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The Composition of Syngas and Biochar Produced by Gasifier from Viet Nam Rice Husk

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***Abstract*— Nowadays, biomass has become one of the renewable energy sources might be filled for the lack of energy in the world. Gasification of biomass in general and of rice husk in particularly has attracted many researchers in Viet Nam. The rice husk gasification experimental study has been done with the GEK 20 kW device which is developed by All Power Labs, USA. The air flow rate from 2 to 4 m^3/h is applied in gasifier. A portable infra-red syngas analyzer is used for simultaneous measurement the concentrations of CO, CO_2, CH_4, H_2 and O_2 of the syngas and for calculation of the heating energy. The effect of air flow rate on temperature, syngas composition, and biochar is analysed and it indicates that the temperature in the combustion area and the content of hydrogen and carbon monoxide in the gas increase when the air-flow rate rises. In contrast, the yield of biochar is decreased.**

***Keywords*— gasification; husk; air flow rate; syngas; biochar.**

I. INTRODUCTION

Lack of energy has become one of ten problems which might challenges the human being in the recent time and in the next 50 years [1]. Furthermore, fossil fuel plays a significant role in the global energy supply and demand but it is limited and might be not enough for supplying in next coming years. Many non-oil producers and agricultural countries have set the target of renewable energy in which biomass utilization plays as alternative energy in their energy policy plan [2] and therefore, biomass might become an important primary energy source as well as renewable energy source. However, how might biomass be converted to other forms in terms of energy? The answer is gasification that is considered as a key technology for the use of biomass [3]. As the most promising biomass utilization method, gasification/pyrolysis produces not only useful fuel gases, char and chemicals, but also some by-products like fly ash, NO_x, SO_2 and tar. Tar in the product gases will condense at low temperature, and lead to clog or blockage in fuel lines, filters and engines. Gasification is one of the promising technologies in terms of the conversion of biomass to heat and power [2]. However, in order to foster the gasification technology in the future, advanced, cost-effective, and highly efficient gasification processes and systems are required and need to be studied [4]. In recent years, there have many studies focused on the energy yield from various biomass or agricultural wastes/residues by different methods or techniques [5-7].

In Thailand, the government has encouraged using of biomass as alternative energy and has financially supported the use of agricultural residue for heat and power production. They conducted some projects for performance test the feedstock consumption rate, producer gas yield, heating value of producer gas, and thermal efficiency. Wood, corncob, palm, etc. have been used as residue for the feedstock. Some projects used producer gas for electrical power generation with the capacity ranged from 250 to 300 kW_e and the others produce heat for use in the ceramics industry, for fertilizer drying, hotels, etc. This study indicated that downdraft air gasification technology is suitable for small-scale heat and power production [2].

In order to improve the quality of syngas, the combined effects of thermal pre-treatment and using a catalyst *in situ* on gasification carbon conversion efficiency, as well as product gas and tar content and compositions have been studied by Singfoong Cheah et al. [8]. The authors used a fluidized bed reactor for gasification study to compare the effects of thermal pre-treatment, pelletized and ground oak with three different levels of thermal pre-treatment. Three pretreatments such as pelletization, drying at 180 °C in air, and torrefaction at 270 °C in nitrogen were applied to the oak. The results indicated that the quality of the syngas in case of the oak has been dried at 180 °C is similar with the case of untreated oak. In addition, the amount of char is approximately the same in two case as treated and untreated oak which is similar as the case of syngas. In case of torrefaction at 270 °C in nitrogen were applied to the oak, the results shown that the syngas composition has lower methane, higher hydrogen to CO ratio, and less than half of the total tar. Moreover, the oak torrefied at 270 °C also produced more than two times the amount of char as the untreated, pelletized oak. In addition, olivine impregnated with nickel and cerium as the fluidized bed material in the gasifier also applied experimentally to determine the effect of catalyst. It is showed that modified olivine can improve hydrogen production and reduce methane and tar levels in the syngas. It also shows that the tar concentrations in the sysgas might be reduced up to 60% with a larger decrease in heavier tars than lighter tars when the modified olivine is applied. It is important because reduction in heavier tar plays a more important role in benefitting downstream operations [8]. Yalkunjan Tursun et al. (2016) has developed in a lab-scale external circulating radial-flow moving bed (ECRMB) gasification system for study steam co-gasification of pine sawdust and bituminous coal [9]. The system includes three decoupled reactors such as a gas–solid counter current moving bed pyrolyzer, a radial-flow moving bed gasifier and a riser-type combustor. The study indicates that the gas and tar yields increased with the increase of biomass blending ratio (BR). At the S/C range of 0 to 1.3, the gas yield and H_2 content in product gas increased but CO_2decreased with the increase of steam to carbon mass ratio (S/C). Higher gasifier temperature promoted the gas yield, $H_2 + CO$ in product gas, carbon conversion and chemical efficiency of the process [9].

The other system used biomass is Biomass Gasification–proton exchange membrane fuel cell (BG–PEMFC) system developed by S.M Beheshti et al. which is of major interest in the context of clean power generation and improving energy efficiency. They developed an Aspen Plus model to simulate the steady-state behavior of an integrated gasification system and a PEMFC [10]. The experimental testing shown that the output of voltage is improved when the feed humidity (cathode humidity) is higher. Furthermore, the biomass moisture content also negative effects on the potential of cell.

The other factor is raw gas derived from low-temperature biomass gasification usually contains condensable hydrocarbons referred to as “tars” as well as other hydrocarbons such as ethylene and other olefins [11]. The question is how to reform these compounds from gasification process? Martin Keller et al. have applied Chemical Looping Reforming of biomass gasification gas for reforming of ethylene by using Cu supported on four different Al2O3/SiO2-based porous support materials [11].

Viet Nam is an agricultural country with around 60% of population are working on this field and the rice production is more than 40 million tonnes annually. Therefore, every year there has more than 10 million tonnes of husk paddy might be used as biomass under different energy forms [12]. Moreover, it can be seen that, in most studies, heat, bio-oil and synthesis gas are successfully produced by combustion, pyrolysis and gasification techniques from biomass [13-16]. However, the gasification process should be focused and deeply researched which aim to enable higher process efficiencies, better gas quality and purity, and lower investment costs. The other factor to improve the economical efficiently and sustainability for a gasification system is how to produce more one product like gas, tar, and biochart than the one product only in a system. This has been confirmed by the study of S. Heidenreich and P. U. Foscolo [3] in which they indicate that the biomass gasification syngas have high efficiency and flexibility if its production are multiple energy products. Following this comment, this study concentrates on how to improve the syngas, tar and biochar quality as multi-energy from biomass gasification. In this study, we focus on the effects of air flow rate to the quality of syngas, tar and biochar gasified from husk paddy in Mekong delta, Viet Nam.

II. MATERIALS AND METHODS

A. Materials

The feedstock was paddy husk from a rice mill located in the Mekong Delta, Vietnam. The reason for choose this material in this area for experimental investigation is the Mekong delta is the biggest paddy production in Viet Nam. Annually, the amount of paddy husk released in this area takes account more than 50% of totally that in Vietnam. It takes around more than 20 millions tonnes per year. The moisture content, combustible fraction, percentage ash, and elemental analysis data of the Vietnam paddy husk in this area are presented in Table 1.

TABLE 1
CHARACTERISTICS OF THE RICE HUSK [16]

Items	Data
Proximate analysis (wt. %)	
Moisture	10.9
Volatile matter	51
Ash	18
Fixed carbon	20.1
Ultimate analysis (wt. %)	
Carbon	34.6
Hydrogen	4.23
Nitrogen	0.46
Oxygen	31.7
Heating value (kcal/kg DM)	3961

B. The experimental device for gasification

Some studies as above have indicated that the bed gasifier and downdraft might be the suitable choice for biomass gasification. Therefore, the gasifier has been used for the experimental apparatus is shown in Fig.1a (the schematic diagram) and Fig.1b (the device) in this study. This device named Gasifier Experimenters Kits (GEK) 20 kW which is developed by All Power Labs, USA. The device has been used and tested in some projects of Mekong Energy supported by EU which has been proved the exact and correct for data received. It classified as fixed bed gasifier types, a downdraft gasifier which can be easily described as an inox cylinder placed vertically. The feedstock enters into the system through the upper part and the syngas goes out from the bottom.

C. Testing equipments

In order to determining the composition of the gaseous products from biomass gasification process, it is needed to use the device with high accurate measurement level. The Gas board 3100P device from Wuhan Cubic Optoelectronics Co, Ltd (Fig.2) is the device might calibrate with the best results and the calibration gas should be within 10% of the concentration of the components analyzed in the gas sample. The resolution and the precision of the compositions for all gas testing are below 0,01% and 2%, respectively. By using this equipment, the syngas might be calibrated as a mixture in a tank with any the combination. In addition, the gas can also be diluted in order to get the right concentration with nitrogen. The calibration process also needs a source of the pure nitrogen and hydrogen for completely, according to the Company documents. Therefore, this device which includes a portable infra-red syngas analyzer and used for simultaneous measurement of the concentrations of CO, CO_2, CH_4, H_2 and O_2 in the syngas and for calculation of the heating value has been choose for the syngas testing.

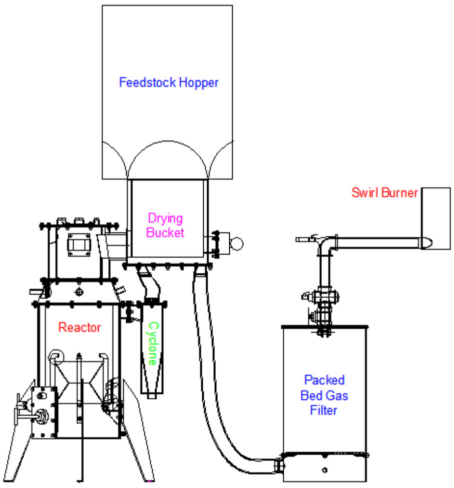

Fig. 1a. Schematic diagram of downdraft gasifier

Fig. 1b. The downdraft gasifier

Fig. 2. The gasboard 3100P syngas analyzer

D. Air flow rate

The air flow rates are normally determined based on the Equivalence Ratio (ER) factor which is defined as the ratio of the actual air flow rate with the stoichiometric air flow rate as:

$$ER = Q_{ac}/Q_{st} \quad (1)$$

where ER is Equivalence Ratio; Q_{ac} is the actual air flow rate (m^3/h); and Q_{st} is the stoichiometric air flow rate (m^3/h). According to Alexis T. Belonio [17], the process of the gasification occurs in different stages depend on the ER magnitude as below:

When $0 \le ER \le 0.2$, is as the process of pyrolysis and the reaction with oxygen begins to occur.

When $0.2 \le ER \le 0.4$ is as the gasification process.

When $0.4 \le ER \le 1.0$ is as the process of burning completely.

Therefore, the ER ratio should be within the range of 0.2 to 0.4 for gasification process, then we have

$$Q_{ac} = ER.Q_{st} = 2 - 4 \ m^3/h$$

The actual air flow rates are tested basing on the orifice plate (Figure 3). It is a device using to measure the air flow rate based on the difference in pressure. This device is used for the study.

The actual air flow rate is calculated as following:

$$Q_{ac} = \alpha * A_2 * \sqrt{\frac{2*\rho_{kk}(P1-P2)}{1-m^2}} \quad (2)$$

Where:

Q_{ac} is the actual air flow rate, kg/s; α is the flow coefficient; A_2 is plate hole area, m^2; ρ_{kk} is the density of air, kg/m^3; $\Delta P = P_1 - P_2$ is the differential pressure before and after the disk, Pa; and $m = A_2/A_1$ is the ratio between the area of the orifice plate hole and the area of the tube.

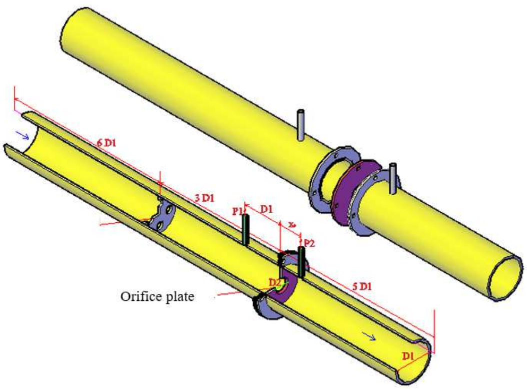

Fig. 3: Schematic diagram of the orifice plate

III. RESULTS AND DISCUSSION

In the gasification process, one of the most important input parameters that affects significantly on the process results is the air flow rate. In this study, the syngas temperature, the syngas composition, the tar and the biochar have been investigated with the effect of this parameter.

A. Effect of the air flow rate on the syngas temperature

The effect of air flow rate on the high temperature syngas behaviour from paddy husk gasification is one of the important factors of a gasifier. According to the Alexis T. Belonio, 2005 [17]. The air flow rate applied in this study ranges from 2 to 4 m^3/h during the experimental testing. The results of temperature are captured by the equipment as shown in Figure 2. Figure 4 presents the effect of air flow rate on the syngas temperature. It indicates that the rate of air-flow and the syngas temperature in the reduction zone increase linearly. However, it can be seen that the increase rate of air flow and the one of temperature is different. The temperature of syngas lightly increases and might be limited even the air flow rate goes up double and more. Therefore, it might confirm that the increase of air flow could not increase the syngas temperature simultaneously.

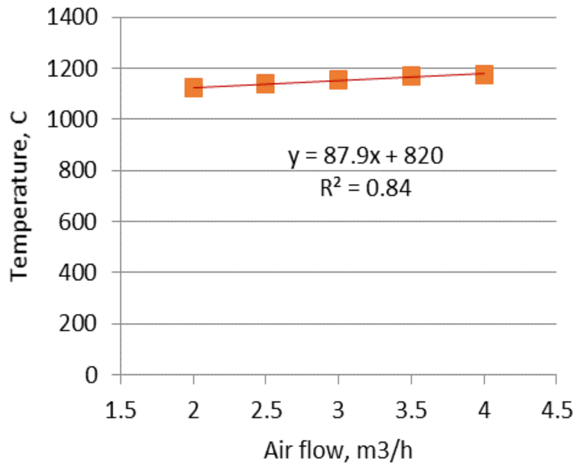

Fig. 4. Effect of air-flow on the syngas temperature

B. Effect of the air flow rate on the syngas composition

The syngas is the main energy desired from biogas gasification process which includes mainly combustible gas such as H_2, CO, CH_4, and other hydrocarbons. Figure 5, figure 6, and figure 7 show the average content of hydrogen, carbon monoxide and methane in the syngas obtained from gasifier due to the effect of the air-flow rate, respectively. Percentage volumes of hydrogen (8 – 11.2 %) and carbon monoxide (23-26 %) (Figures 5 & 6) were comparable with a previous study performed on rice husks using 350 kW downdraft gasifier having hydrogen and carbon monoxide within the ranges of 5.78 – 7.97% and 12.27 – 20.04% volume, respectively [18]. Similar ranges were also reported by Zhao et al [19] in which concentrations of hydrogen and carbon monoxide were 5.17-7.97% and 11.34%-14.42%, respectively. In this study, the methane volume produced was about 9-12 % volume which is much higher than that of reported in literature. For example, in an entrained flow reactor, rice husk gasification produced less than 3% methane [19]. Using a 350 kW downdraft gasifier for gasification of rice husk resulted in 0.61 – 0.69 % methane [18]. This implies that methane strongly reacted with oxygen in this case. When oxygen is more available, oxidation of methane happens more efficiently in the oxidation zone.

In general, there was an increasing trend in concentration of individual gas composition (i.e. hydrogen, carbon monoxide, methane) with increasing air flow rates. The increase in concentration of carbon monoxide with higher air flow rates can be attributed to the reactions between oxygen and char. Thus, the air flow has a significant influence on the syngas of the gasifier. Combustible gas production from rice husk gasification in Viet Nam is gaining attention for use as a clean energy. Therefore, rice husk gasification systems often interested in gas production is obtained. In this study, it is pointed out that the air flow rate in 4 m^3/h resulted in the highest combustible gas.

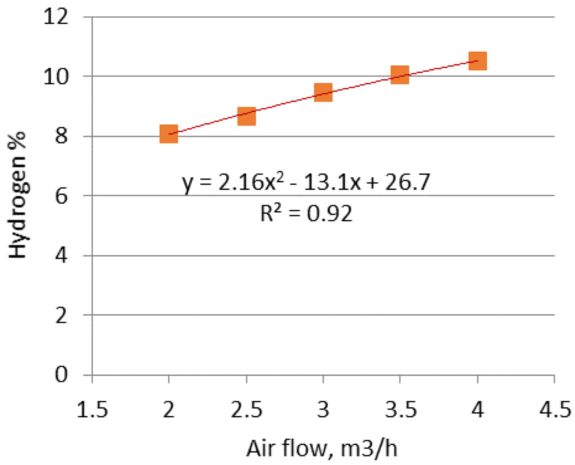

Fig. 5. Effect of air-flow on the Hydrogen

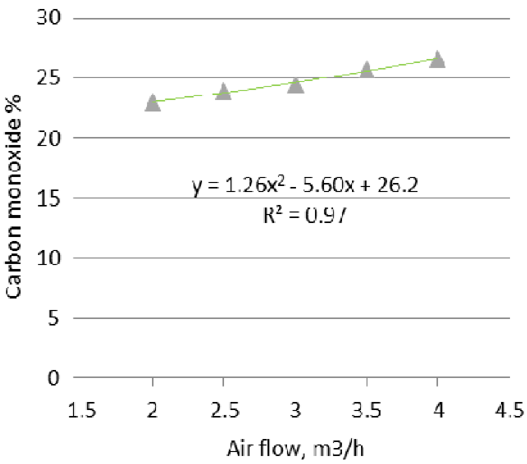

Fig. 6. Effect of air-flow on the Carbon monoxide

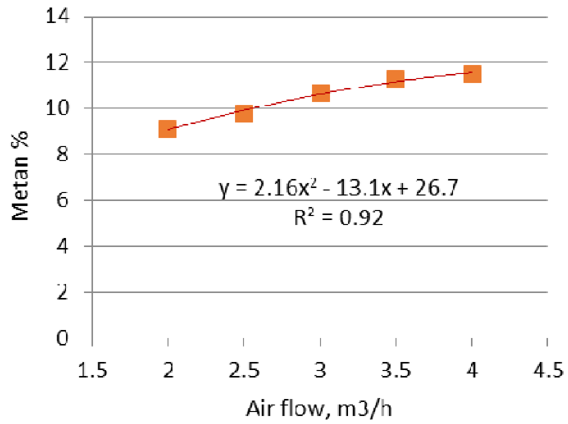

Fig. 7. Effect of air-flow on Methane

C. Effect of the air flow rate on the tar

The tar formation is one of the difficult problems in the gasification process required for selecting the suitable methods. The results show that the tar content mainly depends on gasification air flow, in which it decreases when the air flow of the gasifier increases (Fig.8).

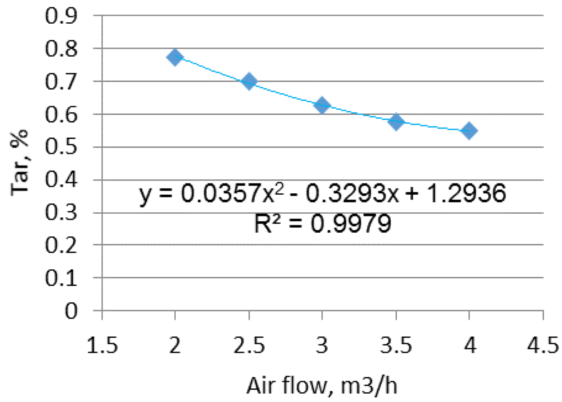

Fig. 8. Effect of air-flow on the Tar

D. Effect of the air flow rate on the biochar

Biochar is produced by carbonization of organic matter at high temperatures and in a restricted flow of oxygen. The yield of biochar when biomass is carbonized depends on the mode of carbonization. The quantities of biochar decrease with the increasing rate of air-flow and temperature. From the point of view of mitigating global warming, it would seem to be that optimizing biochar yield has a greater priority than the yield of syngas (Fig.9).

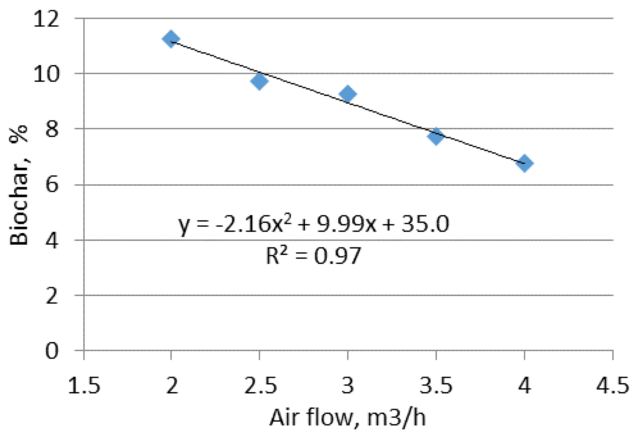

Fig. 9. Effect of air-flow on the biochar

IV. CONCLUSIONS

The experimental study on Viet Nam rice husk gasification has been done successfully. The air flow rate from 2 to 4 m^3/h is applied in gasifier. The concentrations of CO, CO_2, CH_4, H_2 and O_2 of the syngas and for calculation of the heating energy have been investigated. The results indicate that the effect of air flow rate on temperature, syngas composition, and biochar is significantly. It also indicates that the temperature in the combustion area and the content of hydrogen and carbon monoxide in the gas increase when the air-flow rate rises. In contrast, the yield of biochar decreases.

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