Study of making coal water slurry with lignite Pendopo coal

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Abstract. The Coal Water Slurry (CWS) technology increases the calorific value and changes the phase of coal from solid to liquid. The CWS Plant with a coal capacity of 1.4 t/hour located at Karawang, West Java converts lignite coal to CWS. Coal undergoes pulverizing, upgrading, and slurry-making processes to become CWS. Pulverization is the process of refining coal size into 200 mesh. The upgrading process is through reducing the moisture content in heat exchangers (HE). It occurs in HE where the coal is pressurized to 15 MPa and the temperature is maintained at 330 °C for 30 minutes. The research objective was to determine the CWS characteristics of the South Sumatra Pendopo lignite coal. The method used is through testing where the Pendopo coal is converted into CWS at the CWS Plant. The result shows that Pendopo coal which has a heating value of High Heating Value (HHV) 2,725.00 kCal/kg As Received (AR) has an increase in HHV heating value of 3,218.00 kCal/kg AR when it becomes CWS. The total moisture content of Pendopo coal has decreased from 49.36% to 44.58% when it becomes CWS. The fixed carbon content of Pendopo coal increased from 19.78% AR to 24.01% AR.

1. Introduction

Since the booming increase in world oil prices in the 1970s, researchers have begun to study to produce cheap fuels that have the same physical and chemical properties as oil for industrial use. One studied thing is the use of coal by changing its physical and chemical properties to make it similar to oil [1]. Coal can be converted into a liquid phase (liquid) through the slurryification process. Transportation and pollution costs are lower by transporting CWS than coal [2]. Various boilers and gasifiers for power generation, glass, ceramics, petrochemical, chemical, and metallurgical industries have tested and operated the CWS [3,4]. The properties of CWS are influenced by the physicochemical properties of coal, chemical dispersants, and stabilizers [5,6]. The key properties of CWS are coal characteristics [7]. These properties include surface wettability, inherent water content, and the ratio of oxygen to carbon. With the abundance of lignite coal, this type of coal has begun to be widely used in the manufacture of CWS [8,9]. However, CWS formed by lignite coal is not as good as CWS using anthracite coal due to its very high moisture content [10].

Coal water slurry (CWS) is liquid phase coal that has high solids content and high viscosity. In the process of making CWS, water will enter the pores of coal particles to form inner water which results in a decrease in the free water content between the particles and increase the viscosity value [11]. CWS consists of pulverized coal (about 70%), water (about 29%), and one or more chemical additives (less than 1%). CWS’s solid concentration must be high to successfully utilize in commercial plants [12]. The key points of slurryification technology are the choice of a solid size where it will determine the maximum load or composition that the coal can achieve in solution, and the choice of chemical additives for property optimization (essentially stability and viscosity) [1,13,14]. The high ratio of oxygen to carbon of lignite and high moisture content are two major drawbacks that make it difficult to prepare CWS [15–17]. Using CWS can make the use of coal cleaner & more efficient because of its higher
calorific value [18,19]. In addition, CWS can provide various products such as hydrogen and chemicals [20].

Slurryification itself is not a new technology, the initial research activities of CWS were developed in Germany. However, since 1973 when the interest in coal and coal fuels has increased again, several countries have been involved in research and development in this field including the United States, Sweden, Japan, Italy, France, Germany, Britain, the Soviet Union, and others. The research focuses on developing slurry technology, transportation, and combustion system adaptation. The slurryification technology is expected to provide great benefits, especially to obtain clean and environmentally friendly fuels. Atlantic Research Corporation in the United States developed CWS technology in 1986 with a capacity of 115 t/hr in Fredericksburg, VA, USA. The resulting CWS has a heating value of 5,000 to 6,000 kcal/kg AR and TM of 30-35% in 1992 [1].

The Dulong postulate published in 1800 stated that the heating value of HHV was influenced by the constituent elements of coal. In 1900, the Dulong formula began to be used to estimate the heating value of HHV coal through its constituent elements. According to this formula, the heating value of coal is proportional to the combustion of constituent elements released during oxidation [21,22]. The Dulong equation can be used to calculate the heating value of HHV coal, namely [23,24]:

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\text{HHV heating value} = 339.5C + 1442(H-O/21) + 94S
\]

With C: Carbon, H: Hydrogen, O: Oxygen, and S: Sulfur obtained from the ultimate coal test value. The equation has an error of not more than 2% [25].

Indonesia has coal resources of 126 billion tons and reserves of 32 billion tons. It has the majority of medium calorie coal of 64.88% and 32.22% low [26]. Low caloric coal or commonly referred to as lignite has a calorific value of HHV below 4,200 kcal/kg [27]. Pendopo coal originating from the Muara Enim & Pali area in South Sumatra Province is low caloric coal so it has low economic value. Therefore, in the manufacture of CWS in this study, the coal was used as an experimental feedstock. The purpose of this study is to determine the CWS characteristics of the South Sumatra Pendopo coal which is a lignite type.

2. Methodology

The methodology used in this research is through trials, namely converting Pendopo coal from South Sumatra into CWS through pulverizing, upgrading, and slurry-making processes at the CWS Plant as shown in Figure 1. Pulverization is refining coal to a size of 200 mesh or 40 microns in pulverized coal through a hammer mill and ball mill. The following process is upgrading by reducing the moisture content of coal. The fine coal is then streamed into a heat exchanger (HE) to remove moisture. The slurry pump is used to push the fine coal in the pipe to HE. The upgrading process occurs in HE (shell and tube reactor) where the coal is pressurized to 15 MPa or 150 Bar. The temperature is maintained at 330 °C for 30 minutes. The heat source in the reactor comes from hot oil from the auxiliary boiler (for the demo plant using high-speed diesel oil) which is streamed through the tube. This upgrading process does not use any additional chemicals. After the upgrading process, the next process is slurry-making or mixing of fine coal into the water. In this process, the coal that has been removed from moisture will be pressed into the filter press so that the water content in the slurry is lost. After the dewatering process, the fine coal will be added a little water and additives through the tank. Aggregators are used so that fine coal can mix with water with additional additives.
The additives used are the dispersant, stabilizer, and NaOH as the PH balance. Dispersant (Ca) is used to prevent agglomeration or bonding between fine coals. Meanwhile, the stabilizer is used so that there is no separation between fine coal and water. Details of coal & additive parameters are shown in Table 1.

Pendopo and CWS coal samples were taken for testing according to ASTM Gaseous, Coal, and Coke at the Mineral Technology Laboratory, Ministry of Energy, and Mineral Resources in Bandung. Furthermore, the results of laboratory analysis between Pendopo and CWS coals are compared to their characteristics.

3. Results and Discussion

Table 2 shows the results of the proximate and ultimate analysis of the Pendopo and CWS coals at the time of the trial. Coal and CWS samples were taken during the trial. They then tested at the coal laboratory for analysis according to ASTM standards. It shows that there are three parameter’s conversions for each coal sample or CWS. Namely As Received (AR) or actual conditions according to the environment, Air Dried Basis (DB) by reducing inherent moisture, and Dried Basis (DB) by reducing total moisture or removing water content in coal or CWS.

Table 1. Parameters of coal content & additives during the CWS manufacturing process.

| No. | Item                  | Unit | Total (t/h) | Dry (t/h) | Water (t/h) | Additive (t/h) | Dry (%) | Water (%) |
|-----|-----------------------|------|-------------|-----------|-------------|----------------|---------|-----------|
| 1   | Raw coal              | t/h  | 1.395       | 0.742     | 0.653       |                | 53.19   | 46.81     |
| 3   | Additive Dispersant   | t/h  | 0.005       | -         | 0.003       | 0.0025         | 45.16   | 54.84     |
| 4   | Additive Stabilizer   | t/h  | 0.001       | -         | 0.001       | 100.00         | -       | -         |
| 5   | Additive NaOH         | t/h  | 0.009       | 0.007     | 0.002       |                | 21.59   | 78.41     |
| 6   | Coal Water Slurry     | t/h  | 1.190       | 0.690     | 0.500       |                | 57.98   | 42.02     |
| 7   | Ratio of CWS to Raw coal | %  |            |           |             |                | 85.30   |           |
| 8   | Ratio Dispersant to Raw coal | %  |            |           |             |                | 0.18    |           |
| 9   | Ratio Stabilizer to Raw coal | %  |            |           |             |                | 0.07    |           |
| 10  | Ratio NaOH to Raw coal | %  |            |           |             |                | 0.14    |           |
Table 2. Results of proximate and ultimate analysis of Pendopo coal and CWS.

| No. | Items                      | Fuel                  | Raw Coal (Pendopo) | CWS (AR)  | CWS (ADB) | CWS (DB)  |
|-----|----------------------------|-----------------------|-------------------|-----------|-----------|-----------|
|     |                            | Unit                  | Raw Material (AR) | Raw Material (ADB) | Raw Material (DB) | CWS (AR) | CWS (ADB) | CWS (DB) |
| 1   | Calorific value            | kcal/kg               | 2,725.00          | 4,391.00   | 5,381.12  | 3,218.00  | 5,452.00  | 5,806.57 |
| 2   | Inherent Moisture          | %                     | 18.39             | 18.39      | -         | 7.91      | 7.91      | -         |
| 3   | Total Moisture             | %                     | 49.36             | -          | -         | 44.58     | -         | -         |
| 4   | Ash                        | %                     | 5.21              | 8.39       | 10.29     | 7.34      | 12.19     | 13.24     |
| 5   | Volatile Matter            | %                     | 25.65             | 41.34      | 50.65     | 24.07     | 39.99     | 43.43     |
| 6   | Fixed Carbon               | %                     | 19.78             | 31.88      | 39.06     | 24.01     | 39.91     | 43.32     |
| 7   | C                          | %                     | 30.16             | 48.61      | 59.56     | 35.12     | 58.35     | 63.37     |
| 8   | H                          | %                     | 2.35              | 5.85       | 4.64      | 2.52      | 5.08      | 4.55      |
| 9   | N                          | %                     | 0.21              | 0.34       | 0.41      | 0.36      | 0.60      | 0.65      |
| 10  | O                          | %                     | 12.59             | 36.61      | 24.86     | 9.91      | 23.50     | 17.88     |
| 11  | S                          | %                     | 0.12              | 0.20       | 0.24      | 0.17      | 0.28      | 0.31      |

Figure 2 shows the heating value of HHV coal in Pendopo has increased from 2,725 to 3,218 kcal/kg AR when converted into CWS. This is due to the decrease in total moisture (TM) on the AR basis of Pendopo coal from 49.36% to 44.58% (as shown in Table 2). In the Dried Basis condition or without water, it can be seen that the heating value of HHV coal in Pendopo also increases in heating value through the upgrading process from 5,318.12 to 5,806.57 kcal/kg.

Figure 3 shows that with a decrease in the percentage of total moisture, the value of fixed carbon will increase from 19.78% to 24.01%. The value of ash content increased from 5.21% to 7.34%. However, the volatile matter value has decreased from 25.65% to 24.07%.

Figure 4 shows the ultimate test parameters for Pendopo and CWS coals on AR and DB. In AR, it shows that the C value increased from 30.16% to 35.12%, and the O value decreased from 12.59% to 9.91%. Meanwhile, the values of H, N, and S experienced an insignificant increase in both AR. The Dulong equation formulates that the heating value is proportional to the values of C, H, and S. But it is inversely proportional to the value of O. It explains that the increase in heating value in the process of Pendopo upgrading coal to CWS is caused by a relatively high increase in C value and a decrease in O value [11,12].

Figure 2. Graph of the heating value of HHV coal in Pendopo and CWS in AR and DB.
4. Conclusion
The pulverizing, upgrading, and slurry-making processes at the CWS Plant, it was concluded that the solid phase Pendopo coal could be converted into liquid phase CWS. There was an increase in the heating value of HHV coal in Pendopo by 18% from 2,725.00 to 3,218.00 kcal/kg AR when it became CWS. This was due to the total moisture content of the Pendopo coal which decreased from 49.36% to 44.58% when it became CWS.

References
[1] Variali B 1989 Energy: Coal-water slurry contribution to the Europea Economic Community’s energy: A technical and economic study (Luxembourg: Commission of the European Communities)
[2] Sahoo B K, De S, Carsky M and Meikap B C 2011 Rheological characteristics of coal–water slurry using microwave pretreatment – A statistical approach J. Ind. Eng. Chem. 17 62–70
[3] Chen L, Duan Y, Liu M and Zhao C 2010 Slip flow of coal water slurries in pipelines Fuel 89 1119–26
[4] Wan W, Dai Z, Li C, Yu G and Wang F 2014 Innovative concept for gasification for hydrogen based on the heat integration between water gas shift unit and coal–water–slurry gasification unit Int. J. Hydrogen Energy 39 7811–8
[5] Atesok G, Dincer H, Ozer M and Mutevellioglu A 2005 The effects of dispersants (PSS?NSF) used in coal/water slurries on the grindability of coals of different structures Fuel 84 801–8
[6] Atesok G, Boylu F, Sirkeci A. and Dincer H 2002 The effect of coal properties on the viscosity of coal–water slurries Fuel 81 1855–8
[7] Yuchi W, Li B, Li W and Chen H 2005 Effects of coal characteristics on the properties of coal water slurry Coal Prep. 25 239–49
[8] Das D, Dash U, Meher J and Misra P K 2013 Improving stability of concentrated coal–water slurry using mixture of a natural and synthetic surfactants Fuel Process. Technol. 113 41–51
[9] Fu J and Wang J 2014 Enhanced slurryability and rheological behaviors of two low-rank coals by thermal and hydrothermal pretreatments Powder Technol. 266 183–90
[10] Fan Y, Hu H, Jin L, Zhu S and Zhang Q 2013 Static stability and rheological behavior of lignite char–water mixture Fuel 104 7–13
[11] Zhang J, Zhao H, Wang C, Li W, Xu J and Liu H 2016 The influence of pre-absorbing water in coal on the viscosity of coal water slurry Fuel 177 19–27
[12] Phuoc T X, Wang P, McIntyre D and Shadle L 2014 Synthesis and characterization of a thixotropic coal–water slurry for use as a liquid fuel Fuel Process. Technol. 127 105–10
[13] Mesroghli S, Yperman J, Jorjani E, Vandewijngaarden J, Reggers G, Carlee R and Noaparast M 2015 Changes and removal of different sulfur forms after chemical desulfurization by peroxyacetic acid on microwave treated coals Fuel 154 59–70
[14] Cheng J, Wang X, Zhou F, Huang R, Wang A, Chen X, Liu J and Cen K 2015 Physicochemical characterizations for improving the slurryability of Philippine lignite upgraded through microwave irradiation RSC Adv. 5 14690–6
[15] Cheng J, Zhou F, Wang X, Liu J, Zhou J and Cen K 2015 Physicochemical properties of Indonesian lignite continuously modified in a tunnel-type microwave oven for slurrability improvement Fuel 150 493–500
[16] Li P, Yang D, Qiu X and Feng W 2015 Study on enhancing the slurry performance of coal–water slurry prepared with low-rank coal J. Dispers. Sci. Technol. 36 1247–56
[17] Wang N, Yu J, Tahmasebi A, Han Y, Lucas J, Wall T and Jiang Y 2014 Experimental study on microwave pyrolysis of an Indonesian low-rank coal Energy & Fuels 28 254–63
[18] Lee D-W, Park S J, Bae J-S, Ra H W, Hong J-C and Choi Y-C 2011 Preparation and characterization of coal–water–alcohol slurry for efficient entrained-flow gasification Ind. Eng. Chem. Res. 50 11059–66
[19] Núñez G A, Briceño M I, Joseph D D and Asa T 2010 Colloidal coal in water suspensions Energy Environ. Sci. 3 629–40
[20] Li F and Fan L-S 2008 Clean coal conversion processes – progress and challenges Energy Environ. Sci. 1 248–67
[21] Nzhou J F, Hamidou S, Bouda M, Koulidiati J and Segda B G 2014 Using Dulong and Vandralek Formulas to estimate the caloricific heating value of a household waste model Int. J. Sci. Eng. Res. 5 1878–83
[22] Mott R A and Spooner C E 1940 The caloricific value of carbon in coal: The Dulong relationship Fuel 19 226–31
[23] Mason D M and Gandhi K 1980 Formulas for calculating the heating value of coal and coal char: development, tests, and uses Fuel Chemistry Division Meeting (United States: American Chemical Society) pp 1–11
[24] Poole H 1918 The caloricific power of fuels ed R T Kent (New York: John Wiley & Sons, Inc)
[25] Tillman D A 1978 Wood as an Energy Resource (Elsevier)
[26] President of the Republic of Indonesia 2003 Republic of Indonesia Government Regulation No. 45 Year 2003 concerning Tariffs on Non-Tax State Revenues Applicable to the Ministry of Energy and Mineral Resources (Republic of Indonesia)
[27] New Energy and Industrial Technology Development Organization 2015 Clean coal technologies in Japan: Technological innovation in the coal industry (Kanagawa: New Energy and Industrial Technology Development Organization)