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SYNTHETIC GAS (SYNGAS) PRODUCTION IN DOWNDRAFT CORNCOB GASIFIER AND ITS APPLICATION AS FUEL USING CONVENTIONAL DOMESTIC (LPG) STOVE

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ABSTRACT

This research was proposed to an enviromentally fuel from syngan of corncob. The feasibility and operation performance of corncob gasification in small downdraft gasifier was studied. The concorb gasification was carried out at 30-35% of the necessary air for stoichiometric combustion (the equivalent ratio, $\Phi = \pm 0.35$). The gasification temperature of 600-800 ^{0}C and the fire power of gasifier, FP of 5 kW$_{th}$ were obtained in this experiment. The syngas could be burned with a reddish blue flame like liquid petroleum gas (LPG) in conventional domestic stove. The air flow rate of 0.1-0.2 kg/min. for syngas combustion (about 50% for complete combustion) generated flame temperature of around 850 ^{0}C. The thermal efficiency and the cold gas efficiency about 40% and 70%, respectively. Economic and energy evaluation of corncob and syngas utilization was also conducted. The potential energy of waste corncob could fulfill the energy needs of the entire small industries that are located in West Bandung District. An implementation study of syngas utilization in one of the small industries for cooking fish gave the gross profit margin about IDR 15,749. The difference profit between the use of LPG and the use of syngas was about IDR 1,716 /kg fish. The utilization of waste corncob on a small industry as a pilot scale is expected to substitute the use of ±29 million kg of LPG/year.

Keywords: gasifier, corncob, synthetic gas, thermal efficiency.

INTRODUCTION

In 2025, new and renewable energy resources may contribute up to 5% energy consumption in Indonesia. The new and renewable energy resources include biomass [1]. Biomass is the main source of domestic energy requirement in Indonesia. Most of that biomass derived from agricultural and plantation waste which reached 85%, while the rest come from forestry waste sector [2]. Biomass is more widely used in the household and small industry sector for cooking, about 84%, but its utilization is still as a conventional fuel by using a simple stove. However, biomass as solid fuel provides very poor performance environmentally and lowers thermal efficiency. Traditional biomass stoves have low thermal efficiency and high flue gas emission.

Liquid petroleum gas (LPG) is one of the conventional sources of fuel for cooking in Indonesia. The use of LPG as a source of fuel is common both in household and small industry. The need of LPG for every household and small industry is about 0.25 kg/day and 30 kg/day, respectively. Since LPG is easy to control, convenient to operate and clean to use through emission of blue flame, therefore it is widely adopted for household and small industry use. However, because of the continued increase in the price of LPG, that fuel become scarce and hard to find. This condition will drive up the utilization of biomass as one of alternative and renewable energy resources. Therefore pyrolysis and gasification can make it more equivalent to LPG for the end user.

Corncob is potential alternative energy resource with respect to the availability in a sufficient amount. Corncob is a type of agricultural waste that piled up at many small corn grain drying units. Recently, agribusiness in corn production has been promoted national wide. In 2014, corn production is estimated at 19.13 million tons of dry seed or increased by 0.62 million tons (3.33 percent) compared with the previous year [3].

In order to use corncob in a thermal conversion mode, appropriate design of corncob gasifier are needed. By using of small downdraft gasifier, corncob may be converted into synthetic gas (syngas) that can be burned as LPG. Syngas has the potential to replace LPG since the combustion of gaseous mixture of CO and H$_2$ can be complete, thus minimizing the emissions of products of incomplete combustion (PIC), which is a major problem with solid fuel combustion.

Conventional updraft gasifiers have a high production of tars in the synthetic gas [4, 5]. Small conventional updraft gasifiers are in general give unstable flame in combustion of its syngas and so are unsuitable for many applications such as heat generation for household cooking and small industry use [6].

This work presents feasibility and operation performance of the gasification study, as well as economic and energy evaluation of corncob and syngas utilization. Application of corncob gasifier offers the possibility of cleaner, better controlled cooking gas for the household or small industry. The inexpensive corncob gasification can bring the advantages of cooking with synthetic gas fuel to substitute the expensive LPG use.

The experiment study of corncob gasification in a design downdraft gasifier was used to find performance parameters of gasifier, which play an important role in the design of gasifier. While the using of syngas in domestic LPG stove was meant to find fuel consumption, maximum surface flame temperature and thermal efficiencies that

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could be achieved. Economic feasibility was evaluated based on these parameters.

GASIFICATION

Gasification is the thermo-chemical conversion of solid fuel into a gas contains carbon monoxide (CO), hydrogen (H$_2$), and methane (CH$_4$). Converting corncob into thermal energy using gasifier can increase the thermal efficiency up to twice, rather than conventional corncob combustion [5, 7].

Corncob can be gasified by converting into combustible carbon monoxide due thermo chemical reaction of the oxygen in air and the carbon available in corncob. The gasification process is accomplished with excess carbon as partial combustion. In order to gasify corncob, about 30-40% of the stoichiometric air (6.0 kg of air per kg corncob is needed) [4, 5, 6, 7, 8].

Most of gasification processes are air-blown gasification processes, which produce low calorific value synthetic gas with a typical heating value (HHV) of 4-7 MJ/Nm^{-3} [5, 8]

POTENTIAL ENERGY FROM WASTE CORNCOB

The availability waste corncob was conducted by compilation and analysis through survey of primary and secondary data sources from agriculture and forestry department and statistic central bureau in West Bandung District. The result of the waste corncob availability study was then used to predict the energy sufficiency of all small industries by implemented the corncob downdraft gasifier in one of small industries.

PHYSICAL PROPERTIES OF CORNCOB

Corncob was collected from West Bandung District, West Java Province. Corncob was selected as feedstock for testing of a design downdraft gasifier. The corncob was cut into small pieces and store in a dry place for further use. Elements and proximate analysis were carried out before testing by using method suggested by ASTM D 4442-92 and E 1755-95.

EXPERIMENTAL SET UP

A downdraft gasifier was designed and constructed using mild steel sheet with 8 mm thickness from inexpensive waste local material. The total height of the gasifier was 0.95 m with a height of 70 cm and 25 cm combustion chamber and charcoal chamber, respectively.

The inner diameter and outer diameter gasifier was 35 cm and 45 cm, respectively. The insulation of the gasifier was made up of castable with 10 cm thickness and a mild steel exterior cladding to encounter higher temperature up to 1400 ^{0}C, Figure-1.

The system was assembled with one 6 W blower for supplying air. The airflow was divided in two streams by using two pipes with 3.0 cm and 4.5 cm in diameter, respectively. One airflow was used to gasify corncob fuel in gasifier, while the other one was used as combustion air for burning syngas. The combustion air was intended for properly mixing to obtain a full combustion of the syngas.

In theoretical calculation, the amount of air supplied during the combustion of syngas is the same as air stoichiometric needs to achieve the maximum surface flame temperature. In calculation of excess air or lean air, it was assumed that the excess air or uncombustible has taken the heat of the flame and reduced the maximum surface flame temperature (actual measured temperature). The air flow rate of gasified air and combustion air was controlled by using regulator valves and the flow rate was measured using a digital anemometer Krisbow-KW06-653. While the actual surface flame temperature of syngas combustion was measured by using digital thermocouple Krisbow-KW06-283.
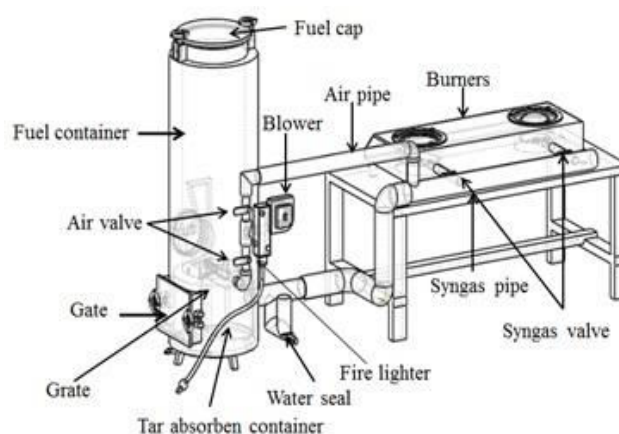

Figure-1. Sketch of the gasifier and LPG domestic burner

EQUIVALENT RATIO, Φ

The equivalent ratio, Φ is commonly used to indicate quantitatively whether a fuel-air mixture is rich, lean, or stochiometric. In the corncob gasification process, the equivalent ratio, Φ indicate whether the gasifier is operating in the pyrolytic mode, combustion mode or gasification mode. For combustion of syngas, the equivalent ratio is to determine whether the syngas is operating in complete combustion. The equivalent ratio is defined as [9]:

$$\Phi = \frac{(\frac{A}{F})_{Act.}}{(\frac{A}{F})_{Stoc.}} \qquad (1)$$

The value of $\Phi = 1$ is means that the amount of air supplied for stoichiometric of one kg syngas. In this work, the stoichiometric air/fuel, $(\frac{A}{F})_{Stoc.}$ ratio was determined based on ultimate analysis of synthetic gas (C, H, S, O), while the actual air/fuel, $(\frac{A}{F})_{Act.}$ was calculated from the combustion air flow rate and syngas flow rate.

THERMAL PROPERTIES OF FUEL

The lower heating value (LHV) of corncob was evaluated using ASTM method base on elements and proximate analysis. Energy potential of corncob as

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feedstock gasification fuel in the West of Bandung District was estimated by using the following formula:

$$Corncob\ energy = (1 - m_s)(C_R.P_r)LHV_{corncob} \quad (2)$$

Syngas samples from corncob gasification process were taken on particularly experiments and analyzed using chromatography gas Shimadzu CR9. The gas composition was then used to calculate LHV of syngas by using equation. (3) [5].

$$LHV_{Syngas} = \sum_i^P y_i\ LHV_i \quad (3)$$

THERMAL EFFICIENCY

Thermal efficiency is the ratio of energy used in boiling and evaporation of water with heat energy available in the fuel. Thermal efficiency can be determined by measuring the amount of heat absorbed by the fuel, and dividing by the total amount of fuel used. To calculate thermal efficiency of gasifier the following mathematical formula was adopted [9]:

$$\eta_{th} = \frac{(m_w\ or\ F + m_v C_p)(T_f - T_i)}{m_f.LHV_s} \times 100 \quad (4)$$

In the current work, the energy efficiency was done by boiling amount of water (from 25 ^{0}C to about 100 ^{0}C) and by frying small fishes until cooked (from 25 ^{0}C to boiling point of cooking oil, 250 ^{0}C). The mass measurement was carried out by a strain gauge base weighing balance with digital display. Water or oil cooking temperature was measured by digital thermocouple Krisbow-KW06-283.

Thermal efficiency also be defined as cold gas efficiency by using the relevant formula was [10]:

$$\eta_g = \frac{H_g \times Q_g}{H_s \times Q_s} \quad (5)$$

In this experiment, the synthetic gas was used for direct burning works for boiling of water or frying of small fishes. The thermal efficiency of syngas was calculated by equation. (6) [4, 5, 6, 7, 8, 9].

$$\eta_{th,g} = \frac{(H_g \times Q_g) + (Q_g \times \rho_g \times C_p \times \Delta T)}{H_s \times Q_s} \times 100 \quad (6)$$

Corncob consumption during water boiling or small fish cooking test on each gasification process was calculated by using equation. (7).

$$m_f = \frac{time\ of\ water\ boiling/fish\ cooking\ test}{time\ of\ gasification\ process} \times m_s \quad (7)$$

The weighing balance of corncob consumption was used to determine the average firepower, FP. The FP is a ratio of the fuel energy consumed by the gasifier per unit time. The FP was calculated by using equation. (8) [10].

$$FP = \frac{m_f\ x\ LHV_s}{60\ x\ t} \quad (8)$$

Corncob consumption rate during gasification process was calculated by equation. (9).

$$FCR = \frac{mass\ of\ biomass\ consumption(kg)}{time\ to\ operate\ (hour)} \quad (9)$$

Gasifier capacity in batch was tested by corncob feed with full capacity of about ±8 kg. This Gasifier capacity was also estimated by average of fuel consumption rate for each experiment.

RESULT AND DISCUSSION

SELF SUFFICIENT ENERGY

West Bandung District is one of the areas in the province of West Java which has plantations and agriculture field. Sub-sectors such as plantation and agricultural crops, particularly corn have a very important and strategic role in the national/regional development and give a big influence not only to food security, but also to the adequacy of energy needs and an increase in the local revenue.

In West Bandung District there are 23 small food industries. All those industries use LPG as a source of energy for its production. The need for LPG average in every small industry is 12-30 kg LPG/day (46.607 MJ/kg).

The waste of corncob from agricultural plantations in West Bandung District was estimated at 11,960 tons/year and this corncob has potential energy approximately 46,903,064 MJ/year (calculated by equation. (3)). This energy potential can fulfill the LPG needs (5,089,494 MJ/year) throughout the small industries in that region. By application of this design downdraft gasifier and burner system (modification of conventional LPG stove), the utilization of waste corncob via gasification process on a small industry is expected to substitute the use of ± 29 million kg of LPG/year.

FUEL COMPOSITION ANALYSIS

Corncob was obtained from West Bandung District. The composition analysis is presented in Table-1. The element contents of C and H would determine in quality and quantity of syngas produced. By mean of water content of 10.97%, corncob could be used as a feedstock fuel to gasify without drying pretreatment. Low water content would also reduce ignition time and start up time, as well as reducing wasted energy for heating corncob in drying zone during gasification process. In this work, water content of 10.97% gave the startup time 0.14 hour.

The average syngas composition during gasification process on the specific operating conditions at gasified air flow rate about 0.1653 kg/min. or about 0.6 Nm^3/kg of air consumption is presented in Table-3. Syngas composition's data from Li Yuping [11] was used as a comparison.

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Table-1. Element analysis of West Bandung's corncob.

Ultimate analysis	
Hydrogen, H (w-%)	7.08
Carbon, C (w-%)	43.17
Oxygen, O (w-%)	47.49
Sulfur, S (%)	0.13
Nitrogen N (%)	0.60
Proximate analysis	
Moisture (%)	10.97
Volatile Matter (%)	72.99
Fix Carbon (%)	14.51
Ash (%)	1.53
NHV (kJ/kg)	16,632

Table-2. Proximate analysis of synthetic gas.

Exhausts gas	This research*	Li Yuping [11] **
	(%-v)	
CO_2	17,99	16-25
H_2	4,5	25-38
CO	9,42	25-38
N_2	65,82	8-10
CH_4	1,79	<2

* Downdraft, P=1 atm, Qa= 0.1653 kg/min
** Pyrolysis comcob

The purified syngas composition from pyrolysis of corncob by Li Yuping was used as a comparison with this work. The differences of composition was caused by the purification of its syngas [11]. Synthesis gas purification led to lower nitrogen content and increase the combustable gases content. Commonly, the synthetic gas composition produce from biomass (corncob) gasification is in the range of 10-20% H_2, 10-20% CO, 2-4% CH_4, 12% CO_2 and 52,5-62,5% N_2 [5, 11, 12]. Therefore, according to the range of these composition of CO, H_2, CH_4, the syngas from this work still could be burned with stable flame in modified domestic conventional burner [14, 15].

In this experiment, according to the carbon dioxide content in syngas, it was supposed that oxidation still dominate rather than pyrolysis and reduction. The supplied air to gasified corncob approximately 0.6 Nm^3/kg (equivalent ratio Φ was about 0.35) was obtained in this experiment. Because of the theoretical air requirement for corncob gasification is about 1.3 to 1.7 Nm^3/kg. It could be concluded that the gasified air feeding was rather small. The small gasified air would affected on the composition of the syngas produced. According this condition, it was

supposed that the gasifier was still operating in pyrolysis mode [9].

GASIFIER PERFORMANCE

In this experiment, corncob was chosen for testing the performance of the gasifier implementation by using dual LPG burner. Each experiment used 7 kg and 8 of corncob with ± 3cm in size and average calorific value of 16.632 kJ/kg and water content of 10.97%. Gasifier performance was represented by the parameters which were calculated from experimental data, as presented in Table-3.

The large porosity, small density and large content of volatile matter of corncob could cause oxidation reaction more quickly in the gasifier reactor and it would effect on the shorter start-up time. Nevertheless, it would lead to increase the consumption of corncob.

Table-3. Gasifier performance.

	7 kg	8 kg
t_{Start} (hour)	0.138	0.140
FCR (kg/hr)	1.171	1,094
FP (kW$_{th}$)	5.412	5.056
FPg (kW$_{th}$)	6.58	6.66
η_{th} (%)	36.92	41.49
$\eta_{th,f}$ (%)	22.18	21,80
η_g (%)	70.69	73.14

The smaller size and relatively uniform of corncob and voids in corncob bed on gasifier would facilitate the flow of incoming air. It would accelerate of oxidation and reduction process and increase the value of FCR and FP. Differences in the amount of corncob fuel feed into the gasifier led to differences in rates of fuel consumption and fire power (Table-3). In this work, on each experiment by using a number of different corncob let the slower of FCR and FP, this was due to voids of corncob bed in the gasifier becomes smaller. The oxidation and pyrolysis process also became slower.

FLAME TEMPERATURE OF BURNING SYNGAS

Flame temperature of burning syngas, T_F, from corncob gasification tended to increase and then decrease due to duration of time, as shown in Figure-2. this was because of the gasification conducted in batch process. The decreasing corncob in gasifier could cause flammable gases in the syngas decreased, as well as decreased syngas heating value and flame temperature. In these experiments, the syngas flow rate was not constant over time; it was because of inconstant gasified air flow rate. Other operating conditions (e.g: temperature, pressure, corncob properties) were might also affect this syngas flow rate. The average maximum surface flame temperature of each experiment approximately 800-900 ^{0}C. It was achieved at the time of 90-20 minutes and gasified air flow rate of 0.1-

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0.2 kg/min. (25 ^{0}C) and cold syngas flow rate of 0.2-0.3 kg/min. (±50 ^{0}C).

The greater or smaller of the air-syngas ratio value, Φ than stoichiometric equivalent ratio, $\Phi = 1$ lead to reduce the composition of the flammable gases (CO, H_2, CH_4). This would affect the quality of the resulting flame. The heating value of syngas and its flammable gases content could be indicated by a flame profile. The syngas would be difficult to burn when the surface flame color would be reddish yellow.
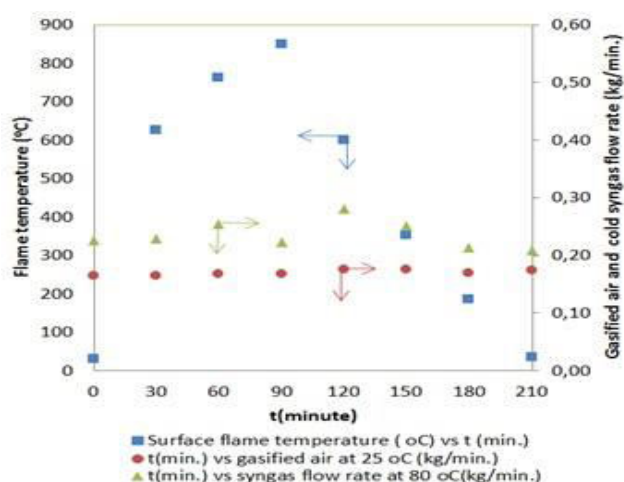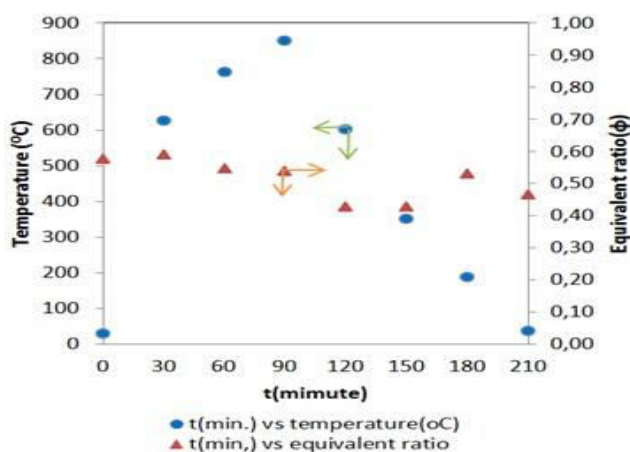

Figure-2. Surface flame temperature.

Figure-3. Equivalent ratio, Φ.

Equivalent ratio is the ratio between the needs of combustion air at actual condition compared with the needs of combustion air at theoretical combustion for burning syngas fuel from corncob gasification. The average equivalent ratio of about 0.5 was found in this work, Figure-3. It was indicated that the combustion air usage for burning of syngas was less than stoichiometric condition that lead to lower surface flame temperature. The average maximum average equivalent ratio was obtained at the time of 30-90 minutes.

In this work, the equivalent also affect the thermal efficiency, the value of the equivalent ratio closer to 1, the greater thermal efficiency could be obtained. The

average thermal efficiencies were calculated by using equation. (4) and equation. (6), as shown in Table-4. Thermal efficiency, η_{th} based on cold gas analysis was bigger than others, it was because of the using of syngas heating value (4500 kJ/kg) that excluded the heat used in its calculations. While the others thermal efficiency utilized of heat for boiling of water or cooking small fishes in its calculation.

ECONOMIC STUDIES

Economical implementation of corncob gasifier in one of the small industries in the area of West Bandung District was accomplished on the basis of the used of corncob and electricity, excluding the investment of gasifier.

In each gasifier runs, 7 and 8 kg corncob and 1 kg of fish was needed. The cost required for electricity consumption of 6 W blower was around IDR 2,991, while the cost of the used of corncob for 1 kg of fish was about IDR 250. The gross profit margin by using corncob was IDR 15,749. On the other hand, as a comparison gross profit margin by using LPG for cooking fish was IDR 14,032/kg of fish. The difference between the benefit of the use of LPG and the use of corncob was IDR 1,716/kg fish.

CONCLUSIONS

The energy need (5,089,494 MJ/year) of 23 small industries in West Bandung District is expected to be fulfilled by waste corncob (46,903,064 MJ/year) via gasification process by using this design downdraft gasifier system. The downdraft gasifier of 5 kW$_{th}$ and 40% of thermal efficiency produced syngas that could be burned in a reddish blue stable flame like LPG in modified conventional domestic stove. The flame temperature of about 850 ^{0}C could achieve by burning of this syngas. The gross profit margin of syngas utilization in one of the small industries for cooking fish was IDR 15,749. The profit difference between the using of syngas and LPG was around IDR 1,716 /kg fish.

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NOMENCLATURE

c_p	Heat capacity, kJ/kg. ^{0}C
C_r	Corncob residue constant, %
d_b	dry basis, %
FCR	fuel consumption rate, kg/h
FP	fire power, kW$_{th}$
H_g	heating value of synthetic gas, kJ/kg
HHV	higher heating value, kJ/kg
H_s	heating value of corncob, kJ/kg
y_i	Gas volume fraction, %
LHV	low heating value, kJ/kg
m_f	corncob consumption, kg
m_s	moisture content of corncob, %
m_W	mass of water, kg
m_V	mass of water vapor, kg
P_r	corn production, ton
Q_a	air flow rate, m^3/min.
Q_g	synthetic gas flow rate, m^3/min
Q_s	corncob flow rate, kg/min.
t	time, hour or min.
T_i	initial temperature, ^{0}C
T_f	final temperature, ^{0}C
T_F	flame temperature, ^{0}C
w_b	wet basis, %
η_{th}	thermal efficiency, %
η_g	cold gas efficiency, %
Φ	equivalent ratio, %