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Experimental and Numerical Study of Coal Swirl Fluidized Bed Drying on 100 Angle of Guide Vane Melvin Emil Simanjuntak1, Prabowo2, Wawan Aries Widodo2, Teng Sutrisno3, Melvin B. H. Sitorus1 1Department of Mechanical Engineering, Medan State Polytechnic 2Department of Mechanical Engineering, Institut Teknologi Sepuluh November 4Department of Mechanical Engineering, Petra Christian University

(Manuscript Received 000 0, 2009; Revised 000 0, 2009; Accepted 000 0, 2009) --- Abstract **1**

Currently, low-rank coal is widely used as fuel in power plants. Swirl flow method is quite effective used to increase heating value through the drying process. This research studies the characteristics of low-rank coal drying using a swirl fluidized method with 100 angle of blade inclination experimentally and numerically. Coal with a moisture content of 25.17% and a size of 6 mm was dried by dry air with a temperature of 55 0C, relative humidity of 10.5% and flow rate of 0.06 kg/sec. Moisture content is measured by the ASTM 5421. Numerical simulations performed in 3 dimensional, transient and multicomponent. The results of the experiment show that drying was effective in the first 5 minutes which reduced moisture ratio to 0.26 while the simulation results reduced moisture ratio to 0.28. Numeri- cal simulations show the pathline, velocity vectors, temperature, and humidity contours. Particle trajectory as simulation results agrees with the experiment. Keywords: Coal; Swirl fluidized bed; Drying; Angle of blade inclination; Experimental; Numerical
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1. Introduction ized bed method is quite effective to use because of the Currently, many power plants use low-rank coal as low operating cost. A heat source can be extracted from fuel so that the power plant

performance is quite low. the condenser or the flue gas [1] Low-rank coal has much moisture, so it has low heating This study aims to obtain information about characteris- value. The moisture content in this coal can be dried so tics of low-rank coal drying by using swirl fluidized bed that it will increase the heating value and reduce the con- method with 100 angle of blade inclination by experimen- sumption of coal in the boiler. One of the process to tally and numerically. reduce the moisture with low energy consumption is dry- ing by swirl fluidized bed method. 2. Methodology Coal drying research has been carried out by many re- searchers such as [1], [2] by the fluidized bed method. 2.1 Experimental Researchers [3] with the hot immersed oil method, [4] The drying process uses a swirl fluidized bed apparatus by microwave method. For more details can be seen in a as shown in Fig. 1. The chamber is made from acrylic review written by [5], and [6]. The utilization of swirl pipe. Dry air enters in the tangential direction and then flow has been widely applied in the combustion by [7]. come out through the blade arrangement. The blade ar- While research which states the positive influence of rangement has an inclination angle of 100 with an amount swirl flow on heat and mass transfer has been investigat- of 30 pieces. In the outlet side, there is a filter to prevent ed by [8], [9] and [10]. coal particles coming out from the chamber during the Reference [11] studied the effect of swirl number, air drying process. dryer flow rate and temperature on drying of wheat. [12] The experiment uses Indonesian low-rank coal with the also studied the effect of inclination angle and air dryer moisture content of 25.17%. Coal in the form of chunks temperature on wheat grain drying. [13] study the effect is crushed and then sorted to obtain a size of about 6 mm. of blade inclination angle, temperature and air dryer velocity in coal drying. Coal drying with the swirl fluid- An electric heater that can be controlled by a thermostat †

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is used to heat the water in the reservoir then circulated to 000 000- *Corresponding author. Tel.: +62-085296764082, Fax.: +62- 061-821 5841 E-mail address: mesimanjuntak@yahoo.com. © KSME & Springer 2010 T and RH Outlet α = 10 0 T and RH Inlet Fig.1. Swirl fluidized bed dryer two radiators. These two radiators heat the ambient air until 55 0C. A blower will suck the dry air and used it to dry coal particles in the chamber. The temperature and relative humidity air dryer are measured at the inlet and outlet of the chamber as shown in Fig. 1. Dry air when entering the chamber has a relative humidity of 10.4% and a temperature of 55 0C. The RH meter has accuracy 2%, and a digital thermometer has 0.1 0C is attached in the chamber. In the experiment, the flow rate of dry air is 0.06 kg/s. The inlet velocity is measured by an anemometer and is controlled by a voltage regulator as shown in Fig. 2. The moisture content of coal particles is calculated based on the ASTM 5421 method. After a steady condition, a sample of 600 grams of coal is poured into the chamber. Before dried, the coal particle is measured for its initial moisture content. During the drying, coal particle periodically is taken 2 - 3 gr to measure the moisture content. The small weighing scale has accuracy 0.001 gr use to weigh the sample mass Decreasing in the moisture content of coal particles is a result of drying. Other explanations can be seen in [13] and [14]. Fig. 2 shows the experimental set-up. The moisture ratio is calculated from the equation = − (1) − Drying efficiency for low temperature for every minute is calculated from equation [15]. = 1−2 (2) 1−0 2.2 Numerical Numerical simulation performs in the 3-dimensional, tran- sient, Eulerian-Lagrangian and multicomponent model. Mesh- ing has a type Tet/Hybrid with 633017 number of cells. Fig. 2. Experimental set-up meshing model is shown in Fig. 3. Viscous model is realizable k-ε, standard wall function which can accommodate swirl flow quite well. Coal particle is introduced into the chamber at the 120th second after fluid simulation reaches convergence 10-3 and energy 10-6. Solution method uses second order up- wind with 50 iterations per time step. The numerical simulation uses the commercial finite volume code. Other explanations can be seen at

[16] and [13]. In this simulation, use the governing equation for the transient case as below Continuity Equation + ∇. ( ) = (3) Outlet Center body Coal inlet Guide vane Wall Air dryer inlet Fig. 3. Meshing model Momentum Equation ( ) + ∇. ( ) = −∇ + ∇. ( ) + + (4) Energy Equation ( ) + ∇ ∗ ((+)) = ∇ ∗ (∇ + (∗)) + *h* (5) Turbulence Modelling Turbulence kinetic energy and rate of dissipation are () + () = [(+] + +) − − + (6) and () + () = [(+)] + 1 − 2 2 +√ + 1 3 (7) Mass transfer equation = *h* (∞ −) − *h* (8) 3. Result and Discussion 3.1 Moisture Extraction Rate The moisture extraction rate as experimental and numerical result simulation shown in Fig. 4. It can be seen that the drying process would more effective during the first 5 minutes of drying. The moisture ratio line is still linear which means that moisture reduction is rela- tively constant for a unit of time. After 5 minutes, mois- ture ratio is reduced until 0.26. In the numerical simulation, the moisture ratio of coal particles become 0.28 after 5 minutes. This result is almost the same as the Moisture Ratio 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0 Experimental Numerical 1.1 0 5 10 15 20 25 30 35 Time (min) 1263 expe2r0imental results. From the experimental, the equilib- rium18moisture is about 3%. Velocity colored by 16 magnitude (m/s) 14 Fig. 4 Moisture extra ction ratio 12 10 8 6 4 2 0 t = 120 s t = 180 s t = 240 s t = 300 s (before coal injected) Fig. 5. Velocity magnitude of the air dryer 3. 2. Velocity and vector The magnitude of air dryer velocity is shown in Fig. 5 as pathline of the air dryer. At 120th seconds when the particles not yet entered into the chamber, the magnitude velocity is higher. After the particle enters into the chamber, the air velocity is less due to the obstacle effect of the existence of the particle. At the 180th minute (equal to the first minute of the experiment), the air dryer velocity is lower than after. The lower velocity due to the coal particles becomes lighter so that the obstacle effect will smaller. At the 240th and 300th seconds, there is no significant change in air dryer velocity. The dry air velocity vector is shown in Fig. 6. At a moment before the particle injected, the air dryer direc- tion at the top is slightly more vertical than at the bottom (around the blade). The changing of direction due to the friction of the air with the wall so that it reduces the in- tensity of swirl [17] and [18] collides air with particles so that the air will turn upwards. 3.3. Temperature and Humidity During the first 120 seconds, the simulation is intend- ed to achieve convergence of the flow of dry air only. Then the coal particles are injected into the chamber, and the drying process begins. The dry air temperature in the chamber is shown in Fig. 7. a. It is seen that the tempera- ture is changed from the initial condition (55 0C) then decreases in the first minute. This decrease is a result of the heat transfer process where the heat is used to evaporate the moisture in coal particles. 20 Velocity vector colored 18 by magnitude (m/s) 16 14 12 10 8 6 4 2 0 t = 120 s (before coal t = 180 s t = 240 s t = 300 s injected) Fig. 6. Velocity vector After that, the dry air temperature gradually increases due to less heat transfer because of reduced the moisture in the coal particles. After 9 minutes, the drying process can be seen that the air temperature has returned to the initial condition where the temperature range is 327 - 330 0K. The hotter air is seen at the edges. The outlet temperature as experimental and numerical data shown in Fig. 6b. The absolute humidity which is the mass fraction of H2O in the dryer air is shown in Fig. 8. It is seen that more humid is in the middle, which has a more H2O mass fraction. It should be remembered that the molecular weight of moisture is lighter than the molecular weight of the air. So, when receiving the same centrifugal force, a lighter object will be in the centre. This higher H2O mass fraction is also comparable to the higher air temperature in the centre where more humid air will have a lower temperature. 330 Static Temperature (K) 327 324 321 318 315 312 309 306 303 300 t = 120 s (before t = 150 s t = 180 s t = 360 s t = 660 s coal injected) Fig. 7.a. Air dryer temperature Mass Fraction of H2O 60 Gas Outlet Temperatur (0C) 55 50 45 40 35 30 Experimental Numerical 0 2 4 6 8 10 12 14 16 Time (min) Fig 7. b. Outlet gas temperature by experimental and numerical 0.020 0.019 0.018 0.017 0.016 0.015 00..001143 0.012 0.011 0.010 t = 120 s t = 180 s t = 240 s (before coal injected) t = 300 s t = 420 s Fig .8. Air humidity 3. 4. Particle Trajectory Particle trajectory is shown in Fig. 9 for 60 s, 120 s, and 300 s after injection into the chamber. The particle looks well- fluidized as shown by the numerical simulation and experimental. At the top of the cone, particles are scattered evenly as the experimental results. Fluidized particles will cause

drying to take place better. Parts of the particles are at the bottom both experimentally and numerically. These parti- 20 Pathline colored by velocity magnitude 18 16 14 12 (m/s) 10 8 6 4 2 0 Particle traces colored by mass fraction 0.250 0.225 0.200 0.175 0.150 0.125 0.100 0.075 Numerical Simulation 0.050 0.025 0.000 t = 60s t = 120s t = 300s Experimental cles are probably that experience a slower drying process so that it is more difficult to fluidize. It can be seen from the colour of the particles which located above the blade having a higher moisture content than the fluidized particles, or because the vector direction of the dry air which has an inclination angle is too small so it difficult to fluidize the particles. It is shown in Fig. 5. The velocity vector which is seen near the blade of the vector inclination angle is smaller than the veloci- ty vector above it. Another study of particle trajectory in the drying process was carried out by [19]. Fig. 9. Particle trajectory 3. 5. Drying Efficiency Drying efficiency changes over time same manner as the changes in dry air temperature and moisture content of coal particle. At the first minute the drying efficiency was obtained by 78.3%, and in the fifth minute became 35.3%. The drying efficiency of the experimental is shown in Fig. 10. It is seen that drying efficiency decreases rapidly 100 90 Energy Efficiency (%) 80 70 60 50 40 30 20 10 0 0 2 4 6 8 10 12 14 16 Time (mnt) Fig. 10. Energy efficiency as a result of a decrease in moisture content which is also relatively fast in the period concerned. 4. Conclusions In this study, Indonesian low-rank coal was drained by swirl fluidized bed method by experimental and numeri- cal with 100 angle of blade inclination. Drying using 600 gr of coal, size of about 6 mm, the moisture content of 25,17%. The drying air is 0.060 kg/sec with the air rela- tive humidity of 10.4% and a temperature of 55 0C. The most effective drying takes 5 minutes. Drying in 5 minutes can reduce moisture ratio from 1.0 to 0.28 this value has not much different from numerical simulations. The numerical simulation can show the particle trajectory quite well as well as the temperature and mass fraction of moisture in the air. 1265 Acknowledgment The author acknowledges for the support of the Sepuluh Nopember Institute of Technology (ITS), Surabaya, Indone- sia. Contract No. 835/PKS/ITS/2017 date April 7, 2017. Nomenclature η = Drying efficiency MR = Moisture ratio M = Moisture content at time t Me = Moisture content at equilibrium M = Moisture content at initial time T0 = Ambient temperature T1 = Inlet temperature of air dryer T2 = Outlet temperature of air dryer

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