

Propagation Characteristic and Performance of Rice Husk Gasification at Different Tuyer Inclination Angle

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Received: 20.10.2018 Accepted: 18.11.2018

Abstract- Although several works on rice husk gasification in downdraft gasifier have been reported, but none of those works investigated and discussed propagation and performance of the gasification at different tuyer inclination angle. The present work aims to investigate an effect of tuyer inclination angle on propagation characteristic and performance of the gasifier fed by rice husk. Gasification of rice husk is performed in small-scale closed top downdraft gasifier at tuyer inclination angle of 0° , 30° and 60° and at equivalence ratio of 0.20. The tuyers are located at 400 mm above the grate. The highest burning propagation rate and effective propagation rate are achieved at tuyer inclination angle of 0° . The values are 0.29 and 0.44 mm/s respectively. The highest higher heating value of producer gas of 3.24 MJ/Nm^3 and the highest cold gas efficiency of 78.39% are also found at tuyer inclination angle of 0° .

Keywords: gasification, inclination angle, propagation, performance, rice husk.

1. Introduction

From many sources of renewable energy, biomass is one of the most promising sources that can be applied for heat generation as well as for electricity generation [1]. According to process followed, biomass conversion is divided into two routes, biological route and thermal route [2]. Biogas production from Olive-mill waste [3] is an example of biological route of biomass energy conversion. Meanwhile, one of well-known thermal route is biomass gasification. Gasification takes place in reactor called gasifier. In downdraft gasifier, burning front moves in opposite direction with feedstock bed and gasification air. Feedstock is initiated through ignition port at lower part of the reactor and air is supplied via tuyer at upper part of the reactor. As gasification proceeds, burning front moves upward and gasification air along with feedstock move downward in the reactor. Product of gasification, "producer gas", exits at lower part of the reactor. The opposite movement between burning front and gasification air is defined as reverse propagation [4] and [5]. Upward burning and downward feedstock velocities are termed as burning

propagation and bed propagation rate, respectively [4], [6], and [7]. Figure 1 shows schematic diagram of burning propagation in downdraft gasifier.

Several works on propagation of solid fuel combustion as well as gasification including biomass fuel have been reported. For gasification regime, propagation front has been investigated by [8], [9], [10], and [7]. Burning front velocity and biomass consumption rate accelerate with increasing air flow rate [10]. With increasing air flow rate, amount of oxygen increases. Higher oxygen content enhances and oxidation rate. Burning front propagates faster as increasing oxidation rate and consumed more feedstock.

The burning propagation rate is obtained from the time required to reach particular reference temperature between two locations along the vertical axis of the gasifier. Depend on midpoint in positive slope of temperature profile, different reference temperatures have been used for obtaining burning propagation rate, such as 400°C [11] and 500°C [4] and [6]. Meanwhile, bed propagation rate is calculated from the downward distance of the feedstock at any given time. The distance is obtained by subtraction of initial height and final height of fuel bed. The sum between flame propagation and

bed propagation rate is defined as effective propagation rate [4].

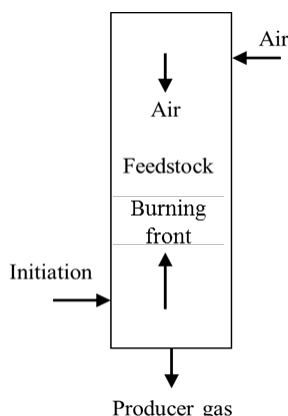
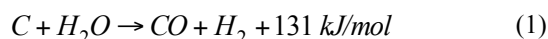


Fig. 1. Schematic diagram of burning propagation in downdraft gasifier

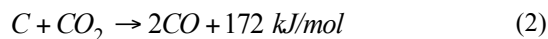
Performance of the downdraft gasifier is indicated by higher heating value of producer gas and cold gas efficiency. The performance of the gasifier can be affected by several factors, such as location of air tuyer above the grate and equivalence ratio. Effect of air tuyer location above the grate on performance of downdraft gasifier has been simulated by [12] and [13]. Height of gasification zone rose as increasing tuyer distance above the grate. Increasing reduction zone resulted in longer residence time of pyrolysis product in reduction zone, thus Water-Gas and Boudouard reactions occurred effectively and produced more CO and H₂. Increasing CO and H₂ in producer gas improved higher heating value of producer gas and cold gas efficiency as well. However, some works have been focused only on production of hydrogen from biomass instead of producer gas [14]–[16]

According to Basu [17], combustible gas CO, H₂, and CH₄ are formed through endothermic as well as exothermic reactions during reduction process as follows

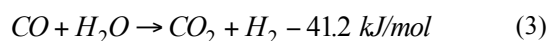
Water-Gas:



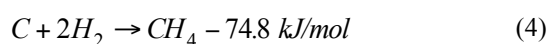
Boudouard:



Water-Gas Shift:



Methane Formation:



Reed & Das [18] defined equivalence ratio as the ratio between actual air flow rate used in gasification to stoichiometric air flow rate for complete combustion. Meanwhile Kaupp & Goss [19], stated that typically equivalence ratio is 0.2 to 0.4 for effective gasification. When equivalence ratio lower than 0.20, pyrolysis dominates

during gasification. In contrast, combustion will dominate when equivalence ratio is higher than 0.4 [20]. Equivalence ratio is proportional to oxidation rate [21] and biomass consumption rate [22]. More oxygen is available in higher equivalence ratio, results in improving oxidation rate in oxidation zone. Higher oxidation rate consumes more feedstock, hence increases biomass consumption rate. Besides, gasification temperature also escalates as enhancing oxidation rate. The effect of equivalence ratio on performance of small-scale closed top downdraft gasifier fed by rice husk has been reported in Susastriawan [23]. Maximum cold gas efficiency was achieved at equivalence ratio of 0.2 where gasification air is supplied via horizontal tuyer located at 400 mm above the grate. The gasifier has a diameter of 300 mm and height of 725 mm. The performance of the gasifier in term of flame continuity of producer gas in flare was also compared with other gasifier whose diameter of 300 mm and height of 950 mm [24].

Although several works have been performed regarding rice husk gasification, but none of the works have discussed effect of tuyer inclination angle on propagation behavior and performance of the gasifier. Besides equivalence ratio and air inlet location, tuyer inclination angle controls air flow pattern when passing through the fuel bed. Tuyer inclination angle may also influence contact time between the feedstock and the air which may affect the propagation characteristic, and in turn the performance of the gasifier. In present work, gasification of rice husk in small-scale closed top downdraft gasifier is performed at different tuyer inclination angles of 0°, 30°, and 60°. The work aims to investigate the effect of the tuyer inclination angle on the propagation characteristic and the performance of the gasifier

2. Material and Method

2.1. Feedstock characterization

Feedstock of rice husk used in this work is obtained from paddy milling industry in Bantul, Yogyakarta, Indonesia. Result of proximate, ultimate, and higher heating value are given in Table 1 at the end of this section.

2.2. Experimental work

The experimental work is performed at the Laboratory of Energy Conversion, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia. Figure 2(a) displays a photo of experimental setup which consists of downdraft reactor, blower, suction fan, flare, and measurement devices. Meanwhile, Fig. 2(b) presents schematic diagram of tuyer location and inclination angle. The reactor has a diameter of 300 mm, height (from grate to top) of 725 mm. The reactor has five stages tuyer which are located at 120, 190, 260, 330, and 400 mm above the grate. The tuyer has a diameter of 1 inch. In order to show better view of tuyer location and orientation, only 1st stage tuyer (120 mm above the grate) and 5th stage tuyer (440 mm above the grate) are shown in Fig. 2(b). Three tuyers in the 1st stage are used as ignition port. Gasification is initiated via the tuyers in the 1st stage.

Meanwhile, nine tuyers are available in the 5th stage for supplying air during gasification. Three tuyers (red color) has inclination angle (α) of 0°, three tuyers (black color) has α of 30°, and the rest (blue color) has α of 60°.

Rice husk gasification is conducted at equivalence ratio of 0.2 for α of 0°, 30°, and 60°. 5 kg of rice husk is fed into the reactor. To meet the equivalence ratio of 0.2 for 5 kg of rice husk, actual air flow rate required is 4.2 m³/h. Since air is supplied through three tuyers for each α , thus air flow rate of 1.4 m³/h is set for each tuyer. During gasification, temperatures at location of 50 mm (T₁), 120 mm (T₂), 190 mm (T₃), 260 mm (T₄), and 330 mm (T₅) above the grate are measured with K-type thermocouples that connected to data logger (OMRON ZR-RX45). Three samples of producer gas

are taken every 10 minutes for each run and analyzed using Gas Chromatograph (SHIMADZU GC-8A) at Department of Chemical Engineering in the same University. Once volume fraction of CO, H₂, and CH₄ are obtained, higher heating value of producer gas and cold gas efficiency are calculated. Time required to reach the reference temperature between two thermocouples is obtained from temperature profiles during gasification. Meanwhile, the distance travelled by the feedstock is obtained by subtraction of initial height and final height of lever rod at starting time and at the end of gasification, respectively.

Table 1. Proximate, ultimate, gross heating value analysis of the rice husk

Proximate	Weight %-Ash Dry Basis	Ultimate	Weight %-Ash DryBasis
Fixed Carbon	12.83	C	34.05
Volatile matter	56.2	H	5.35
Ash	21.17	O	39.14
Moisture	9.8	N	0.17
HHV (MJ/kg)	13.39	S	0.12

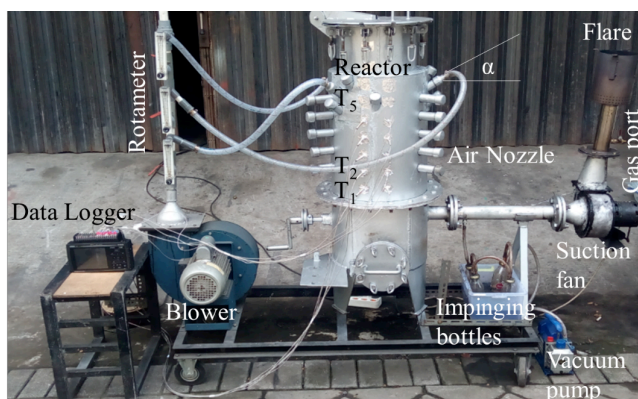


Fig. 2(a). Photo of experimental setup

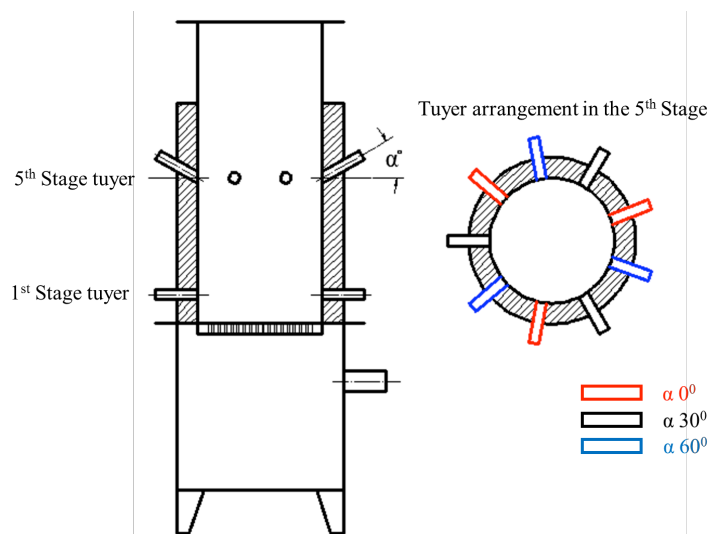


Fig. 2(b). Schematic diagram of tuyer location and inclination

3. Result and Discussion

3.1. Temperature profile

Figure 3 shows effects of tuyer inclination angle (α) on profile of axial temperature of the reactor during 30 minutes gasification. For all α analyzed, temperature T_1 increases firstly, then followed by increasing temperature of T_2 , T_3 , T_4 , and T_5 . This indicates that burning front moves downward in early stage of gasification. Oxidation occurs at the location near to the grate, thus the temperature at 50 mm above the grate (T_1) increases. When fresh feedstock at the location is completely oxidized, burning front moves upward to the fresh feedstock at higher locations, i.e. 120, 190, 260, 300 mm above the grate. Hence the temperature of T_2 , T_3 , T_4 , and T_5 increase later.

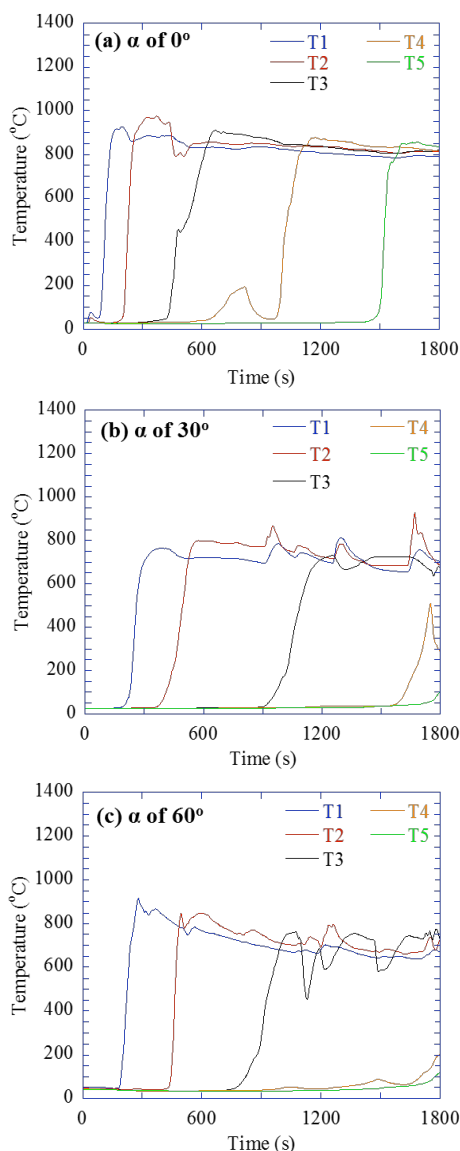


Fig. 3. Effect of tuyer inclination angle on profile of axial temperature

The rising of axial temperature is faster for horizontal tuyer than for inclined tuyer. Uniform air distribution to the feedstock with the use of horizontal tuyer improves oxidation

rate and heat released. Higher oxidation rate for horizontal tuyer results in higher axial temperature as shown in Fig.3. In contrast, non-uniform air distribution for inclined tuyer leads to uneven oxidation across sectional area of the reactor, thus reduces heat released. Uneven oxidation at cross sectional area of the reactor with the use of inclined tuyer is indicated by axial temperatures which is more fluctuate during gasification as can be observed in Fig.3. The fluctuation also due to air stream moves toward the bottom of the reactor for inclined tuyer. After a certain time, the stream contacts with feedstock in fuel channel and burns a channel into the hot fuel bed. The channel will collapse and lead to temperature alteration. This phenomena are called channeling and bridging. Channeling and bridging may reduce performance of the gasifier. Beside, bridging may affect measurement error during experimental work. Significant statistical deviation occurred when bridging is found during gasification [25]

3.2. Propagation characteristic

Figure 4 presents effect of α on burning, bed, and effective propagation rates. Burning front propagates upward to the fresh feedstock, whereas feedstock moves downward. Summation between the two is defined as effective propagation rate. As been discussed earlier, uniform air distribution to the feedstock for horizontal tuyer improves oxidation and burning propagation rates. Burning propagation rates at α 0°, 30°, and 60° are 0.29, 0.12, and 0.16 mm/s, respectively. Although burning propagation rate is higher, but bed propagation rate is lower for horizontal tuyer. Since burning propagation rate is high, oxidation front moves faster to the fresh feedstock above and left highest reduction zone. Highest reduction zone means more char in the zone, results in reduction of downward velocity of the fresh feedstock. Hence, bed propagation rate is lower for horizontal tuyer as indicated in Fig.4. The bed propagation rates are 0.16, 0.21, and 0.21 mm/s for α 0°, 30°, and 60°, accordingly. The highest effective propagation rate of 0.44 mm/s is observed for horizontal tuyer (α 0°). Meanwhile, the values at α 30° and 60° are 0.33 and 0.37 mm/s, respectively.

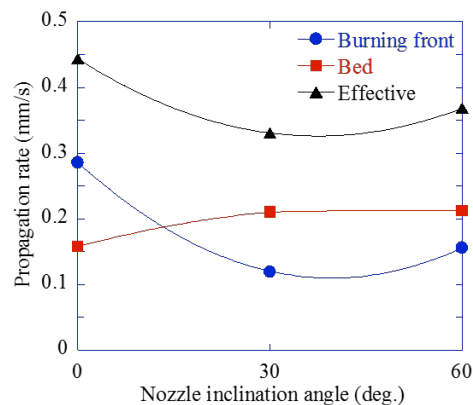


Fig. 4. Effect of tuyer inclination angle on propagation rate

Burning propagation rate affects height of gasification zone during rice husk gasification. As shown in Fig.5, gasification zone is higher for horizontal tuyer than inclined

tuyer. After 20 minutes, the gasification zone reaches 260 mm above the grate at $\alpha 0^\circ$, and the values are 190 mm for $\alpha 30^\circ$ and 60° . This indicates that burning front moves upward, since gasification is initiated at location of 120 mm above the grate. Faster burning propagation rate at $\alpha 0^\circ$ results higher the height of gasification zone.

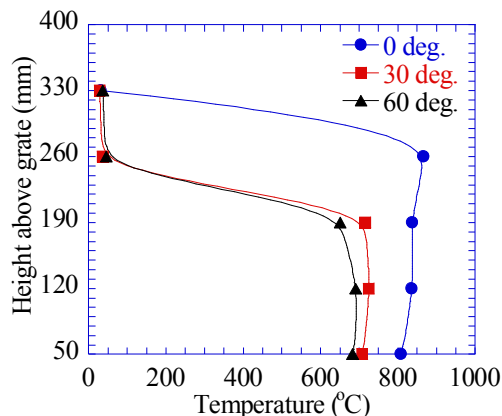


Fig. 5. Height of gasification zone

Meanwhile, effective propagation rate is related to gasification temperature. Similar trend between gasification temperature and effective propagation rate is observed. Gasification temperature is defined as maximum temperature in gasification zone. Fig.6 displays gasification temperature on 20th minute gasification. The curve shows that gasification temperatures reduce with the use of inclined tuyer. The gasification temperatures for the use of α of 0° , 30° , and 60° are 867.3°C , 725.0°C , and 690.8°C , respectively. Lower gasification temperatures at inclined tuyer are caused by burning of fuel channel and collapsing of a channel into hot fuel bed. Gasification temperature reduces effective propagation rate with the use of inclined tuyer. Lower effective propagation rate results in slower oxidation and heat released rate, thus lower gasification temperature.

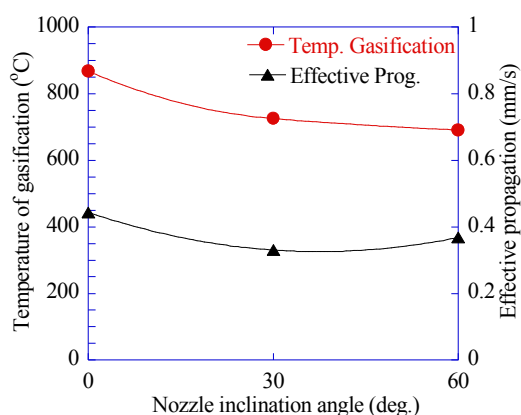


Fig.6. Relation between gasification temperature and effective propagation rate

3.3. Volume fraction of combustible gas

Figure 7 presents volume fraction of combustible gas CO, H₂, and CH₄ in producer gas on 20th minute gasification.

It is observed that volume fraction of CO is the highest for all α investigated. Since reaction rate of Water-Gas is the fastest among the other reduction reactions [23], hence volume fraction of CO is the highest in producer gas. Volume fraction of CO for all α are within 14.98-9.50 %. Meanwhile, volume fraction of H₂ and CH₄ are in the range of 7.49-1.98% and 0.95-0.68%, respectively. Due to very slow methane reaction rate, it is observed that the volume fraction is the lowest among others. According to Basu [11], the reaction rate of Water-Gas > Boudouard >> Methan

Volume fraction of CO and H₂ are the highest at horizontal tuyer. Higher gasification temperature at horizontal tuyer indicates more heat is released by oxidation. The heat is then used for endothermic reaction of Water-Gas and Boudouard in reduction zone. The reaction proceed effectively at high temperature [26], thus more CO, and H₂ is produced at horizontal tuyer. The highest CO and H₂ with a horizontal tuyer is caused by higher height of gasification zone. Higher gasification zone outcomes longer residence time of pyrolysis product in the zone. The endothermic reactions of reduction process occur better with increasing residence time, thus produces more CO and H₂ in producer gas. Shorter contact time between air and feedstock with the use of inclined tuyer, leading smaller reaction volume, thus produces less CO and H₂ in producer gas. It is obvious that lower higher heating value of producer gas and cold gas efficiency are obtained for the use of inclined tuyer. Sharma [12] and Jeya Singh & S. J. Sekhar [13] performed simulation and found similar phenomenon of improving volume fraction of CO and H₂ as rising height of gasification zone.

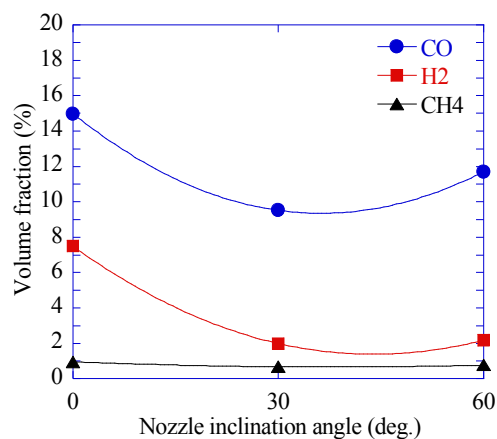


Fig.7. Effect of tuyer inclination angle on volume fraction of combustible gas

3.4. HHV and CGE

Once volume fraction of CO, H₂, and CH₄ are obtained, higher heating value (HHV) of producer gas and cold gas efficiency (CGE) can be calculated. The calculation procedure used in this work follows calculation performed by Susastriawan et al. [23] and Prasad et al.[20],[21]. Performance of rice husk gasification in terms of HHV and CGE are plotted in Fig.8. Increasing CO, H₂, and CH₄ in producer gas improves the HHV. Higher HHV is found at horizontal tuyer. This is due to higher volume fraction of

CO, H₂, and CH₄ as previously shown in Fig 7. The HHVs at α of 0°, 30°, and 60° are 3.24, 1.73, and 2.07 MJ/Nm³. Similar trend between HHV and CGE is observed. The CGE are 78.39, 51.73, and 55.30% at α of 0°, 30°, and 60°, respectively. The highest CGE is achieved at the highest HHV for the use of horizontal tuyer. Based on CGE, the performance of the gasifier fed by rice husk is maximum during horizontal tuyer. More uniform axial temperature during gasification at α of 0° as shown in Fig. 3 results in higher CGE. As stated by Belonio [29], uniform axial temperature during gasification increases performance of gasifier.

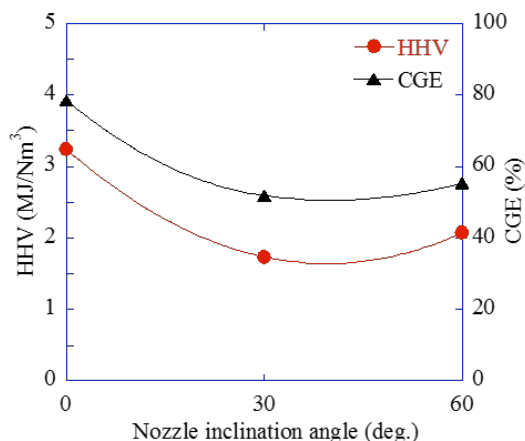


Fig.8. Effect of tuyer inclination angle on HHV and CGE

4. Conclusion

It can be concluded that tuyer inclination angle affects propagation characteristic and performance of rice husk gasification in small-scale closed top downdraft gasifier. Higher propagation rates, gasification zone, and volume fraction of combustible gas, higher heating value of producer gas, and cold gas efficiency are found with the use of horizontal tuyer. Meanwhile, shorter contact time between air and feedstock with the use of inclined tuyer, leads smaller reaction volume and produces less CO and H₂ in producer gas. It is obvious that smaller HHV of producer gas and CGE are obtained for the use of inclined tuyer.

For rice husk gasification in this work, it can be stated that optimum performance of the gasifier is obtained for the use of tuyer inclination angle of 0° (horizontal tuyer). At tuyer inclination angle of 0°, the highest HHV of 3.24 MJ/Nm³ and the highest CGE of 78.39 are obtained. The volume fraction of CO, H₂ and CH₄ at this tuyer inclination angle are found to be 14.98%, 7.49%, and 0.95%, respectively.

Acknowledgements

The authors are grateful to DRPM-Kemenristekdikti (Ministry of Research, Technology, and Higher Education)-Republic of Indonesia for financial support under the scheme of Hibah Penelitian Disertasi Doktor 2018 (DIPA-042.06.0.1.401516/2018; No:109/SP2H/LT/DRPM/2018)

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