion and the lower ash carries over since gases pass through the charcoal bed allowing its filtration and catalysis and a quick response to any load change [8]. The palm oil and tung oil industry have been identified as the key industry for expansion to achieve economic advancement along with the development of greener production processes in Thailand, and also plenty of waste available from the industries. These

* School of Renewable Energy, Maejo University, 50290, Thailand.

[+] Department of Mechanical Engineering, Chiang Mai University, 50200, Thailand.

[1]Corresponding author;
E-mail: natthawud92@gmail.com

wastes are called as biomass, which are value-added materials for fuel production. The biomass appears to be one of the potential energy sources due to its abundance. In addition, the realization of palm/tung biomass for producing value-added products and biochemicals increases the economical and sustainable energy production opportunities for the palm/tung oil biomass industry. Green development indicators are of the utmost importance in ensuring economic and sustainable development. Consequently, this experimental study presents the investigation of oil palm briquette and tung tree briquette for producer gas production through down draft gasifier. In addition, the study explores low heating value producer gas, gas composition, gasification efficiency, gas yields by various fuel equivalence ratio, as well as sampling of tar content from the gasification process of biomass briquette.

2. MATERIAL AND METHODS

2.1 Oil Palm and Tung Tree Waste

The fuel used a waste from oil palm and tung tree in Thailand. The oil palm waste was obtained from the southern of Thailand and tung tree wastes utilized from northern Thailand. The potential of oil palm wastes such as oil palm fronds, empty fruit bunch, palm kernel cake, palm fiber total of 17.162 ton per hectare and the tung tree wastes includes leaf and branch, tung seed kernel cake, tung seed shell of 8.083 ton per hectare. Both biomass were cut into pieces by leaf and branch shredding machine (Diesel engine 10 hp, Kubota), after that dried by solar. The experimental raw materials from oil palm (empty fruit bunch, frond, and kernel cake) and tung tree (seed shell, leaf and branch and kernel cake) were presented in Figure 1.

a.) Empty fruit bunch . b) Oil palm frond c.) Palm kernel cake

d.) Tung seed shell e.) Leaf and branch f.) Tung kernel cake

Fig. 1. Wastes from oil palm and Tung tree.

2.2 Experimental Setup

The fixed bed downdraft gasifier was used in this experiment conducted with a laboratory scale stationary and semi-continuous feeding types; and the characterization of down draft gasifier was illustrated in Table 1. The schematic diagram of the experimental setup is shown in Figure 2. The atmospheric air was supplied into the gasifier using a 185.50 W vortex blower and the amount of air supplied was controlled using a ball valve and monitored using a metal vane anemometer (LUTRON Model: YK-80AM, Australia). The downdraft gasifier of oil palm and Tung oil tree briquette was conducted controlling the inlet airflow into the reactor between ranges of 13-19 m3/h. Various syngas conditioning unit was provided downstream of the gasifier for the cyclone system, cooling system, Venturi wet scrubber and filter tank for cleaning producer gas. The gas flare was provided on the outlet piping in order to check the combustibility of produced syngas and burn poisonous gasses like carbon monoxide (CO) before being released to the atmosphere. The produced gas was periodically collected with a multi-layer foil gas sampling bag (Restek, USA) and analyzed by gas chromatography (Model: GC-8A, SHIMADZU, Japan) using a thermal conductivity detector (TCD) with nitrogen and helium as carrier gasses which was able to analyze H_2, O_2, N_2, CO, CH_4 and CO. The proximate and ultimate analysis was carried on according to ASTM standards.

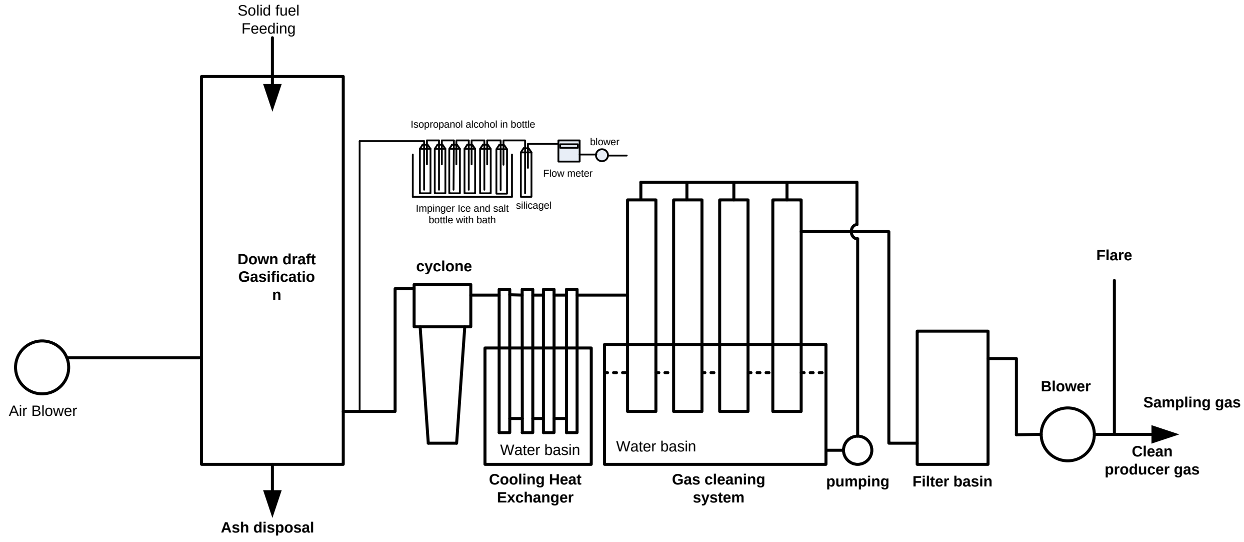


Fig. 2. Schematics diagram of downdraft gasifier.

Table 1. Specification of gasifier system.

Gasifier	
Type	Downdraft
Diameter of throat	166 mm.
Design capacity	50 kWth
Material for construction	Steel, PVC pipes, galvanize pipes
Number of nozzle for inlet air	Nozzle of 5 (diameter = 15 mm.)
Hopper for biomass briquette	35-40 kg.
Air blower	185.50 W
Producer gas cleaning system	Cyclone
	Producer gas cooling by water
	Venturi scrubber
	Pack bed scrubber
	Biomass filter
	Fabrics filter
	Water pump = 500 W
Biomass consumption	Biomass briquette about 8-9 kg/h
Sizing of biomass briquette	Approx. dia. = 50 mm. length = 30 mm.
Producer gas flow rate	Max. about 80 m3/h
Blower of producer gas	400 W

2.3 *Method of Analysis*

2.3.1 Equivalence ratio

The equivalence ratio defined as the ratio of the actual fuel-air ratio to the theoretical fuel-air ratio [9]-[11] which are specified mixture of biomass with oxidizer for combustion by comparing with stoichiometric. It was calculated through Equation 1 and 2.

Fuel Equivalence Ratio

$$\Phi_{Fuel} = \frac{(y_{fuel}/y_{air})_{actual}}{(y_{fuel}/y_{air})_{stoi}} = \frac{(\eta_{fuel}/\eta_{air})_{actual}}{(\eta_{fuel}/\eta_{air})_{stoi}} \qquad (1)$$

Oxidizer Equivalence Ratio

$$\Phi_{oxi} = \frac{1}{\Phi_{Fuel}} \qquad (2)$$

Where is mass basis. Equation 1 and 2 are explained by:

If < 1 or > 1 is Fuel-lean mixture
If < 1 or > 1 is Fuel-rich mixture
If = 1 or = 1 is Stoichiometric ratio

2.3.2 The gas yield, Gy

The gas yield (Nm^3/kg) of producer gas was production from the product gas to dry biomass [12,13]. It was calculated in Equation 3.

$$G_y = \frac{product\ gas(Nm^3)}{dry\ biomass(kg)} \qquad (3)$$

2.3.3 The gasification efficiency

The gasification efficiency is defined by the ratio of the heating of product gas multiple mass flow rate of gas to fuel consumption multiple low heating value of solid fuel [14], [15]. It was calculated in Equation 4.

$$\eta_g = \left[\frac{H_g \times Q_g}{H_s \times M_s}\right] \times 100 \quad (4)$$

Where, are the low heating value of producer gas and solid fuel (kJ/Nm3), is gas flow rate (m3/s), is solid fuel consumption (kg/s) and is gasification efficiency (%). The low heating value of producer gas was calculated by Equation 5.

$$H_g = \sum H_i X_i \quad (5)$$

Where is the heating value of producer gas such as CO, H_2, CH_4 (CO=13.1 MJ/Nm^3; H2=13.2 MJ/Nm^3; CH_4=41.2 MJ/Nm^3) and X_i is mole fraction of producer gas by volume [14], [15].

2.3.4 Tar concentration in producer gas

The concentration of tar in producer gas produced from downdraft gasification of oil palm briquette and Tung tree briquette was calculated using the relation by Equation 6 [16]-[18].

$$C_t = \frac{W_t}{V_g} \quad (6)$$

Where is the weight of tar in unit gram in sampling gas. The weight of tar in sample gas was measured by weighing the residual tar after evaporating the isopropanol alcohol with high precision digital scale is the volume of producer gas in unit Nm^3 and determined from the flow rate of the sample gas by rotameter mounted at the end of the sampling train, and considering the sampling duration recorded using a stop watch is a concentration of tar in producer gas in unit g/ Nm^3.

3. RESULTS AND DISCUSSIONS

3.1 Biomass Feedstock

The waste of oil palm and tung trees, generally known used as a biomass sources for fuel production. Figure 3 demonstrate the potential and availability of oil palm and tung tree wastes in Thailand. Furthermore, the energy potential evaluation of wastes from oil palm and Tung tree wastes are shown in Table 2. In addition, Table 3 lists the physical properties, the proximate analyses, ultimate analyses and chemical analyses of the wastes from oil palm and tung trees. The higher heating value (HHV) is calculated using the empirical according to Sakkampang and Wondwuttanasatian [19]. The heating value of raw materials was between of 14-22 MJ/kg and 14-20 MJ/kg of tung oil tree wastes and oil palm wastes, respectively.

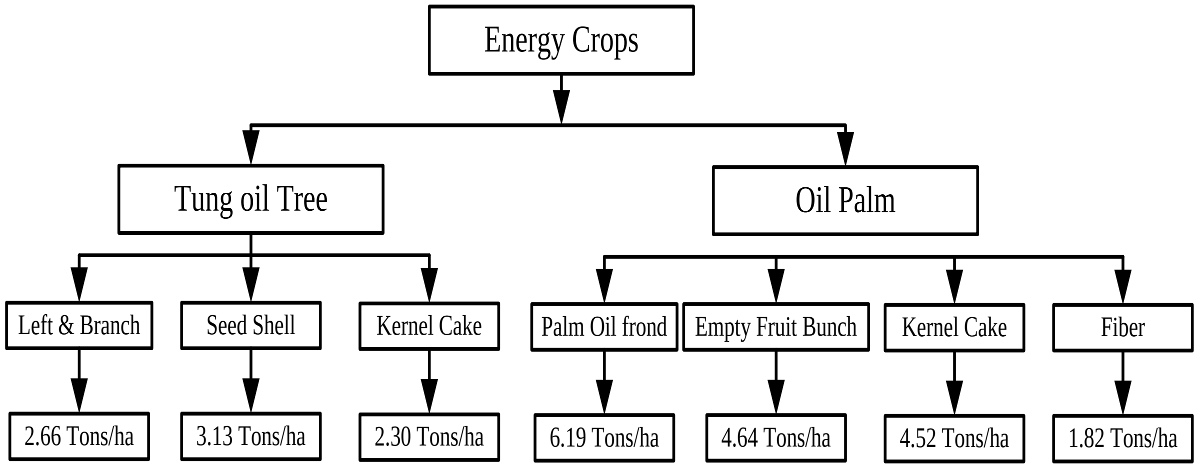


Fig. 3. Oil palm and Tung tree wastes.

Table 2: Evaluation energy potential of wastes from oil palm and Tung tree

Wastes	Energy Crop Wastes (kg/ha)	Heating Value (MJ/kg)	Energy from Wastes (GJ/ha)
Oil Palm			
Oil Palm Fronds	6,188	14.78	91.45
Empty Fruit Bunch	4,638	16.40	76.05
Palm Kernel Cake	4,519	19.10	86.30
Oil Palm Fiber	1,819	11.10	20.18
Tung Tree			
Left and Branch	2,663	15.92	42.38
Tung Kernel Cake	2,296	21.55	49.48
Tung Seed Shell	3,125	14.54	45.43

Table 3: Proximate and ultimate analysis of wastes from oil palm and Tung tree wastes.

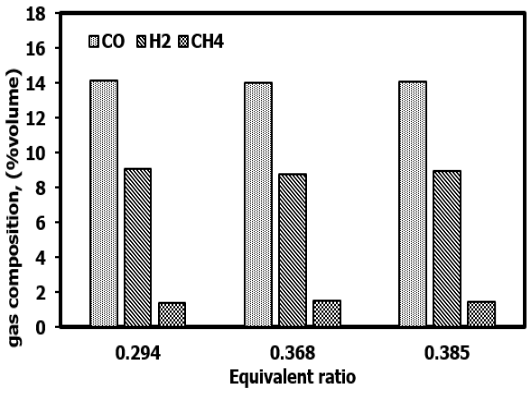
Properties	Tung oil tree wastes, %wt.			Oil palm wastes, %wt.		
	Tung kernel cake	Leaf and branch	Tung seed shell	Oil palm fronds	Empty fruit bunch	Palm kernel cake
Proximate analysis						
Volatile matter	64.79	57.19	57.32	60.15	64.99	70.96
Fixed carbon	21.31	12.50	15.45	10.88	13.81	10.63
Moisture content	9.03	25.11	10.92	21.88	14.73	12.68
Ash	4.87	5.20	16.32	7.08	6.47	5.74
Ultimate analysis						
Carbon	51.62	42.06	38.75	42.05	42.81	47.01
Hydrogen	6.82	6.08	5.31	6.06	6.18	6.94
Nitrogen	2.22	1.56	0.80	0.86	0.92	1.26
Oxygen	34.22	44.09	38.52	42.64	3.09	38.57
Sulphur	0.13	0.09	0.03	0.11	0.08	0.16
HHV (MJ/kg)	21.55	14.45	15.12	14.78	16.40	19.10

The selected materials are biomass briquette from oil palm and tung oil tree wastes in Thailand. Briquetting system produced large cylindrical briquettes with a base diameter of 50 mm and maximum length about 300 mm. The producing machine consists of a screw extruder, 3-phase motor, and circuit breaker. The oil palm and tung oil tree wastes were collected from the floor of the plantation and brought to further processing such as slitting, followed by chipping into the desirable sizes and drying by solar. Subsequently applied briquetting process by the oil palm wastes used mixing at oil palm fronds: empty fruit bunch: palm kernel cake of 1:1:1 and the tung oil tree wastes used leaf and branch: Tung seed kernel cake of 1:1 by using glycerol for the binder in briquetting process. Both raw materials are abundant and low economic value for using in the thermochemical process. The oil palm and tung oil tree briquettes have average dimensions of diameter and length approximately 50 mm and 30 mm, which are more suitable for downdraft gasification of this research. Figure 4 demonstrated the size of oil palm and tung oil tree briquette for fuel in the gasification system. The biomass briquette both have the bulk density of 780 kg/m^3 and 968 kg/m^3, the higher heating value of 20.35 MJ/kg and 18.73 MJ/kg of oil palm and tung oil tree briquette, respectively. The fuel was pre-dried to achieve moisture content by solar between a range of 15-16%. The fuel briquette both have heating value higher raw material shown in a Table 4 because in the briquetting process used glycerol from biodiesel production as a binder mixed with raw material about 30%wt and 5%wt for oil palm and Tung oil tree briquetting, respectively. Since in the process glycerol was used; and it is effect to the fuel has high heating value, at the same time as a glycerol has a heating value about 24.59 MJ/kg [19]. The proximate and ultimate analysis of briquette results was revealed in Table 4.

Fig. 4. Biomass briquetted from a.) Oil palm wastes b.) Tung oil tree wastes.

Table 4: proximate and ultimate of oil palm and Tung oil tree briquette.

Properties	Oil palm briquette	Tung oil tree briquette
Proximate Analysis (%wt.)		
Fixed carbon	6.42	9.60
Volatile matter	75.55	67.26
Moisture	11.00	17.39
Ash	7.03	5.75
Ultimate Analysis (%wt.)		
Carbon	48.23	48.60
Hydrogen	7.43	6.90
Oxygen	36.04	35.80
Sulphur	0.07	0.11
Nitrogen	0.83	2.16
Moisture content (%)	16.50	15.50
Density (kg/m^3)	780	968
Heating value (MJ/kg)	20.35	18.73



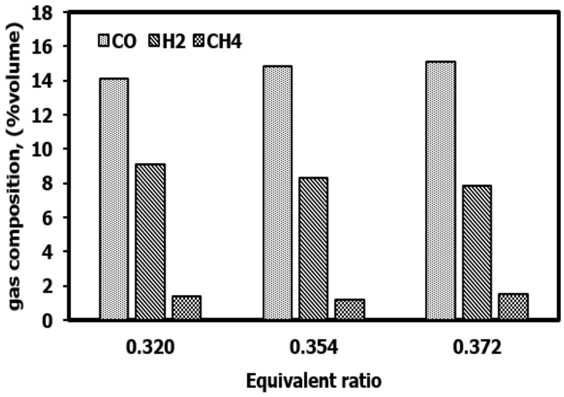


Fig. 5. Producer gas composition from gasification

3.2 Performance Evaluation of Biomass Gasifier and Producer Gas Compositions

Figure 5 revealed the producer gas compositions from oil palm briquette gasification by variation of the equivalent ratio between ranges of 0.294-0.385. It was found increasing of air gasification reaction and less effected with producer gas composition because air input for the reaction has less variation in the ranges of 14.24 – 18.99 m^3/h, which have the less oxygen for fuel combustion in the reactor. The producer gas composition for oil palm briquette gasification value having carbon monoxide between ranges of 14.05 - 14.12 %volume, hydrogen gas between ranges of 8.76 – 9.11 % volume and methane gas between ranges of 1.40 – 1.51 % volume. In the part of tung tree briquette gasification, it was found similar to using oil palm briquette gasification for discussion of data. The producer gas of tung tree briquette gasification showed a carbon dioxide gas value between ranges of 14.12 – 15.11 % volume, hydrogen gas value between ranges of 7.8 – 9.12 %volume and methane gas value between ranges of 1.21 – 1.53 % volume explained in Figure 4(b).

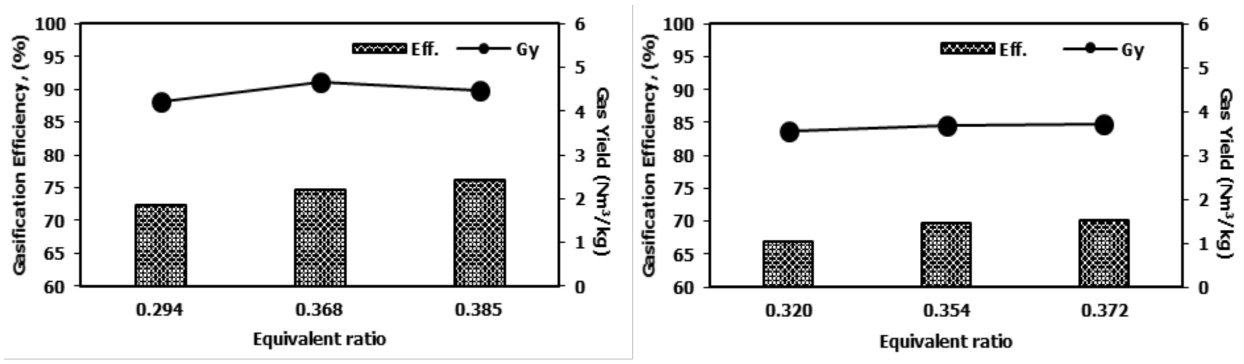
The performance of the biomass gasifier system is evaluated in terms of the producer gas composition, the calorific value of producer gas, gas generation rate, zone temperatures, and cold gas efficiency. The experimental results are compared with those reported in the literature were illustrated in Table 5. It shows that highest calorific value of gas is produced in the present study through using briquette from the oil palm and tung tree wastes.

3.3 Low Heating Value and Gasification Efficiency from the Waste Biomass Briquette

The low heating value of producer gas from briquette gasification was shown in Table 6, which was calculated using the producer gas composition by carbon monoxide, hydrogen and methane are the main components of the producer gas. It was found that low heating value of gas at an equivalent ratio of oil palm briquette shown the value between of 3.20 – 3.21 MJ/Nm^3 and tung tree briquette shown the value between of 3.21 – 3.24 MJ/Nm^3. Figures 5(a) and (b) shows the effect of equivalence ratio on the producer gas production rate per unit weight of biomass or gas yield (Nm^3/kg). It clearly shows that with an increase of air inlet or decreasing of equivalent ratio, producer gas production rate continuously increase. Lower equivalent ratio signifies higher flow rate for a specific biomass consumption rate. According to Sheth and Babu [8]. The producer gas yield of oil palm briquette and tung tree briquette gasification show value ranges of 4.22 – 4.66 Nm^3/kg and 3.57 – 3.69 Nm^3/kg, respectively.

Table 5: Comparison of biomass gasification with literature.

Calorific value (MJ/Nm^3)	Power output from the gasifier (kW)	Cold gas efficiency (%)	Equivalence ratio	Fuel	Reference
4.65	49.81	67.65	0.268	Wood chips	[19]
4.77	65.04	68.37	0.259	Wood chips	[19]
5.19	44.93	76.68	0.287	Wood chips	[19]
5.31	55.68	73.46	0.356	Furniture wood + Charcoal	[19]
5.62	57.81	75.87	0.383	Furniture wood + Charcoal	[19]
5.70	235.92	67.40	0.279	Corn Cobs	[15]
4.50	125	76.70	0.349	Furniture wood	[20]
5.00	1,100	66.80	0.60	SubbA+Palm kernel shell	[21]
3.21	32.32	72.32	0.294	Oil Palm Briquette	This study
3.20	34.13	74.63	0.368	Oil Palm Briquette	This study
3.20	35.66	76.24	0.385	Oil Palm Briquette	This study
3.21	38.01	66.81	0.320	Tung Tree Briquette	This study
3.24	28.21	69.66	0.354	Tung Tree Briquette	This study
3.23	29.74	70.15	0.372	Tung Tree Briquette	This study



a.) Oil palm briquette b.) Tung tree briquette

Fig. 6. Gasification efficiency with equivalence ratio from gasification.

An effect of gasification efficiency with equivalence ratio was shown in Figures 6 (a) and (b). As given in Equation 4 gasification efficiency depends upon the calorific value and the amount of producer gas flow rate released on the low heating value of biomass multiple of biomass consumption rate. It was found the gasification efficiency increase with the producer gas flow rate release and relation with lower fuel equivalence ratio. The both biomass gasification had shown the gasification efficiency values of 72.32 – 76.24% and 66.81 – 70.15% for oil palm briquette and tung tree briquette, respectively.

3.4 Tar and Ash Contents

The amount tar content produced by oil palm briquette gasification and tung tree briquette gasification results were presented in Table 6. It was found an average tar content of both briquette shown value of 89.90 g/Nm^3 and 71.71 g/Nm^3, which is still based on the standard of biomass tar for internal engine application by upper limit value between ranges 50 – 100 g/Nm^3 [22,23]. Consequently, the tar and ash contents were comparable with standard biomass.

Table 6: Effect of equivalent ratio on the biomass briquette gasification.

Parameter / Fuels	Oil palm wastes briquette			Tung tree wastes briquette		
	S1	S2	S3	S1	S2	S3
Equivalence ratio (ER)	0.294	0.368	0.385	0.320	0.354	0.372
Syngas flow rate (Nm^3/h)	36.25	38.40	40.12	31.41	31.34	33.15
Fuel consumption rate (kg/h)	8.60	8.80	9.00	8.80	8.50	8.90
Composition of gas (%vol.)						
CO	14.12	14.05	14.07	14.12	14.81	15.11
H_2	9.11	8.76	8.95	9.12	8.31	7.88
CH_4.	1.40	1.51	1.45	1.39	1.21	1.53
O_2	7.57	7.54	7.54	7.50	7.55	8.54
CO_2	19.58	19.30	19.45	21.00	19.58	20.46
N_2	48.22	48.83	48.54	46.86	48.54	46.47
LHV_g (MJ/Nm^3)	3.21	3.20	3.20	3.21	3.24	3.23
Gas yield (Nm^3/kg)	4.22	4.66	4.46	3.57	3.69	3.72
Cold gas efficiency (%)	72.32	74.63	76.24	66.81	69.66	70.15
Avg. Ash (%wt.)		18.20±2			18.20±2	
Avg. Tar weight (g/Nm^3)		89.90			71.71	

4. CONCLUSION

In this study, biomass gasification of oil palm briquette and tung tree briquette was investigated. The experimental test used downdraft gasifier and various fuel equivalence ratios. It was found the maximum gasification efficiency of 76.24% and 70.15%, the producer gas yield of 4.46 Nm3/kg and 3.72 Nm3/kg, low heating value of 3.20 MJ/Nm3 and 3.23 MJ/Nm3, tar content from process was approximate of 89.90 g/Nm3 and 71.71 g/Nm3, respectively; and these characteristics can be used as fuel gas. According to zero waste concepts was confirmed with this study on the art of waste-to-Energy through producer gas production from fuel briquette used with oil palm and tung oil tree wastes. This study found and verified the practical test for utilization of solid wastes for purpose of fuel gas production from gasification system.

AUTHORS' DECLARATION

The authors declare that there is no conflict of interests regarding the publication of this paper.

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NOMENCLATURE

ASTM	American Society for Testing and Materials
TCD	thermal conductivity detector
GC	gas chromatography
y	mass basis
G_y	gas yield (Nm^3/kg)
ha	hectare
wt	weight
GJ	gigajoules
MJ	megajoules
kW	kilowatt
ER	equivalent ratio
η_g	gasification efficiency
H_g	low heating value of producer gas (kJ/Nm^3)
W_t	weight of tar in sampling gas
H_s	low heating value of solid fuel (MJ/kg)
Q_g	producer gas flow rate (m^3/s)
C_t	tar concentration (g/Nm^3)
V_g	producer gas volume (Nm^3)
H_i	heating value of producer gas (MJ/Nm^3)
X_i	mole fraction of producer gas

Greek symbols

ϕ_{oxi} oxidizer equivalent ratio

ϕ_{fuel} fuel equivalent ratio

η mole basis

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