

# Hybrid Coal: Effects Of Composition And Co-pyrolysis Retention Time in Low Rank Coal and Biomass Waste Co-pyrolysis Process on The Product's Yield

Jenny Rizkiana <sup>1,2</sup>

Slamet Handoko <sup>1</sup>

Winy Wulandari <sup>1,2</sup>

Muhammad Afif Ridha <sup>1</sup>

Hendi Aviano Prasetyo <sup>1</sup>

Dwiwahju Sasongko <sup>1,2</sup>

<sup>1</sup> Chemical Engineering Departement, Institut Teknologi Bandung, Ganesha 10, Bandung 40132, Indonesia

<sup>2</sup> New and Renewable Energy Research Center, Institut Teknologi Bandung, Ganesha 10, Bandung 40132, Indonesia

\*e-mail: sasongko@che.itb.ac.id

Low rank coal upgrading into a more efficient and environmentally friendly fuel can be done through copyrolysis with biomass into a fuel called hybrid coal. The purpose of the research is to determine the effects of biomass composition and copyrolysis retention time to the hybrid coal yields. Copyrolysis process conducted in a vertical tubular fixed bed reactor in an inert condition with atmospheric pressure and temperature set at 300°C. Inert condition achieved by flowing nitrogen gas into the reactor with a flowrate of 1.6 L/minutes. Biomass mixing composition is varied at 20, 30, and 40% from the total weight of the mixture. Copyrolysis retention time varied at 30, 60, and 90 minutes. Hybrid coals are characterized by proximate analysis, ultimate analysis, and calorific value measurement. Increase in retention time of copyrolysis from 30 to 90 minutes causing an increase in calorific value of 12.57-23.80%. From the proximate analysis results, fixed carbon content rise with the increase of co-pyrolysis time. The highest fixed carbon content obtained in the variation of 90 minutes, in the range of 49.36-49.75%. Increasing of sawdust composition from 20 to 40%, lowering the calorific value in the range of 0.58-8.55%.

**Keywords :** hybrid coal, co-pyrolysis, low rank coal, biomass waste

## INTRODUCTION

Indonesia is one of biggest coal producers in the world. Indonesia's coal reserves and resources respectively reaching 32.38 billion tons and 124.79

billion tons [1]. However, around 70% from its resources and reserves are low rank coal with calorific value less than 21.35 kJ/g and moisture content (up to 30%) that will be not efficient for direct combustion. Beside that, direct

---

combustion of coal will produce CO<sub>2</sub> which is not environmentally friendly.

Co-pyrolysis of coal with biomass is one of methods that can enhance the quality of low rank coal. Indonesia having biomass waste potential estimated equal with more than 400 million GJ each year. Biomass waste are produced from agriculture, plantation, and forestry sectors such as: (i) sawdust, (ii) husk and rice straw, (iii) biomass waste from palm oil plantation (empty fruit bunch, etc.), (iv) biomass waste from rejuvenations of rubber plantation, (v) biomass waste from sugar industry (bagasse), and (vi) others agriculture waste such as corncob. Generally, biomass waste is not effectively used as energy sources.

Co-pyrolysis of low rank coal with biomass waste would produced solid fuel which is popularly called hybrid coal [2]; [3]; [4]. The process of copolysis is expected to give some advantages such as: (i) Increase of coal calorific value, (ii) decrease of coal moisture content, (iii) change of biomass to hydrophobic to prevent decaying, (iv) Utilization of biomass waste for the same energy generation will result in lower CO<sub>2</sub> emissions because CO<sub>2</sub> coming from burning biomass waste is considered neutral due to the utilization by plants in the process of photosynthesis into a renewable energy source [2]; [3]; [4]; [5]; [6]. Therefore, research on co-pyrolysis of low rank coal with biomass waste is important. The purpose of this research is to observe the effect of process variable on coal quality. The process variables are co-pyrolysis temperatur, and retention time of co-pyrolysis. Coal quality

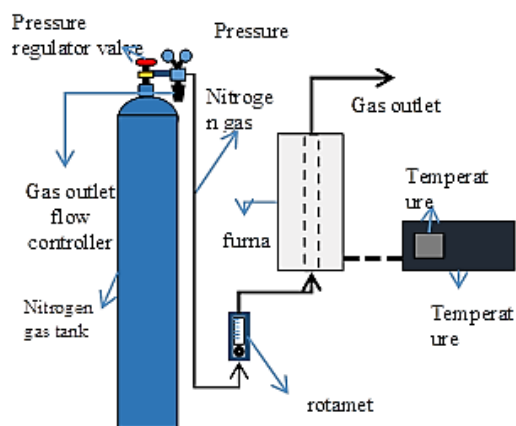
determined by proximate analysis, ultimate analysis, calorific value, and reduction of un-neutral CO<sub>2</sub> emissions.

## EXPERIMENTAL METHOD

The experiment was conducted using a vertical tubular furnace with 5 cm diameter and 50 cm height. Nitrogen gas from the tank was flowed into the furnace which flow was controlled by rotameter. Indonesian sub-bituminous coal and mahogany sawdust obtained from a furniture factory in Ciamis, Indonesia were used as hybrid coal raw materials.

Both of sawdust and coal were crushed and sieved in order to get smaller particle size, 50-100 mesh for sawdust and 30-100 mesh for coal. Coal and sawdust were mixed on a determined composition and were added by binding agent made from starch. The mixture was then granulated into 1 cm in diameter size. Granules were the dried using an oven on 110°C temperature for an hour. Granules were then packed on a steel sieved basket which later be placed inside the furnace on a position of 0 to 15 cm from the middle of the furnace. Mass of the granules put into the basket was measured in order to obtain the initial mass of the raw materials before co-pyrolysis. Nitrogen gas with 97% purity was flowed into the furnace with a flow rate of 1.6 litre per minutes for 5 minutes in order to remove non-inert gas such as oxygen. Electric heater was then be turned on and was set at temperature of 300°C which was the determined temperature of the co-pyrolysis process. Co-pyrolysis time counting was started when the

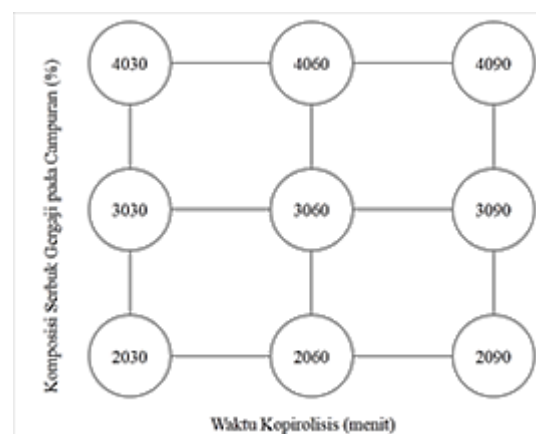
temperature indicator reached the set temperature. After co-pyrolysis time was achieved, the furnace was then be cooled until it reached 100°C. Hybrid coal which was formed was then be taken out from the furnace and it mass was measured. Hybrid coal was then be stored in a dessicator before being analyzed. **Figure 1** shows the scheme of co-pyrolysis experimental tools. Process parameters which were investigated on the experiment were sawdust content on the mixture and retention time of co-pyrolysis. Sawdust contents were varied at 20, 30, and 40% from total mass of sawdust and coal mixture while retention time of co-pyrolysis were varied at 30, 60, and 90 minutes.



**Fig. 1:** Scheme of Co-pyrolysis Experimental Tools

Total 9 experiments were conducted based on the determined parameter variations. **Figure 2** shows the code of samples which were copyrolyzed and analyzed. The code consist of 4 digits, the first 2 digits showed the sawdust content on the mixture while the last 2 digits showed the retention time of co-pyrolysis. Hybrid coal characteristics were then be

investigated by the result of proximate analysis, ultimate analysis, calorific value measurement, and reduction of non neutral carbon dioxide emission calculation. Proximate, ultimate analysis and calorific value measurement were conducted at the Research and Development Center of Mineral and Coal Technology (tekMIRA) which located in Bandung, Indonesia.



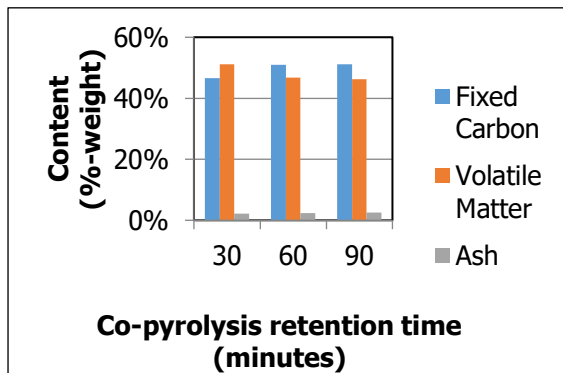
**Fig. 2:** Experimental Sample Codes

## RESULTS AND DISCUSSION

### Effect of Co-pyrolysis Retention Time to Hybrid Coal Characteristics

The increase of co-pyrolysis retention time, increases the calorific value of hybrid coal. The increase of calorific value is proportional with increases of fixed carbon and decreases of volatile matter. Proximate analysis results show that in biomass mixing composition 30%, fixed carbon increases caused by increases of co-pyrolysis retention time 30, 60, and 90 minutes respectively 46.57; 50.90; and 51.18%. This contrasts with volatile matter that decreased respectively 51.22; 46.71; and 46.28%. Both effects are due to more volatile matter are released when co-

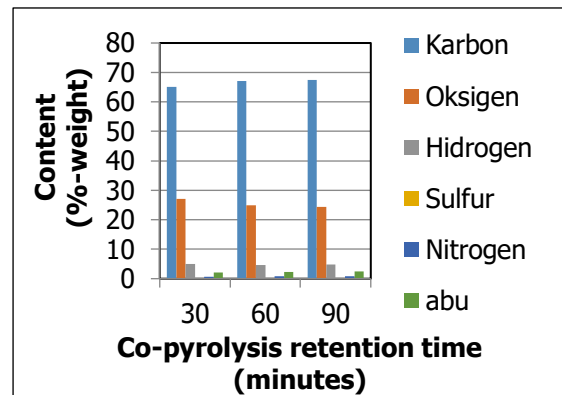
pyrolysis retention time increased. The volatile matter released are from degradation of biomass lignocellulosic components in temperature under 300°C [7], and from the coal. Ash content in the hybrid coal increased respectively 2.20; 2.39; and 2.54%. Small percentage of ash from the coal and biomass respectively 2.07 and 1.1% makes the ash content in hybrid coal not significantly affected. **Figure 3** shows the results of proximate and ultimate analysis of hybrid coal with 30% sawdust mixing composition. The effect of co-pyrolysis retention time on variations of 20% and 40% sawdust mixing composition shows the same trend.



**Fig. 3:** Effects of Co-Pyrolysis Retention Time To Proximate Analysis of 30% Sawdust Mixing Composition Hybrid Coal

Increase of co-pyrolysis retention time also affecting ultimate analysis of hybrid coal. Carbon content tend to increase and oxygen content tend to decrease. Ultimate analysis of 30% sawdust mixing composition variation show that carbon content increase respectively 65.07; 67.14; and 67.47%, while the oxygen content decreases respectively 27.04; 24.95; and 24.44% when co-pyrolysis retention time increases from 30, 60, and to 90 minutes. Both effects occur due to thermal

degradation of biomass tend to release hydrogen and oxygen than carbon [8]. **Figure 4** shows the results of ultimate analysis. Effects of co-pyrolysis retention time to carbon content in 20 and 40% sawdust composition variations basically also shows a similar trend with 30% sawdust mixing composition. In fact, the change of each element in the ultimate analysis of hybrid coal is difficult to predict because of constraint about what element and quantity of each element that are released, also the release mechanisms of these elements during the co-pyrolysis process.



**Fig. 4:** Effects of Co-Pyrolysis Retention Time To Ultimate Analysis Of 30% Sawdust Mixing Composition Hybrid Coal

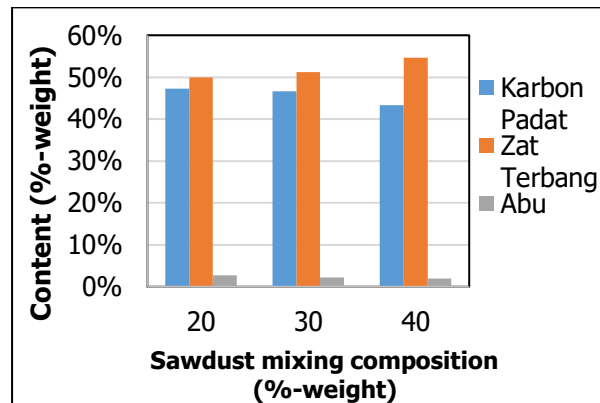
**Effect of Biomass Mixing Composition to Hybrid Coal Characteristics**

Changes in biomass mixing composition affect the results of the proximate analysis, ultimate analysis, and calorific value of hybrid coal. The increase of sawdust mixing composition about 20-40% reduces the calorific value 0.58-8.55% compared with pyrolyzed-coal calorific value. The increase of sawdust on the feed decrease solid product (char), while the liquid and gases products increase [9];

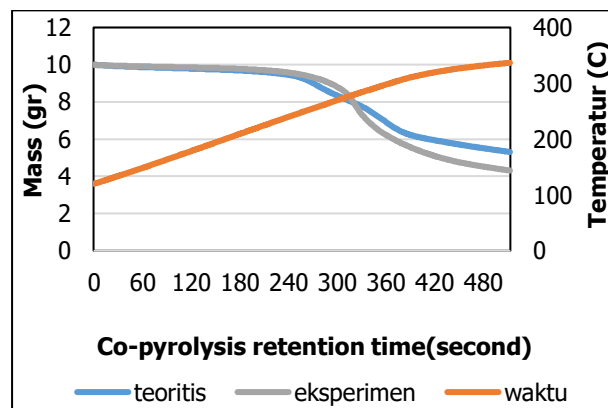
[10]. The lower charcoal content is proportional to the low carbon content so that the calorific value becomes decreased. The lowest decrease in calorific value was 3090, while the highest decrease was 4030.

The results of proximate analysis show that the increase in sawdust mixing composition leads to decreased of fixed carbon and increase of volatile matter. Increase of sawdust mixing composition from 20, to 30, and to 40% at 30 minutes of co-pyrolysis retention time resulted in decreased of fix carbon from 47.33, to 46.57, and to 43.43%, while the volatile matter increased from 49.92, to 51.22, and to 54.69%. **Figure 5** shows the proximate analysis results variation at 30 minutes of co-pyrolysis retention time. Decreased of fix carbon content due to additional degradation process caused by release of radicals of OH and H from biomass to coal tar into gases so that the fixed carbon content was decreased [11]; [12]; [13]; [14]. However, similar trends do not occur in variation 60 minutes of co-pyrolysis retention time that fixed carbon changes from 50.23, to 50.90, and to 48.92% as well as sawdust mixing composition increased. This condition is explained by thermogravimetry analysis (TGA) in variations of sawdust mixing composition 20 and 30% for co-pyrolysis retention time 60 minutes. **Figure 6** and **Figure 7** shows TGA samples of 20 and 30%. TGA results showed that the mass decreased in variations of 20% sawdust mixing composition are more significant compared to 30%. Difference between experiments result with calculations in TGA may happen, and maximum 8.3% for fixed

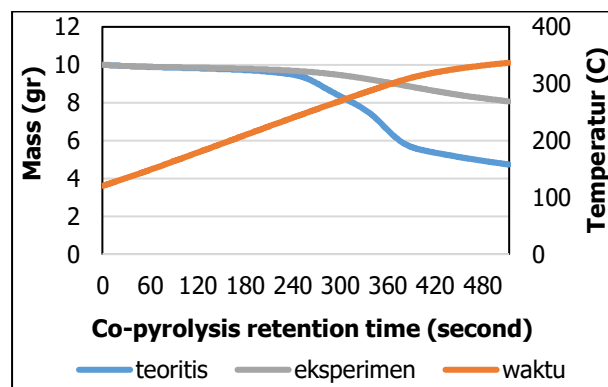
carbon calculation [4]. It shows that in co-pyrolysis of 30% sawdust mixing composition, difference between experimental and theoretical results may occur.



**Fig. 5:** Proximate Analysis of Variation 30 Minutes Co-Pyrolysis Retention Time



**Fig. 6:** Comparison of Variation Sawdust Mixing Composition 20% by Theoretical and Experimental Using TGA



**Fig. 7:** Comparison of Variation Sawdust Mixing Composition 20% by Theoretical and Experimental Using TGA



**Fig. 8:** Repolymerization Effects in Hybrid Coal Variation of Sawdust Mixing Composition 40%

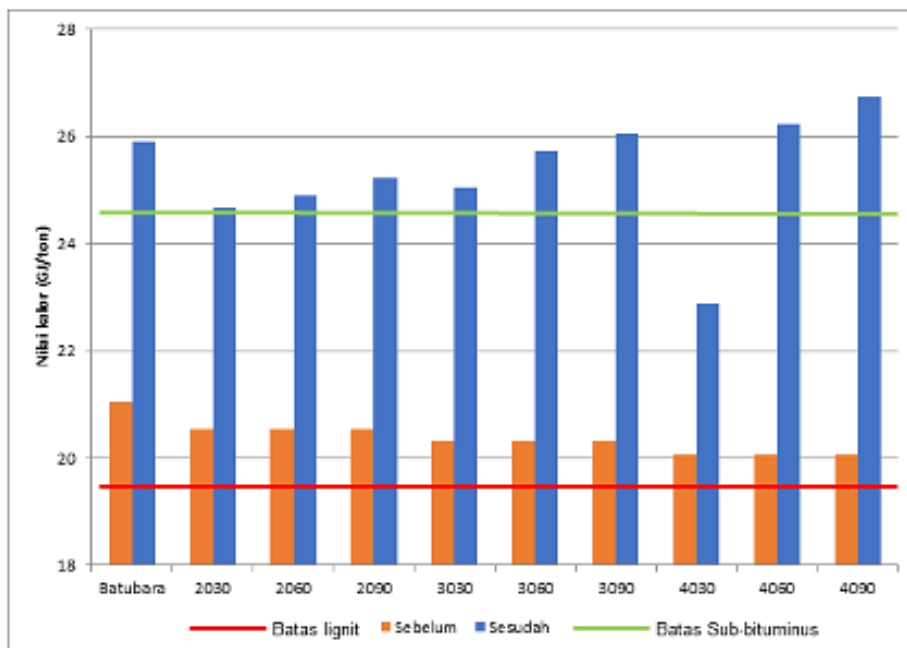
While the fixed carbon in variation co-pyrolysis retention time 90 minutes was changed from 52.18, to 51.18, and to 51.46% as the sawdust mixing composition increased from 20, 30, to 40%. Increase in fixed carbon from variations of sawdust mixing composition 30 to 40% due to tar repolymerization on the surface of hybrid coal. **Figure 8** shows the repolymerization evidence that occurred in a sample 4090. The repolymerization process at low temperatures occurs because of the

accumulation of residuals char formed on the coal surface during co-pyrolysis [15]; [16]; [17]; [18].

### Analysis of Calorific Value and Energy Yield of Hybrid Coals

**Figure 10** shows the bar charts of calorific value from hybrid coals and their raw materials before and after co-pyrolysis completed with upper limit line from lignite and sub-bituminous coal calorific value. Based on the figure, there were 8 from 9 or 88,89% samples of hybrid coals had calorific value which were classified as bituminous coal. Based on that result it could be concluded that co-pyrolysis of coal and biomass could increase the calorific value of the raw coal from low rank coal into a higher rank coal.

Calorific value increasement of hybrid coal had also been followed by mass loss of raw materials during the co-pyrolysis. Energy yields of hybrid coal were calculated in order to investigate how



**Fig. 10:** Calorific Value of Hybrid Coal Before and After Co-Pyrolysis

much total energy which could still be generated by hybrid coals compared to total energy generated by the raw materials before losing mass caused by co-pyrolysis happened.

## CONCLUSION

From the results it could be concluded that hybrid coal had a higher calorific value than sub-bituminous coal with the value up to 26.8 kJ/g. Hybrid coal had also produce less non neutral carbon dioxide emission than the coal used as raw material up to 44%. Increasing the retention time from 30 to 90 minutes would enhance the calorific value up to 12.57%-23.80% which value ranged from 23.69 to 26.05 kJ. From the proximate analysis results, fixed carbon content increased as the retention time was increased with a value of 49.36-49.75% range. Increasing the sawdust content on the feed mixture from 20 to 40% decreased the calorific value of the feed 0.58-8.55%. There were 8 from 9 samples of hybrid coal were succesfully upgraded from sub-bituminous coal into bituminous coal.

## ACKNOWLEDGMENTS

We would like to thank Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Institut Teknologi Bandung for providing research grant through Program Penelitian, Pengabdian Masyarakat, dan Inovasi (P3MI) 2017.

## REFERENCES

1. Kementerian Energi dan Sumber Daya Mineral (ESDM) Republik Indonesia. Outlook Energi Indonesia. (2014)
  2. Jeong. H.J.; Hwang. J.H.; Seo. D.K.; Park. S.S. Journal of Thermal Analytical Calometry 1867-1875 ; **120**(3) (2015)
  3. Lee. D.W.; Bae. J.S.; Lee. Y.J.; Park. S.R.; Hong. J.C.; Lee. B.H. Environmental Science and Technology 1704-1710 ; **37** (2013)
  4. Park. D.K.; Kin. S.D.; Lee. S.H.; Lee. J.G. Bioresource Technology 6151-6156 ; **101** (2010)
  5. Rizkiana. J.; Guan. G.; Widayatno. W.B.; Hao. X.; Huang. W.; Tsutsumi. A.; Abudula. A. Fuel 414-419 ; **134** (2014)
  6. Sasongko. D.; Wulandari. W.; Rubani. I.S.; Rusydiansyah. R. AIP Conference Proceedings; **1805**(1) (2017)
  7. Basu. P. Elsevier. Inc.. Oxford (2013)
  8. Bergman. P.C.A.; Boersma. A.R.; Zwart. R.W.R.; Kiel. J.H.A.. Energy research Centre of the Netherlands ECN-C—05-013 (2005)
  9. Guo. M.; and Bi. J.-C. Fuel Processing Technology 743–749; **138** (2015)
  10. Quan. C.; Xu. S.; An. Y.; Liu. X. Journal of Thermal Analysis and Calorimetry 817–823; **117** (2014)
  11. Sonobe. T.; Worasuwannarak. N.; Pipatmamomai. S. Fuel Process Technology 1371-1378; **89**(12) (2008)
  12. Blesa. M. J.; Fierro. V.; Miranda. J. L.; Moliner. R.; Palacios. J. M. Fuel Process Technology 1-17; **74**(1) (2001)
-

- 
13. Shui. H.; Shan. C.; Cai. Z. *Energy* 6645-6650; **36**(11) (2011)
  14. Rizkiana, J. ; Guan, G. ; Widayatno, W. B. ; Yang, J.; Hao, X. ; Matsuoka, K. ; Abudula, A. *RSC Advances* 2096-2105 ; **6** (2016)
  15. Chen. C.; Ma. X.; He. Y. *Bioresources Technology* 264-273; **117** (2012)
  16. Li. S.; Chen. X.; Liu. Y.J.; Wang. L.; Yu. G. *Bioresources Technology* 414-420; **179** (2015)
  17. Moghtaderi. B.; Meesri. C.; Wall. T.F. *Fuel* 745-750; **83**(6) (2004)
  18. Aboyade. A. O.; Carrier. M.; Meyer. E. L.; Knoetze. H.; G'orgens. J. F. *Energy Conversion Management* 198-207; **65** (2013).
-