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EXPERIMENTAL STUDY ON THE EFFECT OF TEMPERATURE AND FLUIDIZATION VELOCITY ON COAL SWIRL FLUIDIZED BED DRYING WITH 10^0 ANGLE OF BLADE INCLINATION

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ABSTRACT

Experimental study on swirl fluidized bed used 10^0 angle of blade inclination to dry lignite. This study utilizeda sample of mass 600 gr with a variation of dry air temperature of 50, 45, and 40 ^{0}C, and variation of fluidization velocity, which parallel with the gapof 10.9, 13.6, and 16.4 m/s, respectively. The effects of temperature and fluidization velocity difference in drying characteristic and moisture, which released from coal, thus received by dry air were investigated in this study. During the seven minutes of drying for a variation of temperature of 50, 45, and 40 ^{0}C, were able to decrease moisture content as much as 24.73, 23.6, and 21.32%, respectively. For a variation of fluidization velocity of 16.4, 13.6, and 10.9 m/s were able to decrease moisture content as much as 22.83, 21.23, and 14.63%, respectively. The amount of moisture which released from coal was not a significant difference with received by dry air.

Keywords: coal, 10^0 angle of blade inclination, swirl fluidized bed, moisture content, drying rate.

1. INTRODUCTION

Currently, low-rank coal using in a boiler, although it's designed by using high-rank coal. It will give effect to the decrease of boiler's performance. To improve that performance back, the calorific value needs to be upgraded. One of coal upgrading calorific value technology that's widely used is drying. Swirl fluidized bed drying able to dry material faster than other fluidized bed technology.

Research of coal drying by fluidized bed method wasperformed by Levy *et al*., [3]. The study showed that increasing superficial velocity and dry air temperature would increase the drying rate. While increasing the humidity would decrease the drying rate. Jeon *et al*., [2] was used the bubbling fluidized bed to dry coal and the result showed higher temperature and larger diameter would increase the drying rate. Kim *et al*., [4] reported that higher temperature, lower humidity, and faster fluidization velocity would increase the drying rate. Wang [8] also reported that higher temperature increases drying rate of lignite.

Ozbey and Soylemez [7] investigated swirl fluidized bed drying method on wheat. The study informed, this method was able to increase drying efficiency up to 38% compared to the non-swirl fluidized bed. The study wasconducted by Boonlai and Promvonge [1] shows this method able to reduce drying time up to 30% compared to non-swirl fluidized on peppercorns drying. Mohideen *et al*., [6] observeddrying of palm oil leaf and frond by using swirl fluidized bed method. The study informed that drying of the palm oil leaf was falling rate period, while on palm oil frond was linear before reach falling rate period. The study was performed by Simanjuntak *et al*., [5] showed that the smaller inclination of the blade would dry out coal particle faster.

This study aimed to observe the effect of inlet temperature and fluidization velocity of dry air on drying characteristicand observe the moisture, which released by coal and received by dry air. This experiment uses a swirl fluidized bed method with 10^0 angle of blade inclination to dry low rank-coal.

2. EXPERIMENTAL SET-UP

The apparatus that used in this experiment was shown at Figure-1 with a height of drying chamber of 363 mm, diameter of 200 mm and amount of blade of 30. Dry air was introduced from the bottom with tangential direction against chamber while coal was poured from the outlet as soon as possible. The outlet was covered by the filter to prevent coal leave-out from the chamber.

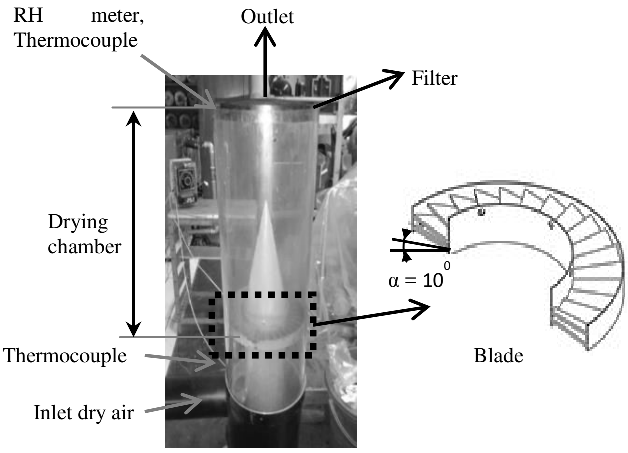

Figure-1. Swirl fluidized bed apparatus.

The moisture content was calculated by wet basis with

$$MC = \frac{M_{H_2O}}{M_{solid} + M_{H_2O}} \quad (1)$$

where:

MC = moisture content,
M_{H2O} = mass fraction of H_2O
M_{solid} = mass fraction of coal (solid).

Drying rate was calculated with

$$DR = \frac{MC_1 - MC_2}{t_2 - t_1} \quad (2)$$

where:
MC_1 = initial moisture content
MC_2 = last moisture content
t_2-t_1 = time difference

Schmidt Number (Sc) was calculated from

$$Sc = \frac{\upsilon}{D_{AB}} \quad (3)$$

Sherwood Number (Sh)wascalculated from

$$Sh = 2 + 0.6\ Re_D^{\frac{1}{2}} Sc^{\frac{1}{3}} \quad (4)$$

Mass transfer coefficient (h_m) was calculated from

$$h_m = Sh\left(\frac{D_{AB}}{D}\right) \quad (5)$$

where:
υ = kinematic viscosity
D_{AB} = mass diffusion H_2O vapor to the air
Re_D = Reynolds number
Sc = Schmidt number
D = particle diameter

3. OBSERVATION PROCEDURE

The dry coal was taken as much as 2 - 3 gr for 5 times with 1-minute interval, then 3 times for 2-minute interval and next 4 times with 5-minute interval, so total drying time was 31 minutes. At the same time, temperature and relative humidity at the inlet were measured at the position as shown in Figure-1. Then coal samples were dried, follow ASTM D 5421 method to remove out the remains of moisture. Some data were evaluated only for seven minutes due to the effectivity of drying.

4. RESULTS AND DISCUSSIONS

4.1 Variation of dry air temperature

This experiment investigated the effect of the difference of dry air temperature on drying characteristic. The particle diameter of 6 mm was assuming as spheric and initial moisture content of 33.3% (we basis). Humidity of dry air was 6.93 gr/kg, the flow rate was 0.0355 kg/s and the dry air temperature was 40, 45 and 50 ^{0}C, respectively.

4.1.1 Moisture content and drying rate

The effect of inlet temperature of dry air on moisture content is shown in Figure-2. It can be seen that decreasing of inlet temperature 45 ^{0}C is nearer to inlet temperature 40 ^{0}C than to inlet temperature 50 ^{0}C. Until 7th minute, decreasing of moisture content is faster than next. This is due to moisture content of coal particle is much enough. For the experiment with inlet temperature 50, 45 and 40 ^{0}C until 7th minute's moisture content decrease to 8.57%, 9.70% and 11.98%, respectively. At the 31st-minute moisture content decrease to 2.59%, 2.66 %, and 3.14%respectively. On the drying with 50 ^{0}C inlet temperature, drying process is faster due to more heat which available to vaporize moisture.

The drying rate in this experiment is shown in Figure-3. It can be seen the line of drying rate has the same trend. The slight difference is only seen at the first minute. After 16th-minute, the drying rate looks relative constant, this is indicating that drying process almost complete. Average drying rate during seven minutes for the inlet temperature of 50, 45 and 40 ^{0}C is 24.73, 23.60 and 21.32 gr/minute, respectively. From Figure-3. also can be seen until seven minutes, the drying processisconsidered as first falling rate periods and next is considered as second falling rate period.

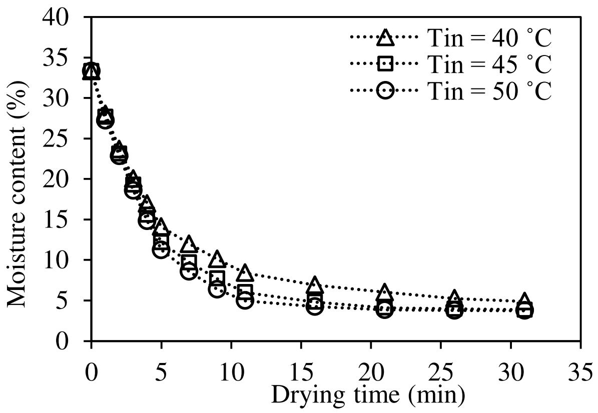

Figure-2. Particle moisture content vs time.

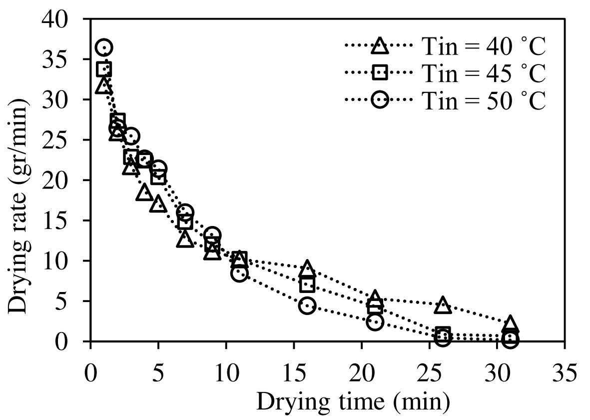

Figure-3. Drying rate vs time.

4.1.2 The effect of temperature on relative humidity dry air at outlet

The effect of temperature on the relative humidity (RH) at the outlet is shown in **Figure-4**. On the graph, it

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can be seen in those three lines havethe same trend and its value is proportional to the inlet temperature. Decreasing of RH due to less moisture to evaporate and increasing of outlet temperature.

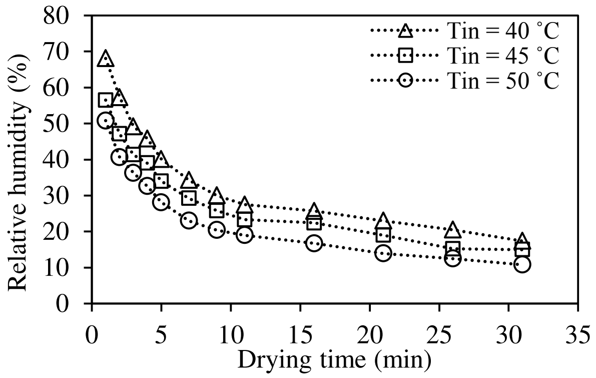

Figure-4. RH dry air at outlet vs time.

Until seven minutes, for dry air temperature of 40 ^{0}C, 45 ^{0}C, and 50 ^{0}C, relative humidity fall from 68,1% to 34,3%, 56,5% to 29,2 % and 50,8% to 23%, respectively For the next minutes dry air temperature at outlet does not undergo significant changes. Crossing occurs between 9th to the 11th minute. The lower relative humidity at outlet indicates a slower drying rate so the dry air temperature of 50 ^{0}C result fastest drying compared to other inlet temperature.

The effect of inlet temperature of dry air on the outlet temperature shown in Figure-5.It can be seen the three lines have the same trend. The temperature at the outlet the chamber for the inlet temperature of 50 ^{0}C is higher than inlet temperature 45 ^{0}C and 40 ^{0}C. The difference of temperature is proportional enough where the inlet temperature of 45 ^{0}C is between the inlet temperature of 50 ^{0}C and 40 ^{0}C. It can be seen from the equation$m_p c_p \frac{dT_p}{d_t} = hA_p(T_{\infty} - T_P) - \frac{dm_p}{dt} h_{fg}$, which has linear correlation. The higher the evaporation temperature the less evaporation enthalpy h_{fg} but the difference is not much for the small temperature difference. The position of the inlet temperature 45 ^{0}C is nearer to the inlet temperature of 50 ^{0}C than to the inlet temperature of 40 ^{0}C. This related to the decrease of the moisture content of 45 ^{0}C is nearer to 50 ^{0}C than 45 ^{0}C.

Until seven minutes for inlet temperature 50 ^{0}C, 45 ^{0}C, and 40 ^{0}C, the outlet temperature of dry air is 44.4 ^{0}C, 42.2 ^{0}C and 38.2 ^{0}C and for 31 minutes is 47.2 ^{0}C, 43.8 ^{0}C, 39.7 ^{0}C, respectively. On this experiment, the higher inlet temperature will generate higher temperature and lower relative humidity at the outlet.

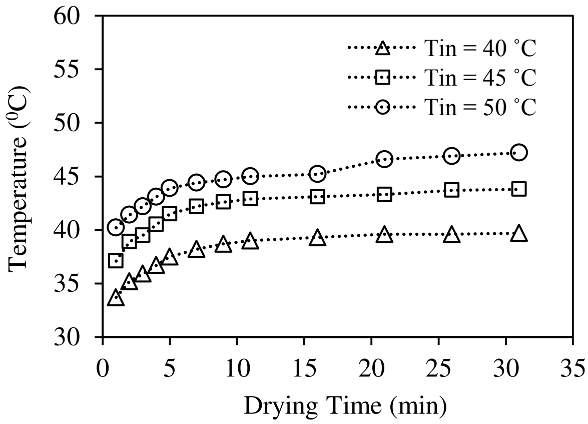

Figure-5. Dry air temperature at outlet vs time.

4.1.3 Comparison of mass transfer rate from coal to the dry air

The drying process which occurs until seven minutes is shown in the psychrometric chart in Figure-6.The process from ambient point to inlet point is heating of dry air i.e from ambient temperature to 50 ^{0}C. At this time, the humidity is ω_0. From inlet point tominute1 is drying process on the first minute. The dry air temperature is reduced and humidity will increase from ω_0 to ω_1. The value of $\Delta\omega = \omega_0 - \omega_1$ is moisture, which received by dry air from coal in the first minute and so does the second minute onwards.Basically, the amount of moisture which received by dry air will be equal to the amount of moisture which releasedfrom coal.

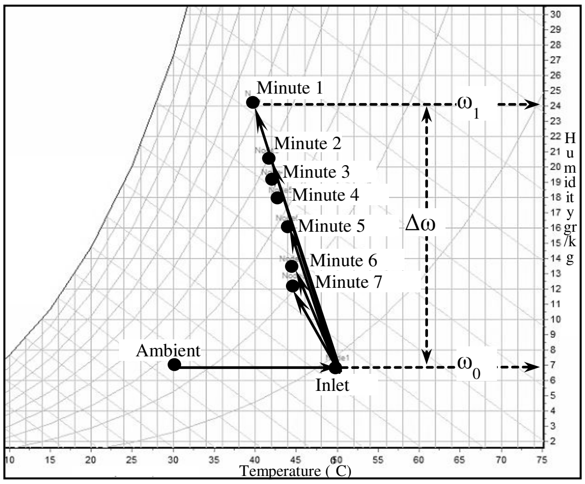

Figure-6. Psychrometric chart drying process at inlet temperature 50 ^{0}C until seven minutes.

Comparison of the mass which released from coal and received by dry air for each inlet temperature of dry air is shown in Figure-7. The three lines have the same trend and have a small difference. In the experiments with variation of dry air inlet temperature, it can be seen that the inlet temperature of dry air of 50 ^{0}C generates more moisture compared to another inlet dry air. In this experiment also seen that more moisture is released earlier of drying process compared to other inlet temperature. For

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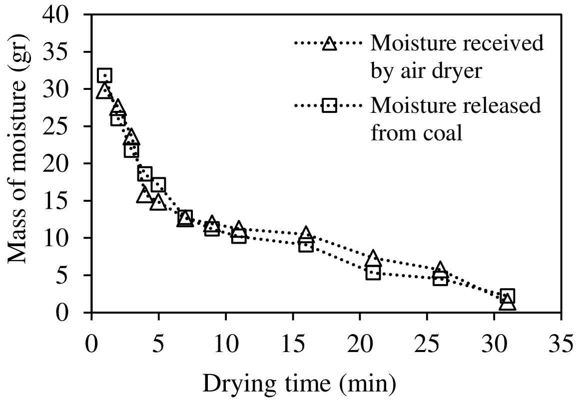
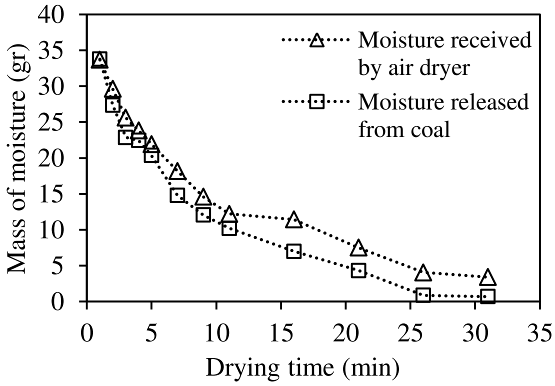
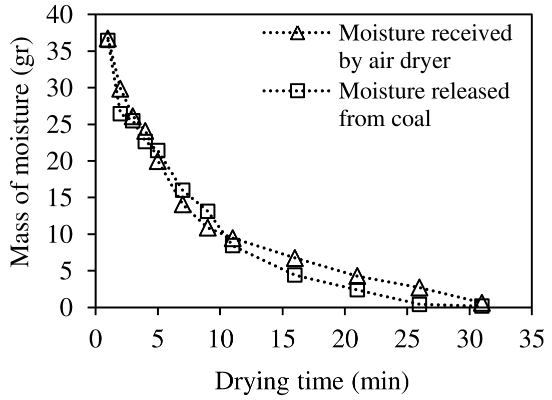
the inlet temperature of dry air of 45 ^{0}C, there is a slightly significant difference between moisture, which released from coal and received by dry air from the 11th minute and so on.



(a)



(b)



(c)

Figure-7. Moisture received by dry air and released by coal on inlet temperature of dry air (a). 40 ^{0}C, (b). 45 ^{0}C and (c). 50 ^{0}C.

The value of mass transfer coefficient can be seen in Figure-8. Temperature and density will affect to *Reynolds number* (Re), *Schmidt numbe*r (Sc) and *Sherwood numbe*r (Sc). Mass transfer coefficient calculated based on equation (3), (4) and (5). The value of mass transfer coefficient for inlet temperature of dry air of 40 ^{0}C, 45 ^{0}C, and 50 ^{0}C is 0.149, 0.152 and 0.153m/s respectively.

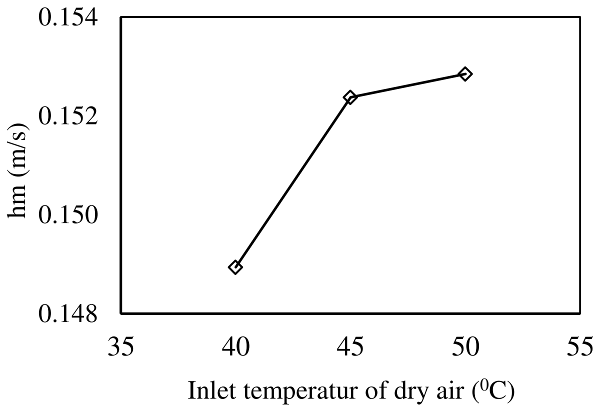


Figure-8. Mass transfer coefficient (h_m) vsinlet temperature of dry air.

4.2 Effect of fluidization velocity

In this experiment, the mass of the sample used is 600 grams, particle diameter of 6 mm, dry air temperature of 40 ^{0}C and humidity 6.901 gr/kg dry air. Fluidization velocity where parallel with the blade is 16.4, 13.6 and 10.9 m/s with initial moisture content (wet basis) 37.65%, 36.38% and 34.80%, respectively.

4.2.1 Moisture content and drying rate

The effect of dry air inlet velocity on the particle moisture content of coal shown in Figure-9. It can be seen that higher velocity will dry faster. Until 7 minutes for dry air velocity of 16.4 m/s, 13.6 m/s and 10.9 m/s able to decrease the particle moisture content from 33.65% to 10.82%, respectively, and from 36.38% to 15.15% and from 34.80% to 20.17%, respectively.

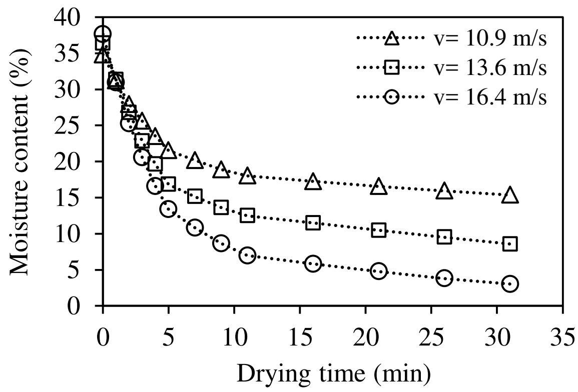


Figure-9. Particle moisture content vs time.

From Figure-9 also seen, until seven minutes the drying is considered as the first falling rate period and the next is considered as second falling rate period. Decreasing of moisture content is shown proportional enough to fluidization velocity and Reynolds number.

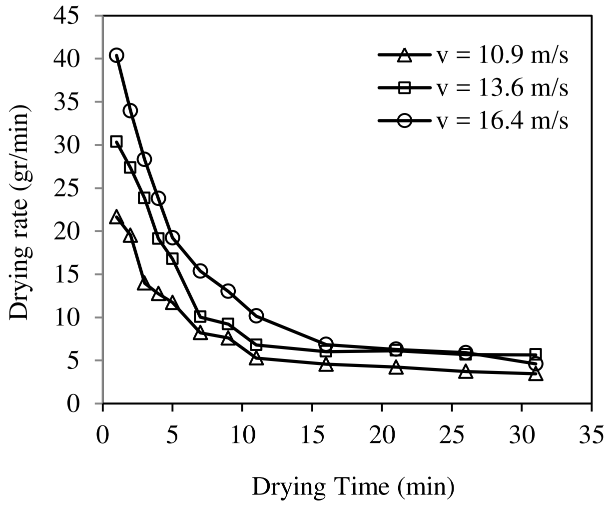


Figure-10. Drying rate vs time.

From the changing of moisture content in Figure-9, drying rate shown in Figure-10.It can be seen that higher drying rate obtains from fluidization velocity of 16.4 m/s, followed by 13.6 m/s and the last is 10.9 m/s. The drying rate at the 17th minute and the next has relatively constant value and indicate that moisture difficult to evaporate. The average drying rate until seven minutes for fluidization velocity of 16.4, 13.6 and 10.9 m/s is 26.83, 21.23 and 14.63 gr/minute, respectively.

4.2.2 The Effect of fluidization velocity on relative humidity and outlet temperature

The effect of fluidization velocity on the relative humidity in the outlet chamber shown in Figure-11. In the first minute, it is shown that relative humidity with fluidization velocity of 16.4 m/s is highest and followed by 13.6 m/s and the last is 10.9 m/s. For the seven minutes, relative humidity decrease from 62.5% to 26.2%, from 59.0% to 27.0% and from 53.8% to 28.6%, respectively. The rapidly decreasing caused by Reynolds number is higher so that the mass transfer coefficient is higher. A relative humidity line of 16.4 m/s crosses RH line of 13.6 m/s between the 4th minute and 5th minute and RH line of 13.6 m/s crosses RH line 10.9 m/s between the 9th minute and 11th minute. This is due to the drying rate of fluidization velocity 16.4 m/s is faster than the fluidization velocity 13.6 m/s in the early of drying. So that the moisture content is faster removedout from the particle. Those crossings indicate that mass transfer of fluidization velocity 16.4 m/s was lower than the mass transfer of fluidization velocity of 13.6 m/s and 10.9 m/s at that time.

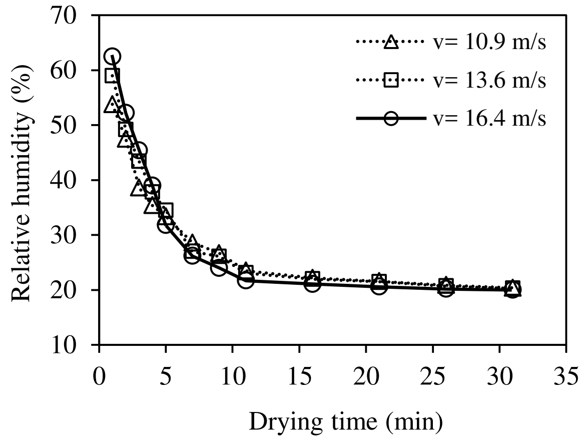


Figure-11. RH dry air at outlet vs time.

The effect of fluidization velocity on the outlet temperature of dry air shown in Figure-12. Fluidization velocity of 16.4 m/s, 13.6 m/s and 10.9 m/s has an outlet temperature of 33.5 ^{0}C, 33.9 ^{0}C and 34.3 ^{0}C at the first minute for. This outlet temperature is affected by moisture from coal. In this experiment, can be seen that the fluidization velocity of 16.4 m/s crosses the temperature of fluidization velocity of 13.6 m/s around 6th minute and outlet temperature of fluidization velocity 13.6 m/s cross the temperature of fluidization velocity 10.9 m/s around 8th minute. Those crosses indicate that balance of moisture on particle was running low.

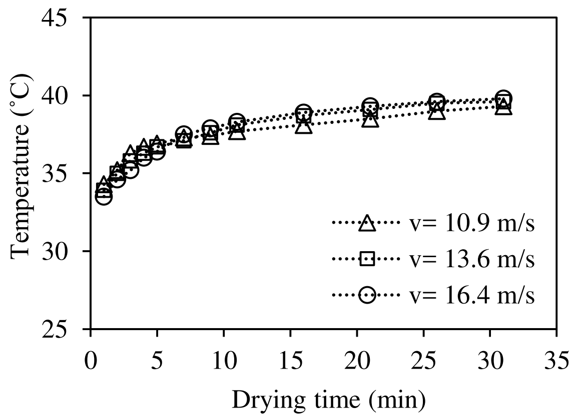


Figure-12. Dry air temperature at outlet vs time.

4.2.3 Comparison of mass transfer rate from coal to dry air

Explanation of drying process until seven minutes in psychrometric charts same with section 4.1.2. The mass of moisture, which removed from coal obtained from difference of coal moisture content which measured for every interval time. While moisture, which received of air dryer is difference of humidity for every time interval as shown in Figure-13. The slightly difference occurs on the first minute of drying on fluidization velocity 13.6 m/s where the mass of moisture released from coal is 30.33 gr/kg dry air while received by dry air is 34.92 gr/kg dry air.

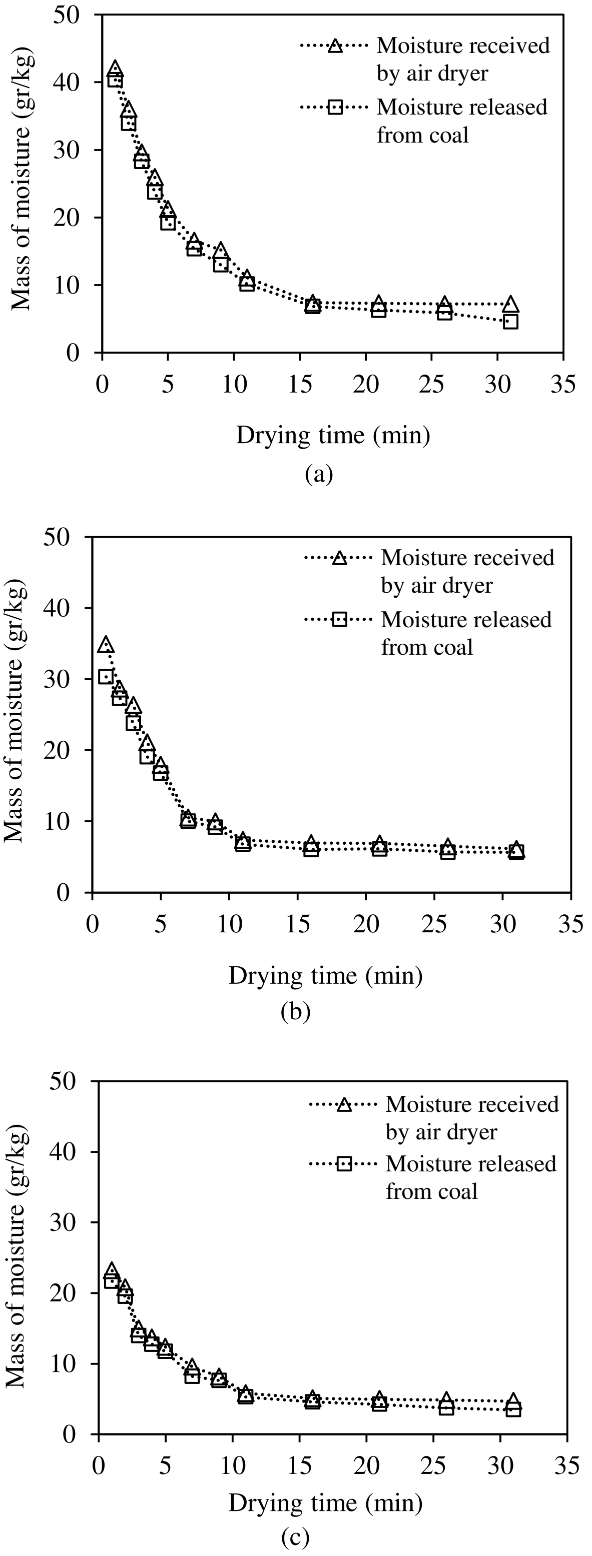


Figure-13. Moisture received by dry air and released from coal on dry air inlet velocity (a). 16.4 m/s (b). 13.6 and (c). 10.9 m/s

4.2.4 The Effect of fluidization velocity on mass transfer coefficient

The Value of mass transfer coefficient calculated follow equations 3, 4 and 5 and obtained these values as shown in Figure-14. The values obtained correlated linearly with fluidization velocity. Where higher velocity will result in higher mass transfer coefficient. Those values for fluidization velocity of 10.9, 13.6 and 16.4 m/s are 0.143, 0.159 and 0.174m/s, respectively.

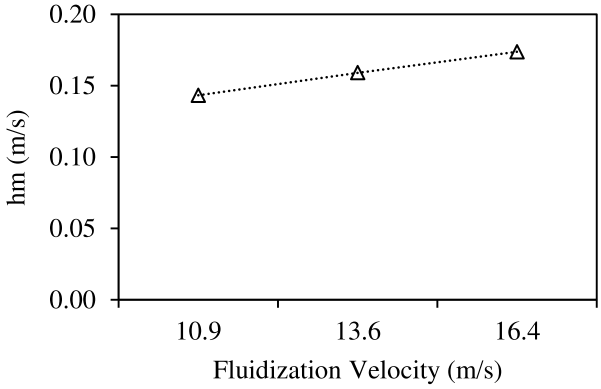


Figure-14. Mass transfer coefficient (h_m) vs fluidization velocity.

5. CONCLUSIONS

The effects of dry air temperature and fluidization velocity on lignite drying with swirl fluidized bed method with 10^0 angle of blade inclination are studied experimentally. From this study can be concluded.

a) For seven minutes of drying with a variation on inlet temperature of dry air of 50, 45 and 40 ^{0}C able to reduce coal particle moisture content as much as 24.73%, 23.60% and 21.32%, respectively. The average drying rate is 23.08, 21.65 and 19.88 gr/minute respectively, and average mass transfer coefficient is 0.153, 0.152 and0.149m/s respectively.

b) Variation of fluidization velocity of 16.4, 13.6 and 10.9 m/s for seven minutes of drying, able to reduce moisture content as much as 22.83%, 21.23% and 14.63%respectively. The average drying rate is 26.83, 21.23 and 14.63 gr/minute, respectively, and average mass transfer coefficient is 0.174, 0.159 and 0.149 m/s respectively.

c) The amount of moisture that released from coal and received by dry air does not have a significant difference for all experiments performed.

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