International Journal on Advanced Science Engineering Information Technology

Vol.7 (2017) No. 6
ISSN: 2088-5334

Determining of Drying Characteristics for South Sumatera Low-Rank Coal using Solar and Laboratory Scaled Oven

Irwin Bizzy[#], Riman Sipahutar[#], Eddy Ibrahim[*], Muhammad Faizal[$]

[#]*Mechanical Engineering Department, Sriwijaya University, Indralaya, 30662, Indonesia*
E-mail: irwin@unsri.ac.id

[*]*Mining Engineering Department, Sriwijaya University, Indralaya, 30662, Indonesia*
E-mail:eddyibrahim838@yahoo.com

[$]*Chemical Engineering Department, Sriwijaya University, Indralaya, 30662, Indonesia*
E-mail:mfaizal1405@gmail.com

***Abstract*— South Sumatera is one of the provinces in Indonesia that has the largest coal reserve in Indonesia. Unfortunately, the type of coal is mostly in the low-rank coal. Through a national energy policy, the government of the Republic of Indonesia has set an increased consumption of coal for domestic use. The energy derived from coal will be increased approximately 33 percent of the total Indonesia energy consumption in 2025. Currently, approximately 70 percent of Indonesia's coal production is used by the State Electricity Company as fuel for power generation, 10 percent for the manufacturer of cement, and the rest for industrial and metallurgical processes. The low-rank coal, which contents a high moisture into solution be decreased firstly and then through drying process before using in industry. In the power generation industry, usually, low-rank coal is dried naturally in a closed stockpile before being used as fuel, and spontaneous ignition happens frequently. The results show a decrease in moisture content for solar drying and using laboratory scale oven. Solar drying depends on the solar radiation falling onto the surface, so coal drying depends on highly weather and time.**

***Keywords*— low-rank coal; moisture content; solar drying; oven drying, spontaneous ignition**

I. INTRODUCTION

Coal is one of the main energy sources in the world, which is used as a fuel for power plants. Therefore, it is still considered as an important source due to it's cheap in price and spread in some countries as energy reserves. Generally, coal is classified into the category of anthracite, bituminous, sub-bituminous, and lignite. As an energy source, Indonesia has a bulk of coal reserves, which is mostly categorised as lignite (58%), sub-bituminous (27%), bituminous (14%), and anthracite (<1%). Lignite is the type of coal that characterised by very high moisture content and requires the drying process before use. In addition, lignite tends to ignite spontaneously due to its high volatile content and porous structure. The moisture content is dried typically at temperatures 75, 100, and 150°C. These temperatures were used for the required drying period in achieving the equilibrium of moisture content. This drying period varied significantly. They proofed that increasing of the drying temperature caused by the decreasing of the required drying period. It has also been proven that the distribution of the particle size of a coal sample mass depends on the method used in handling and mining and its inherent degrees fracture. [1], [2], [3].

The main problem occurs in processing the brown coal or lignite is its very high content in moisture and lower calorific values (LCV). These unique properties caused a higher transport cost, complicated grinding and handling operations. Some technologies have been developed in removing the moisture occurred in mining and power plant. This was surveyed by the United States recently. The brown coal or lignite also referred as Low-rank coals (LRCs) is taken into account to more than 50 percent of the coal reserves in the world. Due to its LCV and spontaneous combustion property, the application of LRCs is very limited. Compare to the high-rank coals, the LRCs rendered a low energy output, fuel fouling and contain a high amount of moisture. In contrary, dried LCRs improved combustion efficiency, safety enhancement, and mitigation of gas emission. Although many existing technologies have been already known, it is often a challenge to find the opportunity of a cost-effective solution [4], [5].

In selecting the dryer for coal upgrading, many factors should be considered. The following factors, such as energy consumption, particle size, throughput, carbon footprint, capabilities of material handling, safety factor, capital and operating costs, return on investment, etc., are important considerations [6].

As it is known, coal consists of complex components of organic substances, non-organic, and water vapor. Each of these components will respond when the existence of the treatment from the outside, such as a given external warming. On another side, the types of water in the coal consist of the interior and surface adsorption water, capillary water, inter-particle water, and adhesion water. Interior adsorption water is contained in microspores and micro-capillaries within each coal particle deposited during formation. Surface adsorption water forms a layer of water molecules adjacent to coal molecules but on the particle surface only. Capillary water is contained in capillaries and small crevices found between two or more particles. Inter-particle water is contained in capillaries and small crevices found between two or more particles. Adhesion water forms a layer or film around the surface of individual or agglomerated particles [7]. An equipment is required to remove the water content of the coal. The designed coal dryer must consider the speed of removing water from the coal, temperature and relative humidity of the fluid, particularly for LRC's. Some researchers have already used dryer equipment for drying LRC's. Researchers [8] have studied drying of coal having a total moisture content of 40% by using rotary dryer equipment. After the drying process and 100 hours of contact with open air, total moisture content was stable in the range of 18 to 19.5% (ar). Other researchers [9] have examined the drying process of Indonesian low-rank coal by using the fluidized bed. They stated that 70 to 80 wt. % (wet basis, wb.) of the initial total moisture can be decreased, if the gas temperature 150^{o}C and the gas velocity of 2.0 m/s used. By employing DI-Methyl Ether method, the coal sample from the city of Prabumulih had been examined. This research resulted in the ability to extract moisture content from the coal, in which the smaller particle size of coal will be more easily moisture content removed. Energy consumption for dewatering of low-rank coal at about 1100 kJ/kg. Less than 50% of the latent heat of vaporization of water and several –fold more efficient than conventional thermal drying of coal. Low rank coals that have a high moisture content are generally dried first by using disc type dryers equipped with rotary blades. The results of the experiment show that the temperature of the rotary blades will significantly decrease the moisture content. Moreover, reducing the flow rate can also decrease the moisture content, while the high speed of the rotary blades resulted in slightly decrease of the vapor content. [11].

Self-heat recuperation is a technology that circulates latent and sensible heat without the addition of heat. This technology is able to reduce energy consumption by 1/7 - 1/12 of the energy required for conventional heat-recovery drying systems [12]. Other researchers had studied the lignite-fired power plant by using Drying and Water Recovery Technologies. The integration of pre-drying and water recovery technologies within lignite-fired power plants were analyzed with the attention to its influence on the energy and water conservation. Results showed that these technologies have the potential to overcome the shortcomings of conventional lignite-fired power plants and make lignite-fired power plants more environmentally friendly [13].

Currently, approximately 70 percent of Indonesia's coal production is used by the State Electricity Company as fuel for power generation, 10 percent for the manufacturer of cement, and the rest for industrial and metallurgical processes. Indonesia as one of the world's coal producers have the availability of this type of coal is very abundant, especially on the island of Kalimantan and Sumatera. Especially, the island of Sumatera, low-rank coals is in the province of South Sumatera.

South Sumatera which is one of the provinces in Indonesia, has abundant coal reserves but their properties have a high total moisture and low caloric content. Therefore, they are categorised as low-rank coal. In contrary, their ash and sulphur contents are low, which are an advantage for the environment and preferred by Japan customer [14].

Nukman and Sipahutar reported that South Sumatera Province also possess a diversity of crops potential in biomass fuel. They are biomass in the form of wood, leaves, grass as renewable energy, which used as firewood and charcoal. The higher levels of moisture effects on the duration of initial combustion. The produced volatile matter consisted of a combination of several materials, such as light hydrocarbon gases, carbon dioxide, carbon monoxide, hydrogen, water, and tar. The very important light hydrocarbon component is the early incendiary material in combustion process [15]. In addition, according to researchers [16] that the low-rank coal can be used to optimize the growth and productivity of the corn crop.

There are 3 (three) districts in South Sumatera that possess plenteous coal reserves such as the district of Muara Enim, Musi Banyuasin, and Lahat, which were used in this research.

Increasing the calorific value of South Sumatera low-rank coal is needed for the combustion process. One of the methods is to remove the moisture content of the coal using drying process. This method has been observed by [17] using experimental parameters such as particle size, drying temperature, gas flow rate, and chemical structure. The change of chemical structure during drying was investigated using FTIR technique. FTIR technique was employed to investigate the changes of chemical structure of coal upon drying in air and nitrogen. Drying temperature and fluidising gas flow rate were the most dominant factors affecting drying characteristics of lignite. Drying rate increased with increasing drying temperature and fluidising gas flow rate as well as with decreasing the particle size.

II. Material and Method

Coal studied were taken under the criteria of the location of the coal producer in South Sumatra province and had a fairly high moisture content, namely Muara Enim, Musi Banyuasin, and Lahat. Samples taken examined in the laboratory to determine the characteristics of the coal proximate analysis (Table 1, 2, and 3). Furthermore, the manufacture of coal sizes with 3 variations that 100 mesh, 60 mesh, and 20 mesh.

The coal samples were dried for 90 minutes using sunlight and laboratory scaled oven. After the drying process, the sample was sent back to the laboratory for proximate analysis. The stages of testing on South Sumatera low-rank coal are as follows.

A. The Preparation of Low-Rank Coal Samples

Coal studied were taken from Muara Enim, Banyuasin, and Lahat having a high moisture content. Proximate analyses are based on the following standards.

- Total Moisture (TM): ASTM D3302-12
- Inherent Moisture (IM): ASTM D3173-11
- Ash: ASTM D3174-11
- Volatile Matter (VM): ISO-562: 2010 (E)
- Fixed Carbon (FC): ASTM D3172-02(11) and
- Calorific Value (CV): ASTM D5865-11a.

B. Solar and Laboratory Scaled Oven Drying

Drying of South Sumatera low-rank coal samples was conducted using sunlight and laboratory scaled oven. Some measuring equipment were used including solar power meter MSS-1116SD, anemometer, thermocouple, WTC Binder oven of 62 x 60 cm, and digital weight scale (Denver Instrument Company AA-160).

Sunlight drying was conducted from 11.30 a.m. to 1.00 p.m. having an average solar energy of 965 W/m2, coal temperature of 65oC, the ambient temperature of 45oC, and wind velocity of 0.3 m/s.

III. Results and Discussion

From the proximate analyses, it can be seen that all coal samples selected in this study belong to the kind of low-rank coal having a high total moisture content, low fixed carbon, low ash content, and LCV. Details of the results can be seen in Table 1, 2, and 3 below.

A. Proximate Analysis Results

TABLE I
THE SUMMARY OF CHARACTERISTIC OF RAW COAL SAMPLES OBTAINED FROM MUARA ENIM MINE SITE (SOUTH SUMATERA)

Proximate Analysis	**Units**	**Values**
the total moisture (tm)	% ARB	24.75
inherent moisture (im)	% ADB	7.81
fixed carbon (fc)	% ADB	43.72
volatile matter (vm)	% ADB	44.71
ash content (ash)	% ADB	3.76
calorific value (cv)	kcal/kg ADB	6299

ARB: as received basis; b. ADB: air dried basis.

TABLE II
THE SUMMARY OF CHARACTERISTIC OF RAW COAL SAMPLES OBTAINED FROM MUSI BANYUASIN MINE SITE (SOUTH SUMATERA)

Proximate analysis	**Units**	**Values**
the total moisture	% ARB	28.04
inherent moisture	% ADB	8.22
fixed carbon	% ADB	44.87
volatile matter	% ADB	43.42
ash content	% ADB	3.49
calorific value	kcal/kg ADB	6190

ARB: as received basis; b. ADB: air dried basis.

TABLE III
THE SUMMARY OF CHARACTERISTIC OF RAW COAL SAMPLES OBTAINED FROM LAHAT MINE SITE (SOUTH SUMATERA)

Proximate analysis	**Units**	**Values**
the total moisture	% ARB	21.17
inherent moisture	% ADB	8.27
fixed carbon	% ADB	39.39
volatile matter	% ADB	36.25
ash content	% ADB	16.09
calorific value	kcal/kg ADB	5162

ARB: as received basis; b. ADB: air dried basis.

According to Tables 1, 2 and 3, the highest total moisture of low-rank coal was Musi Banyuasin coal having low ash content. Meanwhile, Lahat coal had the lowest total moisture compared with Muara Enim and Musi Banyuasin coals but having significantly high ash content. Muara Enim coal had the highest calorific value with significantly low ash content. In addition, Lahat coal had the lowest calorific value compared to Muara Enim and Musi Banyuasin coals.

The Lahat, Muara Enim and Musi Banyuasin coals have significantly different characteristics, but they are still categorised as low-rank coals.

Drying process by using the direct solar heating system and laboratory scaled oven were conducted to increase the calorific values of each coal and to examine other effects on the quality of coal.

B. Drying Rate Curves

The moisture content values and the drying rate values were calculated through the following equations:

$$X = \frac{W_1 - W_2}{W_2} \tag{1}$$

The results of low-rank coal drying from Muara Enim, Musi Banyuasin, and Lahat districts using sunlight are shown in Fig. 1, Fig. 2, and Fig. 3, respectively. Fig. 4 to Fig. 12 showed the drying results using laboratory scaled oven. Both methods have proven that the drying temperature has been effective significantly to remove the amount of moisture content.

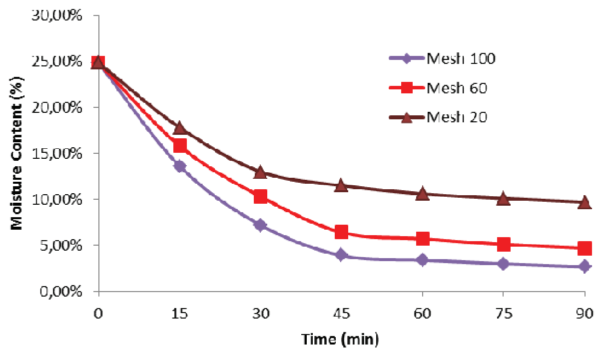

Fig. 1 Typical moisture contents at various times and coal particle sizes for Muara Enim coal

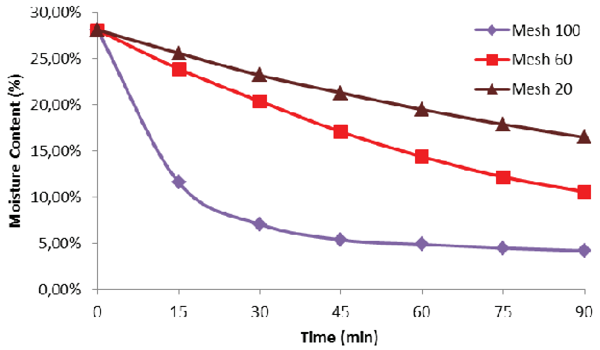

Fig. 2 Typical moisture content at various time and coal particle sizes for Musi Banyuasin coal

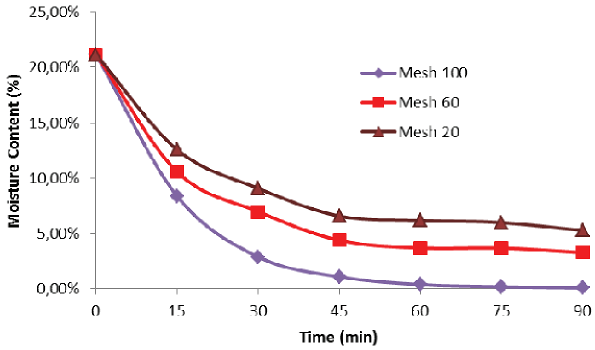

Fig. 3 Typical moisture content at various average time and coal particle sizes for Lahat coal

Drying process by applying solar heating system directly as shown in Figs. 1, 2 and 3 resulted in the decreased moisture content differently.for the three coals collecting from three different sources. It can also be seen that the coal size affect the decreasing process of that moisture content. The mean drying air temperature reached was about 65 ^{o}C due to the instability of solar heat and air velocity on coal surface. The decrease of moisture content on coal with the particle size of 100 mesh was faster compared with coals with particle sizes of 60 and 20 mesh. Lahat coal had better-decreased trend compared with Muara Enim and Musi Banyuasin coals for the same drying time.

Fig. 4 to Fig. 12 show drying process curves by using the scaled oven for Muara Enim, Musi Banyuasin, and Lahat coals. The maximum drying temperature was 90 ^{o}C, and minimum drying temperature was 40 ^{o}C in drying time of 90 minutes.

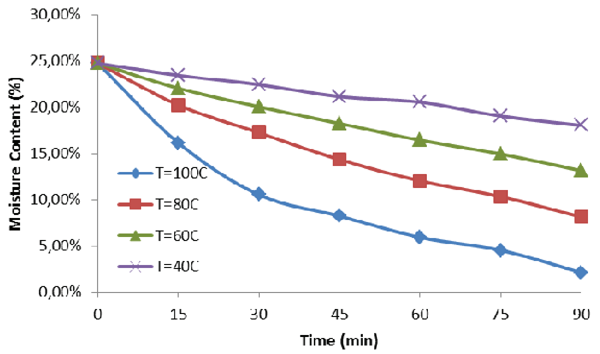

Fig. 4 Typical variation of moisture content at various times and drying temperatures for Muara Enim coal (mesh 100)

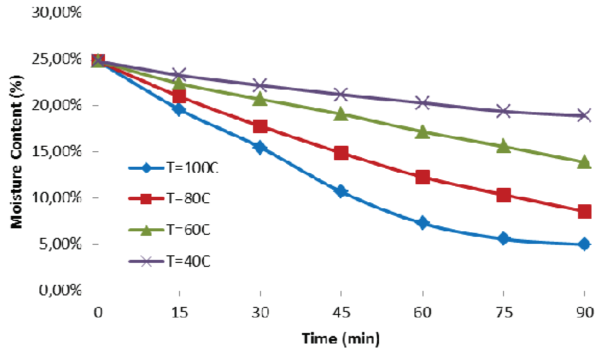

Fig. 5 Typical variation of moisture content at various times and drying temperatures for Muara Enim coal (mesh 60)

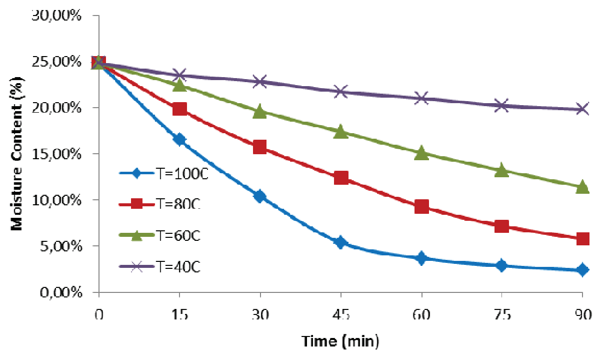

Fig. 6 Typical variation of moisture content at various times and drying temperatures for Muara Enim coal (mesh 20)

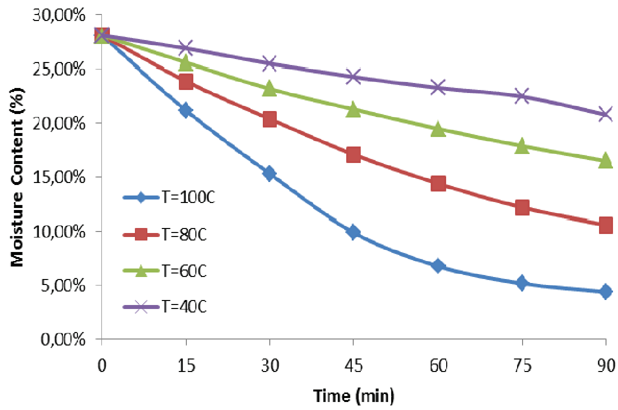

Fig. 7 Typical Margin is divided in of moisture content at various times and drying temperatures for Musi Banyuasin coal (mesh 100)

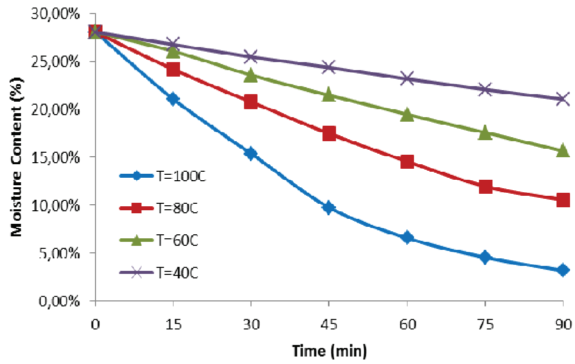

Fig. 8 Typical variation of moisture content at various times and drying temperatures for Musi Banyuasin coal (mesh 60)

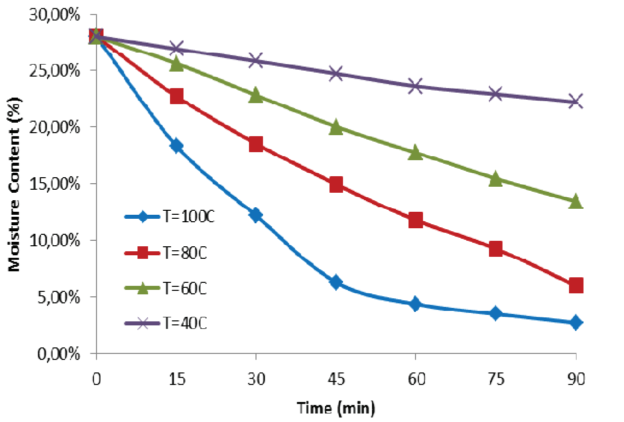

Fig. 9 Typical variation of moisture content at various times and drying temperatures for Musi Banyuasin coal (mesh 20)

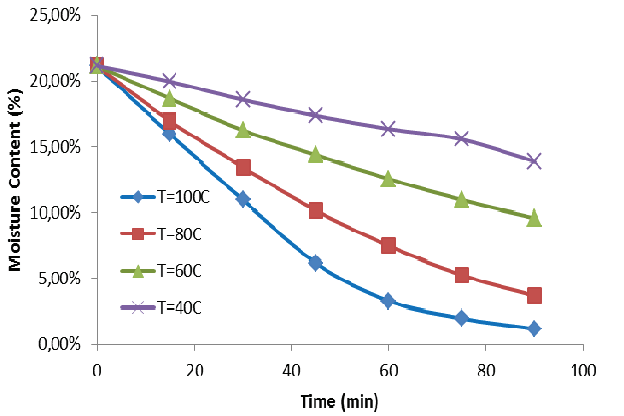

Fig. 10 Typical variation of moisture content at various times and drying temperatures for Lahat coal (mesh 100)

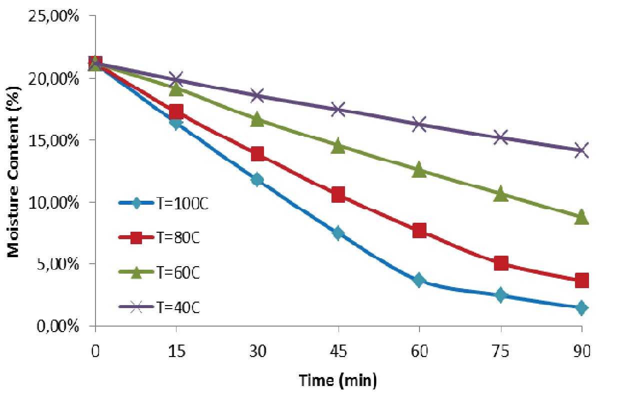

Fig. 11 Typical variation of moisture content at various times and drying temperatures for Lahat coal (mesh 60)

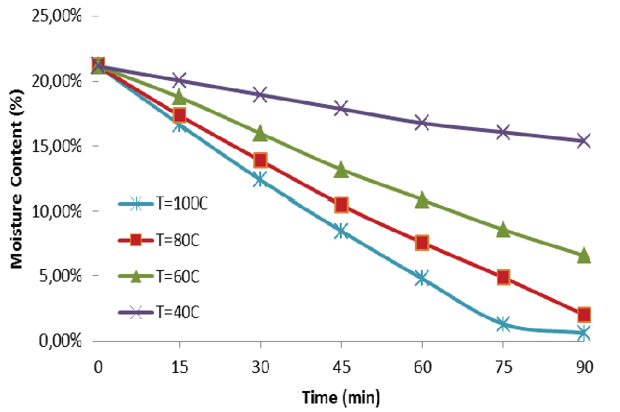

Fig. 12 Typical variation of moisture content at various times and drying temperatures for Lahat coal (mesh 20)

The decrease in moisture content for the three different coals examined showed almost the same trend. Temperature plays an important role in the drying process, a higher temperature will remove much more moisture from the low-rank coal, and also smaller size of coal particles will remove moisture more easily.and fastly.

C. Proximate Analysis

Proximate analysis of the South Sumatera LRC's samples was carried out after drying process in the oven. The changes in the chemical properties of the coal were revealed. Generally, the moisture content decreased with increasing drying temperature. The highest decreased was 91.3 % for Muara Enim coal at drying temperature of 100 °C and coal particle size of 20 mesh. The highest decreased was 90.6 % for Musi Banyuasin coal at drying temperature of 100 °C and coal particle size of 20 mesh. The highest decreased was 97.3 % for Lahat coal at drying temperature of 100 °C and coal particle size of 20 mesh.

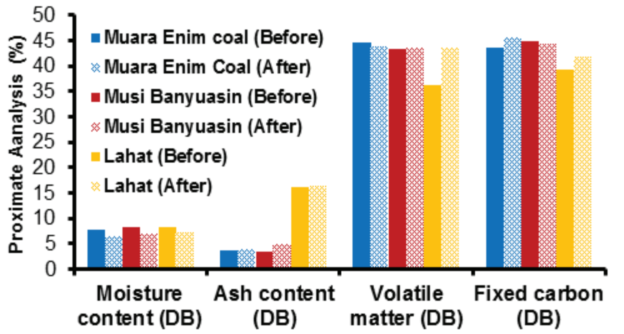

Fig. 13 Proximate analysis of the Muara Enim, Musi Banyuasin, and Lahat coal samples before and after upgrading (drying in an oven at temperature of 100 °C)

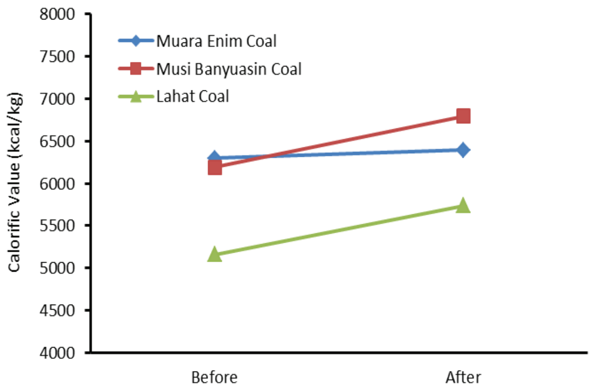

Fig. 14 Calorific values of the Muara Enim, Musi Banyuasin, Lahat coal samples before and after upgrading (drying in an oven at temperature of 100 °C)

The calorific values for Muara Enim coal increased from 6299 to 6393 kcal/kg (an increase of 1.49 %), for Musi Banyuasin coal increased from 6190 to 6792 kcal/kg (an increase of 9.73 %), and for Lahat coal increased from 5162 to 5737 kcal/kg (an increase of 11.14 %).

IV. Conclusions

The results of the experimental low-rank coal showed increased percentages of caloric values varying for the three types of coal investigated. The highest increased percentage obtained from Lahat coal as much as 11.14% at a drying temperature of 100°C and coal particle size of 20 mesh.

The results of experiments also showed a decrease in moisture content as a function of temperature drying and coal particle size. The highest increased percentage obtained from Lahat coal as much as 97.3% using the oven at a temperature of 100 °C and coal particle size of 20 mesh.

Drying processes with sunlight and laboratory scaled oven at various temperatures didn't experience spontaneous ignition.

Nomenclature

x	moisture content at any time	%
W_1	initial coal sample weight	kg moisture/kg dry coal
W_2	dried coal weight	kg moisture/kg dry coal
T	temperature	°C

Acknowledgment

Authors would like to express our gratitude to the Mining and Energy Agency of South Sumatra, Indonesia for providing the proximate analysis and to Hansen and Andri for supporting the experiments.

References

[1] M. Karthikeyan, J. V. M. Kuma, C. S. Hoe, and D.L.Y. Ngo. *Factors affecting Quality of Dried Low-Rank Coals*. Drying Technology, vol. 25, pp. 1601-1611, 2007.

[2] N. Chandralal, D. Mahapatra, D. Shome, and P. Dasgupta. *Behaviour of Low Rank High Moisture Coal in Large Stockpile under Ambient Conditions*. American International Journal of Research in Formal, Applied & Natural Sciences: *AIJRFANS*, vol. 6, pp. 19-26, March-May, 2014.

[3] X. Gao, C. Man, S. Hu, X. Xu, and D. Che. *Theoretical and Experimental Study on Spontaneous Ignition of Lignite during the Drying Process in a Packed Bed*. Energy Fuel: vol. 26, pp. 6876-6887, 2012.

[4] R. Zhonghao, Z. Yuemin, H. Congliang, D. Chenlong, H. Jingfeng. *Recent developments in drying and dewatering for low rank coals*. Progress in Energy Combustion Science, vol.46, pp. 1-11, 2015.

[5] H. Osman, S.V. Jangam, J.D. Lease, A. S. Mujumdar. *Drying of Low-Rank Coal (LRC) - A review of recent patents and innovations*. Drying Technology: vol. 29, pp. 1763-1783, 2011.

[6] S. Niksa, B. Krishnakumar. *Predicting the steam drying behavior of brown coals and lignites*. Fuel, vol. 159, pp. 345-353.

[7] M. Karthikeyan, W. Zhonghua, A. S. Mujumdar. *Low-rank coal drying technologies-current status and new developments*. Drying Technology, vol. 27, pp. 403-415, 2009.

[8] M. Huda, and D. Yaskuri. *The Influence of Coal Feed Rate on the Effectivity of Drying Process*. Journal of Mineral and Coal Technology: vol. 11, pp. 18-28, 2015.

[9] J. H. Park, C. H. Lee, Y. C. Park, D. Shun. D. H. Bae, and J. Park. *Drying Efficiency of Indonesian Lignte in a Batch-Circulating Fluidized Bed Dryer*. Drying Technology: vol. 32, pp. 268-278, 2014.

[10] M. Faizal, SD Sumbogo, D. Bahrin, T. Saksono, Harminuke, and Barlin. *Drying of Low Range Coal Using DI-Methyl Ether (DME)*. The First Middle East Drying Conference, Mahshahr, Iran: Feb. 19-20, 2012.

[11] S. H. Moon, I.S. Ryu, S. J. Lee, T. I. Ohm. *Optimization of Drying of Low-grade Coal with High Moisture Content using a Disc Dryer*. Fuel Processing Technology: vol. 124, pp. 267-274, 2014.

[12] Y. Liu, M. Aziz, Y. Kansha, A. Tsutsumi. *A Novel Exergy Recuperative Drying Module and its Application for Energy-Saving Drying with Superheated Steam*. Chemical Engineering Science: vol. 100, pp. 392-401, 2013.

[13] M. Liu, Y. Qin, H. Yan, X. Han, D. Chong. *Energy and Water Conservation at Lignite-fired Power Plants using Drying and Water Recovery Technologies*. Energy Conversion and Management: vol. 105, pp. 118-126, 2015.

[14] S. Kinoshita, S. Yamamoto, T. Deguchi, and T. Shigehisa. *Demonstration of upgraded brown coal (UBC) process by 600 tonnes/day plant*. Kobelco Technology Review, vol. 29, pp. 93-98, 2010.

[15] Nukman, and R. Sipahutar. *The Potential of Biomass from Wood, Leaves, and Grass as Renewable Energy Sources in South Sumatera, Indonesia*. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects: vol. 37, pp. 2710-2715, 2015.

[16] Herviyanti, Gusnidar and M. Harianti. *Using of Humic Matter from Low Rank Coal to Increase Phosphorous Fertilizer Efficiency and Production of Corn at Oxisol*. International Journal on Advanced Science Engineering Information Technology, vol.3, pp. 21-25, 2013.

[17] A. Tahmasebi, J. Yu, Y. Han, X. Li. *A study of chemical structure changes of Chinese lignite during fluidized-bed drying in nitrogen and air*. Fuel Processing Technology, vol. 101, pp. 85-93, 2012.