JMES The International Journal of
Mechanical Engineering and Sciences
https://iptek.its.ac.id/index.php/jmes
e-ISSN 2580-7471

Study of Coal Drying Characteristics Using Boiler Blowdown in A Rotary Coal Dryer

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Received: 21 January 2022, Revised: 14 March 2022, Accepted: 18 March 2022

Abstract

Drying lignite coal to reduce its moisture content has become popular in the last decade. Previously, coal dryers used typical energy such as steam, fuel, or electrical as heat sources. Waste energy had never been implemented in a coal dryer while using it would reduce the cost of production and raise the economic value of the coal itself. An experimental study of drying low-rank coal was conducted using waste energy boiler blowdown in a rotary coal dryer. With variations of 0.595 mm, 1.18 mm, and 4.75 mm coal particle size and the flow's changes of 20 kg/hour, 30 kg/hour, and 40 kg/hour. The hot air temperature of 70°C, mass flow rate of 36 kg/hour, and pressure of 0,03 MPa were the constant parameters on the 15 rpm rotary drum. The results found that the coal moisture decreased significantly at 0.595 mm particle size and 20 kg/hour of flow. The final coal moisture dropped by 20.685%, and the calorific value increased by 879.6 kcal/kg from its initial value. In addition, the efficiency of the rotary coal dryer is 81,8%.

Keywords: boiler blowdown, rotary coal dryer, low-ran coal, moisture, calorific value

1. Introduction

Pangkalan Susu Power Plant uses lignite coal as the primary fuel, which results in a low-boiler efficiency and often blocks the coal conveying lines. Based on Indonesia's coal mines, which are dominated by lignite coal (low-rank coal), a particular technology is needed in the power plant to adequately substitute the medium-rank coal with dried lignite coal (upgraded of lignite coal to medium-rank coal within a drying process) [1]. Several alternative technologies had been developed in a coal dryer to produce simple design, low-cost, and reliable. In their development, Pangkalan Susu Power Plant implemented waste energy from boiler blowdown [2]. The heat generated from the blowdown is water vapor discharged from the steam generator drum or boiler, where the purpose of the water vapor disposal is to maintain water quality [3], with an average mass flow rate of 5 tons/hour.

One of the ways to improve the quality of coal is to reduce the water content [4]. The water content in the coal itself is divided into two: the surface water content and the water content available in the coal particles (inherent moisture). Surface water content can be easily removed from coal by a conventional drying process. While the releasing energy required is more significant to break down coal molecules bound to inherent moisture.

Research related to coal drying technology has been carried out by Levy et al. [5]. The study designed a piece of experimental equipment to analyze coal drying. The test was carried out under the auspices of the Energy Research Center Fluidized Bed Laboratory. The study resulted in the benefits of drying the coal—the Research and Development Agency of PT. PLN (Persero) has also conducted a coal drying technology at Nagan Raya Power Plant using Coal Moisture Control Fluidized Bed. The result showed the production cost reduction by 21% during the study [6].

From previous research and case studies, a coal drying technology is needed to improve the lignite coal by reducing moisture content and increasing calorific value. This technology certainly provides benefits for the company through reducing electricity production costs and improving the company's image.

Coal dryer is a technology that can be used to dry coal, the process of drying coal aims to increase the caloric value of coal. Coal dryers generally require a heat source used for the drying process. Heat sources used to dry coal can be taken directly or indirectly. Directly means heat taken without intermediaries (direct dryer) and indirectly means there is a barrier to drain hot steam (indirect dryer) [7]. With several heat sources, such as exhaust gas, steam extraction turbine, or blowdown steam [8], the heat exchanging process is categorized as direct and indirect contact. As seen in Figure 1, manufactured by Henan Hongji Mine Machinery Co., Ltd. [9], the rotary coal dryer uses hot air as the heat source.

The rotary coal dryer uses a direct contact heat trans-

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fer, as seen in Figure 2. The compressed hot air contacted the raw/wet coal directly in the motorized rotary drum. It is equipped with a screw conveyor and four flights, the drum rotating continuously to ensure the homogenous mixture between hot air and raw coal. At the end of the process, the moisture of raw coal will be released.

A comparison is made between the moisture content to determine the rotary coal dryer efficiency by the following formula:

$$\lambda = \frac{(H_2O)_{raw} - (H_2O)_{pre-dried}}{1 - (H_2O)_{pre-dried}} \tag{1}$$

Where λ is the degree of pre-drying, i.e., the mass of water removed from per unit mass of raw lignite (kg/kg). $(H_2O)_{raw}$ and $(H_2O)_{pre-dried}$ is represent the mass of water contained in per unit mass of raw and pre-dried lignite respectively (kg/kg), can be calculated from the water content in the initial coal and after the coal dryer. The heat balance in the rotary coal dryer can be seen in Figure 3. As for the calculation of the efficiency of the rotary coal dryer, it can be calculated in the heat balance equation according to IAPWS-IF 97 (industrial formulation 1997 of the International Association for the Properties of Water and Steam) following [10]:

$$\begin{aligned} & m_{fg-d}.Cp_{fg}.\left(tf_{fg-d} - t_{de}\right).\eta_d \\ & = MF_1.\lambda.(h_{dw} - h_{wo}) + MF_1.\left(1 - \lambda\right).(h_{c1} - h_{c0}) \end{aligned} \tag{2}$$

The thermal utilization efficiency of the dryer (η_d) is the ratio between useful heating for lignite drying and the input, which considers the influence of dryer and associated pipes' heat dissipation. Where $Cp_{fg}$is the specific heat capacity of boiler flue gas (kJ/kg); h_{dw} and h_{wo} represent the specific enthalpy of the water contained in pre-dried lignite and raw lignite respectively (kJ/kg), h_{c1} and h_{c0} stand for the specific enthalpy of pre-dried lignite at the outlet temperature and inlet temperature respectively (kJ/kg) [11], MF1 is the lignite feeding rate in rotary coal dryer (kg/s), m_{fg-d} is the mass flow rate of flue gas(kg/s), tf_{fg-d} is temperature of flue gas (°C), and t_{de} is temperature of dryer.

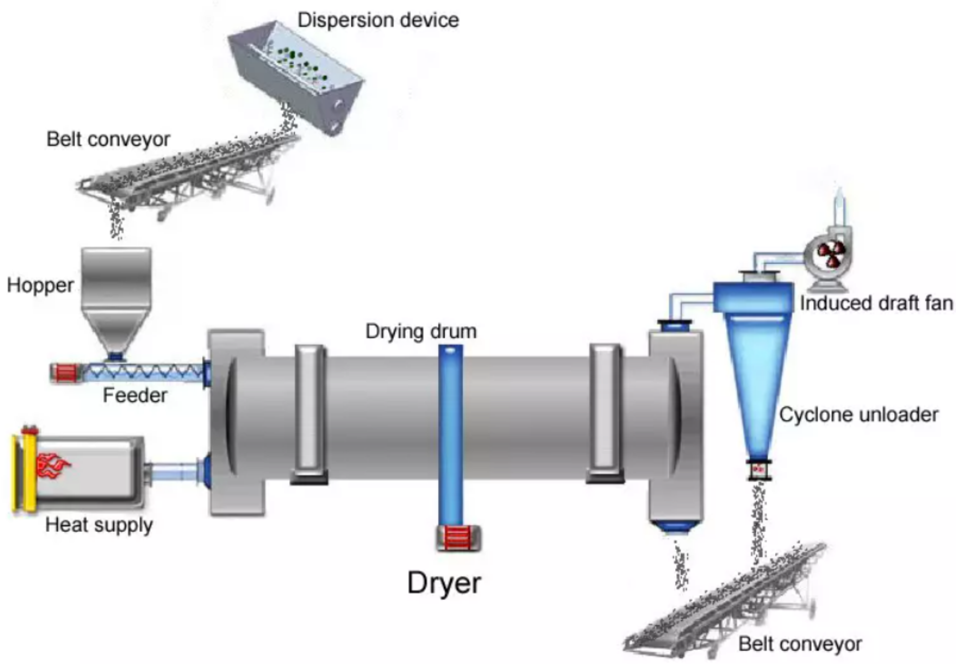

Figure 1. Rotary coal dryer.

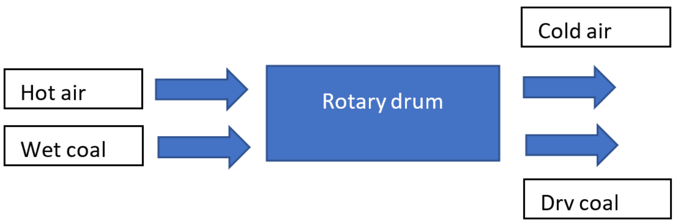

Figure 2. Coal dryer working principle.

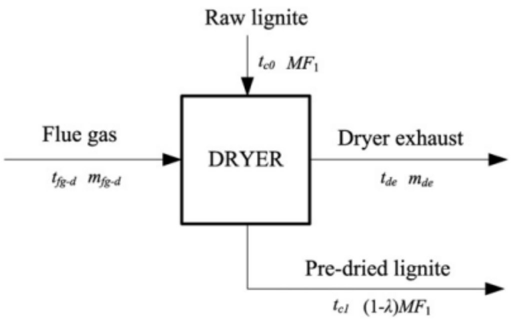

Figure 3. Heat balance in rotary coal dryer.

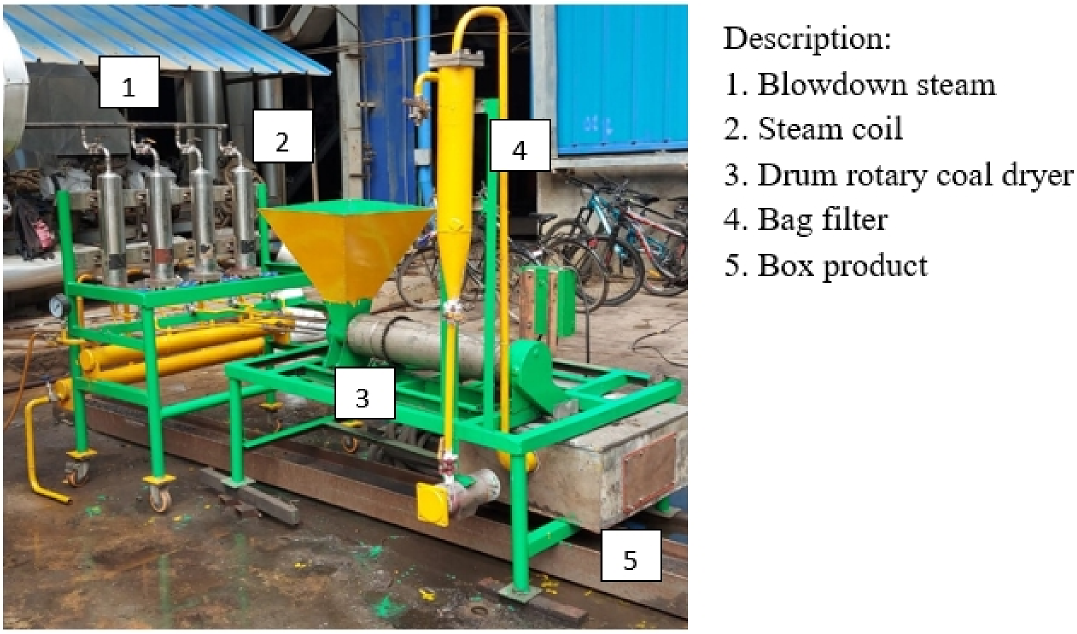

Figure 4. The prototype of rotary coal dryer.

2. Experimental Method

The prototype design of the rotary coal dryer can be seen in Figure 4. In this design, the dryer's energy used the principle of heat transfer within four sets of steam coils. The boiler blowdown from wastes energy steam drum entered the steam coils and heated the compressed air [12]. The heated air flowed through four pipes, entered the rotary drum, and dried the raw coal by direct contact heat transfer. Finally, the dried coal and the dust separated at the end of the rotary drum. The rotary drum was made of stainless steel 304 without being equipped with heat insulation [13]. Therefore, the possibility of heat loss during drying can occur. The dried coal was collected on the product box, while the dust accumulated in the filter bag. The specifications of the rotary coal dryer are shown in Table 1. Several tools were used to support data accuracy and data validation. The measuring instruments were the temperature indicator on the air compressor header ranged up to 100oC, pressure indicator on the air compressor header ranged up to 1 MPa, thermograph Avio, Carbolite Gero MSF as certified coal laboratory with the proximate analysis used total moisture, Leco AC 500 to calculate the calorific value, coal meshing, coal weigher (digital) 2 x 15 kg and oven to calculate the moisture content, manufactured by Memmert. The constant and independent variables data collection during the experiments are shown in Table 2, followed by the data collection steps in Figure 5.

Table 1. Rotary coal dryer specification.

Parts	Parameter	Unit	Value
Blowdown	Maximum flow rate steam	kg/hour	5000
	Pressure steam	MPa	1.2
Steam coil	Airflow rate	kg/hour	36
	Specific heat steam	kJ/kg. °C	4.3139
	Specific air heat	kJ/kg. °C	1.006
	Inlet steam temperature	°C	157.5
	Outlet steam temperature (drain)	°C	98
	Inlet air temperature	°C	30
	Outlet air temperature	°C	70-80
Drum rotary	Rotary drum diameter	mm	185
	Rotary drum thickness	mm	6
	Rotary drum length	mm	967.1
	Fin drum thickness	mm	5
	Fin drum length	mm	887.1
	Drum rotary	rpm	15
Bag filter	Diameter	mm	100
	Height	mm	340
Box product	Length	mm	60
	Height	mm	29
	Width	mm	65

Table 2. Constant variables and independent variables.

Variable	Parameter	Unit	Value
Constant	Hot air from steam coil:		
	· Flow	kg/hour	36
	· Temperature	°C	70
	· Pressure	MPa	0.03
	· Drum rotary	rpm	15
	Coal type:		
	· Coal moisture	%	33.88
	· Coal calorific value	kcal/kg	4,189
Independent	Coal flow:		
	· Variant 1	kg/hour	20
	· Variant 2	kg/hour	30
	· Variant 3	kg/hour	40
	Coal size:		
	· Variant 1	mm	0.595
	· Variant 2	mm	1.18
	· Variant 3	mm	4.75
Box product	Height	mm	340
	Length	mm	60
	Height	mm	29
	Width	mm	65

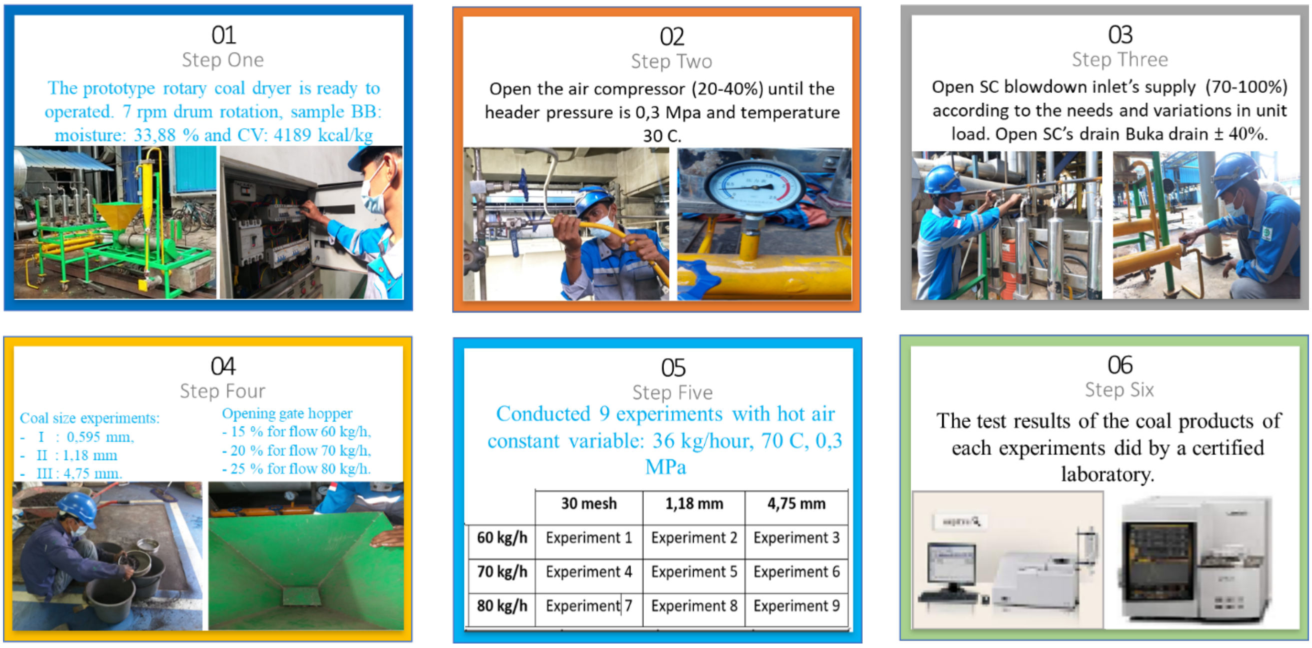

Figure 5. The experimental steps.

3. Result and Discussion

3.1. Data Analysis

After the coal sampling was carried out, the value of each sample according to its particle size was collected as initial data. The initial data of coal sampled were coal moisture 35.37% with standard ASTM D3302M-17 and calorific value 4065 kcal with standard ASTM D5865-13.

The process of reducing moisture and increasing calorific value was carried out during the operation of the rotary coal dryer. From the sample test results after the experiment on the rotary coal dryer, the moisture content and calorific value of coal were explained.

Moisture reduction was carried out in a rotary coal dryer with two variations of the coal mass flow rate and the particle size. The experiment was carried out on a fixed rotary speed of 15 rpm, hot air temperature of 70°C, hot air pressure of 0.03 MPa, and hot airflow of 36 kg/hour. The variation combines coal particle sizes of 0.595 mm, 1.18 mm, and 4.75 mm within the interpretation of coal mass flow rate of 20 kg/hour, 30 kg/hour, and 40 kg/hour.

3.2. Effect of Coal Flow on Moisture Reduction

Figure 6 shows the effect of mass flow rate on coal moisture. The most decreased moisture occurred in the coal flow of 20 kg/hour for each particle size. At 0.595 mm, the moisture dropped from 35.37% to 14.69%.

This moisture drop was caused by the same amount of heat energy used in a smaller mass flow rate (less coal volume). The coal volume impacts greater energy to remove the moisture content. In the K.S. Hatzilyberis experiment, the smaller the flow of coal, which conducted in the rotary coal dryer, the less moisture will be even more significant [14]. With the result, the most optimal value in this experiment to reduce moisture was at 20 kg/hour coal flow.

3.3. Effect of Coal Particle Size on Moisture Reduction

Figure 7 shows the effect of coal particle size on the decrease in moisture. The most significant reduction in moisture was at the smallest particle size of 0.595 mm from the initial moisture of 35.37% to 14.685%. There was a decrease of 20.685%. With the result, the most optimal value in this experiment to reduce moisture in the coal was the coal particle size of 0.595 mm.

This moisture drop occurred because the smaller the particle size, the larger the coal's surface (of heat and mass transfer) got the drying heat. Therefore, the water content in the coal is evaporated. From the results of the data analysis, there was a correlation in the experiments carried out regarding variations in the particle size of coal by previous research from Komariah [15]. The study stated that the smaller the coal particle size to be dried, the more significant the decrease in moisture experienced by the coal.

3.4. Effect of Coal Flow on Increasing Calorific Value

In Figure 8, the most significant increase in calorific value was at the minor coal flow for each particle size, which was 0.595 mm, 1.18 mm, and 4.75. Compared with pre-drying, the calorific value of coal was 4,065 kcal/kg, then the most significant increase in calorific value was at coal flow of 20 kg/hour and particle size of 0.595 mm, which was 4,911.6 kcal/kg. The drying heat from the coal dryer at a smaller coal flow was absorbed greater than a more significant coal flow. Therefore, the increase in calorific value will also be even more effective. With the result, the most optimal value in this experiment for the effect of coal flow on increasing calorific value was coal flow of 20 kg/hour.

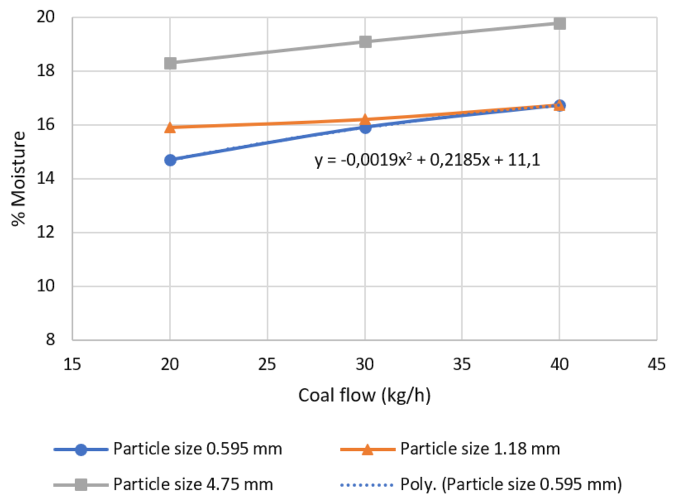

Figure 6. Effect of coal flow on moisture reduction.

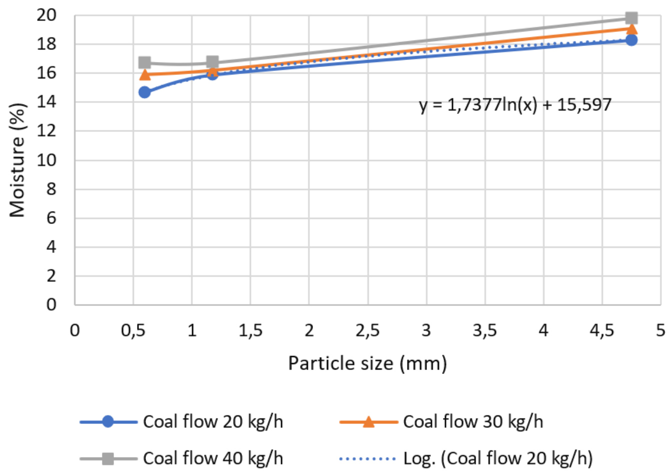

Figure 7. The effect of particle size on the decrease in moisture.

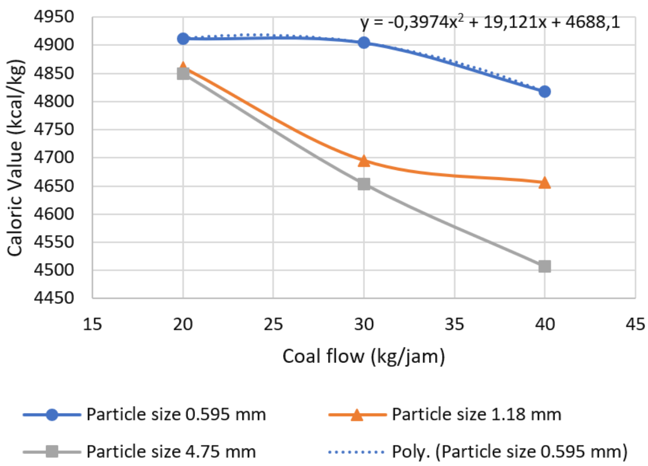

Figure 8. Effect of coal flow on increasing calorific value.

3.5. Effect of Coal Particle Size on Increasing Calorific Value

In Figure 9, the smaller the coal particle size, the higher the increase in calorific value, at flows of 20 kg/hour, 30 kg/hour, and 40 kg/hour. Compared with pre-drying, the calorific value of coal was 4,065 kcal/kg, then the most significant increase in calorific value was at particle size 0.595 mm and flow 20 kg/hour, which was 4,911.6 kcal/kg. The smaller the particle size, the greater the absorption of heat experienced by the coal. By increasing the heat absorption, more water content was discharged, which increased the calorific value of coal. With the result, the most optimal value in this experiment for the effect of coal particle size on increasing calorific value was at a coal particle size of 0.595 mm.

3.6. Rotary Coal Dryer Efficiency

A heat balance calculation of energy on the rotary drum was carried out to determine the rotary coal dryer efficiency. The input energy in the drum was hot air from the compressor mixed with coal that had not been dried.

Meanwhile, the output energy produced was air mixed with coal at the outlet side of the rotary coal dryer drum. Figure 10 shows the coal outlet temperature for variation of coal flow and particle size data after drying for each experiment.

For the calculation of all experiments according to the above formula for thermal efficiency and total efficiency of each experiment on a rotary coal dryer, it is as in Table 3 below.The calculation shows that the efficiency of the rotary coal dryer designed with test 1 at coal flow of 20 kg/hour and particle size of 0.595 mm is 86.98%. This means that during the drying process, there was a 13.02% loss on the equipment, which could be minimized by improving the rotary coal dryer system such as changing the type of material, providing insulation on the drum, and improving the sealing system to prevent fluid from leaving the system. Figure 11 shows a graph of the variation of coal flow and particle size on the efficiency of the thermal coal dryer.

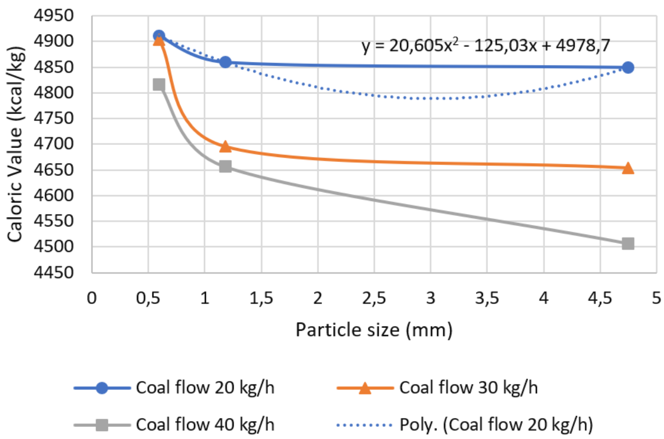

Figure 9. Effect of particle size on increasing calorific value.

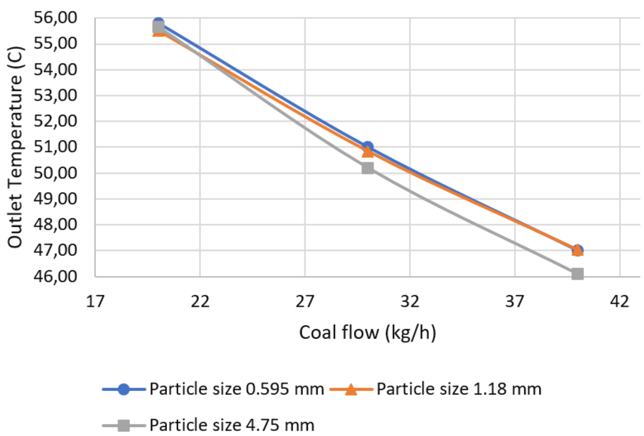

Figure 10. Coal outlet temperature for variation of coal flow and particle size.

Table 3. Experimental data.

Parameters	Unit	Experiments								
		1	4	7	2	5	8	3	6	9
Flow rate mass of hot inlet air	kg/jam	37	37	37	37	37	37	37	37	37
The specific heat capacity of the hot inlet air	kj/kg.ºC	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006
The water content of coal before drying	kg	0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354
The water contentof coal after drying	kg	0.147	0.159	0.183	0.159	0.162	0.191	0.167	0.167	0.198
Inlet hot air temperature	ºC	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Outlet air temperature	ºC	55.80	55.50	55.65	51.00	50.85	50.20	47.00	47.05	46.10
Inlet coal flow rate	Kg/jam	20.00	20.00	20.00	30.00	30.00	30.00	40.00	40.00	40.00
Rotary coal dryer drying rate	kg/kg	0.242	0.232	0.209	0.232	0.229	0.201	0.224	0.224	0.194
Specific enthalpy water content after drying	kJ/kg	2605.50	2604.90	2605.20	2596.50	2596.20	2595.00	2589.00	2589.10	2587.40
Specific enthalpy water content before drying	kJ/kg	2557.30	2557.30	2557.30	2557.30	2557.30	2557.30	2557.30	2557.30	2557.30
Specific enthalpy of rotary coal dryer outlet air	kJ/kg	353.53	353.56	353.55	353.95	353.96	354.02	354.29	354.29	354.36
Specific enthalpy of rotary coal dryer inlet air	kJ/kg	368.45	368.45	368.45	368.45	368.45	368.45	368.45	368.45	368.45
Power of drum motor	kj/jam	837.21	837.21	837.21	959.62	959.62	959.62	1044.9	1044.9	1044.9
Efficiency thermal of coal dryer	%	86.98	83.24	81.62	85.77	84.48	77.82	84.49	84.79	77.34
Total Efficiency of coal dryer	%	33.66	32.63	31.79	36.39	36.01	33.80	38.05	38.14	35.56

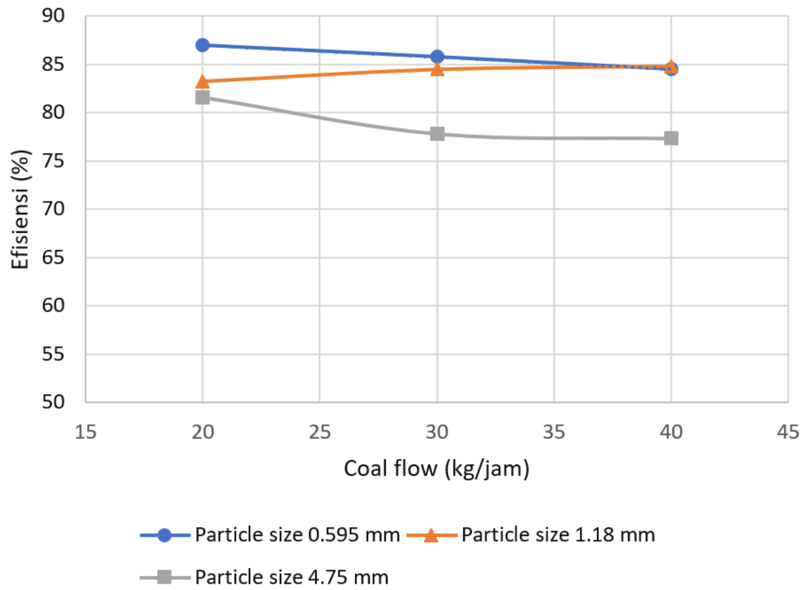

Figure 11. The relationship between coal flow and particle size on thermal efficiency.

4. Conclusion

Based on the experimental data, with the procedures carried out for variations flow and particle size of coal at fixed variables 70ºC hot air, 37 kg/hour airflow, 0.03 MPa pressure, and the type of coal, it was found that the most significant decrease of coal moisture was in the flow variation with the smallest coal particle size is 20 kg/hour and 0.595 mm, with a decline of 20.685%. The most significant increase of the calorific value of coal was in the variation of flow with the largest coal particle size, 20 kg/hour and 0.595 mm, with an increase of 879.6 kcal/kg. The value of efficiency when test 1 was carried out on the rotary coal dryer was η_d=86,98% and the losses experienced by the equipment was 13.02%.

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