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DESIGN OF RICE HUSK ROTARY DRYER USING WASTE HEAT ELECTROSTATIC PRECIPITATOR OF THE CEMENT INDUSTRY

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ABSTRACT

ESP or electrostatic precipitator is a device used to capture particulate matter, such as dust, in exhaust gases using electrostatic principles. In the cement industry, ESP is commonly placed after the clinker cooler to clean the exhaust air from the cooling process, ensuring it is free from clinker dust. The clinker cooler is a device that cools down the clinker using air, reducing its temperature from an initial temperature of around 1450°C to approximately 100°C - 120°C. The exhaust air from the clinker cooler is then passed through the ESP at temperatures ranging from around 237°C to 311°C. Based on the temperature data, the exhaust air from the ESP has the potential for heat reuse for other processes, including as a heat source for drying rice husk, which is a common alternative fuel used in the cement industry and typically has a moisture content of around 25%-37%. The results of this design indicate that the exhaust heat from the ESP, with an input temperature of 275°C, is capable of drying rice straw pellets from a moisture content of 25% to 14.73% using a designed rotary dryer with a capacity of 21.6 t/h, a length of 41.58 m, and a diameter of 2.92 m. It is constructed using ASTM 283 C material with a thickness of 8.76 mm and is insulated with a 15.6 mm thick layer of aluminum foil.

Keyword: *electrostatic precipitator, rice husk, rotary dryer, water content*

1. INTRODUCTION

In the cement industry, after the combustion process in the reinforced suspension preheater (RSP) and kiln, the next step is the cooling process carried out by the clinker cooler. The clinker cooler is a device used to reduce the temperature of the clinker from the kiln, which is around 1450°C, to approximately 100°C-120°C [1]. The clinker cooler operates by blowing cooling air through the bottom grate/bars using fans, which move the clinker through various compartments [2].

The exhaust air from the clinker cooling process is commonly used for other processes such as combustion in the RSP, combustion in the rotary kiln, and drying of additive materials like trass. The remaining hot air is discharged through the electrostatic precipitator (ESP) at temperatures ranging from around 237°C to 311°C.

The ESP serves as a device to capture solid particles (dust), specifically clinker dust, in the grate cooler exhaust gas using electrostatic principles. This ensures that the output air from the ESP is free from clinker dust, which could potentially contaminate the environment by maintaining a relative constant temperature [3]. As a result, the waste heat from the grate cooler passing through the ESP presents an opportunity for heat recovery in other processes.

Efforts to utilize the waste heat from the ESP can be implemented by using it as a heat source for fuel drying [4]. One of the applications can be done in the cement industry to dry rice husk with a moisture content of 25%-37% to its saturation level, which is around 9%-15% [5], [6].This utilization not only maximizes the potential of the ESP exhaust air but also enhances its calorific value [7].

Among the various types of dryers suitable for rice husk, which consists of particulate/grain-like material, are rotary dryers, flash dryers, and fluidized bed dryers [8]. In this research, a rotary dryer was chosen due to the grain-like nature of rice husk, and because the other dryer types share the drawback of not evenly reversing the material, leading to uneven drying of the product.

2. METHODOLOGY

The research methodology used in this design consists of several stages. These stages are arranged in the following sequence:

2.1. Determining Intial Parameters

The initial parameters that need to be determined in the design include temperature, mass flow rate, initial moisture content, and design criteria and boundary conditions as indicated in Table 1 and Table 2 below.

Table 1. Initial Parameters

No.	Parameters	Value	Unit
1.	Temperature Input Dryer	275	°C
2.	Temperature Input Material	30	°C
3.	Mass Flow Rate of Hot Air	20000	kg/h
4.	Mass Flow Rate of Rice Husk	18000	kg/h
5.	Initial Moisture Content of Wet Rice Husk	25	%

Source: Cement Industry Average Consumption Data, 2022.

Table 2. Design Criteria

No.	Parameters	Value	Unit	Source
1.	Dryer Capacity	> 18000	kg/h	Cement Industry Average Consumption Data
2.	Temperature Output *Dryer*	< 90	°C	JS 1140/2006
3.	Final Water Content of Rice Husk	9 - 15	%	Suharno & DTC IPB, Clean Tech Energy

Source: Result Processing Documents, 2023.

2.2. Calculating the Number of Transfer Units

The number of transfer units is calculated to ensure that the specified output temperature of the hot air corresponds to an effective Nt value ranging between 1.5 and 2.5 [9].

$$N_t = \ln \frac{T_{hb} - T_{wb}}{T_{ha} - T_{wb}} \quad (1)$$

Where:

 P-ISSN : 2598-1277
E-ISSN : 2621-3966

N_t = Number of transfer unit

T_{ha} = Temperature input of hot air (°C)

T_{hb} = Temperature output of hot air (°C)

T_{wb} = Temperature wet bulb inlet (°C)

(Source: R. H. Perry 1999)

2.3. Calculating Heat Duty

These parameters are used to calculate the amount of heat that the dryer can obtain from the ESP.

$$Q = m_u \times Cp_u \times (T_{hb} - T_{ha}) \tag{2}$$

Where:

Q = Heat obtained from the ESP (kJ/h)

$\dot{m}_u$ = Mass flow rate of hot air (kg/h)

Cp_u = Specific heat of air (kJ/kg.K)

T_{ha} = Temperature input of hot air (°C)

T_{hb} = Temperature output of hot air (°C)

(Source: W. L. McCabe 1993)

2.4. Calculating the Final Moisture Percentage

The final moisture content percentage of the material using the heat from the ESP should be in the range of 9% - 15%. Therefore, calculating the final moisture content is crucial to ensure the success of this design.

$$\%X_b = \frac{\left(\frac{Q}{\dot{m}_u}\right) - \left(Cp_r \times (T_{rb} - T_{ra})\right)}{-\lambda + \left(Cp_l \times (T_{rb} - T_v)\right) - \left(Cp_v \times (T_{ha} - T_v)\right)} - \frac{\left(X_a \times Cp_l \times (T_v - T_{ra})\right)}{-\lambda + \left(Cp_l \times (T_{rb} - T_v)\right) - \left(Cp_v \times (T_{ha} - T_v)\right)} - \frac{\left(X_a \times Cp_v \times (T_{ha} - T_v)\right)}{-\lambda + \left(Cp_l \times (T_{rb} - T_v)\right) - \left(Cp_v \times (T_{ha} - T_v)\right)} \times 100\% \tag{3}$$

Where:

$\%X_b$ = Final moisture of material (%)

Q = Heat obtained from the ESP (kJ/h)

$\dot{m}_u$ = Mass flow rate of hot air (kg/h)

Cp_r = Spesific heat of material (kJ/kg.K)

Cp_l = Spesific heat of water (kJ/kg.K)

Cp_v = Spesific heat of hot air (kJ/kg.K)

P-ISSN : 2598-1277
E-ISSN : 2621-3966

T_{ha} = Temperature input of hot air (°C)

T_{hb} = Temperature output of hot air (°C)

T_{ra} = Temperature input material (°C)

T_{rb} = Temperature output material (°C)

T_v = Temperature evaporate (°C)

λ = Coefficient of laten heat for air (kJ/kg)

X_a = Initial moisture content fraction of the material

(Source: W. L. McCabe 1993)

2.5. Calculating the Dimensions of Rotary Dryer

The dimensions of the rotary dryer are divided into several size parameters with the following design stages:

2.5.1. Area of Rotary Dryer

The surface area of the rotary dryer is obtained by comparing the mass flow rate of the air with the mass velocity of the air inside the dryer.

$$A = \frac{\dot{m}_u}{G} \tag{4}$$

Where:

A = Area of rotary ryer (m^2)

G = Mass velocity of hot air ($kg/m^2.h$)

$\dot{m}_u$ = Mass flow rate of hot air (kg/h)

(Source: W. L. McCabe 1993)

2.5.2. Diameter of Rotary Dryer

Based on the surface area obtained in the previous calculation, the diameter of the dryer can be calculated.

$$D = \left(\frac{4\,A}{\pi}\right)^{0.5} \tag{5}$$

Where:

D = Diameter of rotary dryer (m)

A = Area of rotary dryer (m^2)

(Source: W. L. McCabe 1993)

2.5.3. Length of Rotary Dryer

The length of the rotary dryer can be calculated after determining the following parameter delta temperature below.

P-ISSN : 2598-1277
E-ISSN : 2621-3966

$$\Delta T = \frac{(T_{hb} - T_{wb}) - (T_{ha} - T_{wa})}{\ln[(T_{hb} - T_{wb})/(T_{ha} - T_{wa})]} \qquad (6)$$

After calculating the delta temperature, the length of the rotary dryer can be calculated based on the equation below.

$$L = \frac{Q}{0{,}125\pi D G^{0.67} \Delta T} \qquad (7)$$

Where:

L = Length of rotary dryer (m)

D = Diameter of rotary dryer (m)

Q = Heat obtained from ESP (kJ/h)

G = Mass velocity of hot air (kg/m^2.h)

ΔT = Delta differensial temperature

T_{ha} = Temperature input of hot air (F)

T_{hb} = Temperature output of hot air (F)

T_{wa} = Temperatur wet bulb outlet (F)

T_{wb} = Temperatur wet bulb inlet (F)

(Source: W. L. McCabe 1993)

2.5.4. Volume of Rotary Dryer

The volume of the rotary dryer is given a safety factor of 20% to avoid overcapacity, and it is calculated using the following equation.

$$V = \frac{QD}{0{,}5 G^{0{,}67} \Delta T} \qquad (8)$$

Where:

V = Volume of rotary dryer (m^2)

L = Length of rotary dryer (m)

D = Diameter of rotary dryer (m)

Q = Panas obtained from ESP (kJ/h)

G = Mass velocity of hot air (kg/m^2.h)

ΔT = Delta differensial temperature

(Source: W. L. McCabe 1993)

2.6. Designing the Flight Geometry

Flights, also known as lifters, are fins within the rotary dryer that lift and evenly mix the material.

 P-ISSN : 2598-1277
E-ISSN : 2621-3966

2.6.1. Calculating the Number of Flights in a Circle

The number of flights here refers to the number of lifters present in one circle. According to standards, the number of lifters is typically 2.4 to 3 times the diameter [9].

2.6.2. Calculating the Height of the Flight

According to the standard, the height of the flight has a specified range, which is typically between 1/12 to 1/8 times the diameter of the dryer [9].

2.6.3. Length of Lips

Lips on the flight are required for certain types of materials that have roughness and small particle sizes. The ratio between the height of the flight and the length of the lips (I2/I1) can be selected as 0.375, 0.75, or 1 for such materials [10].

2.6.4. Calculating the Number of Flight Rows

Based on the standard, it is known that the distance or offset between flights in the rotary dryer typically ranges from 0.6 m to 2 m [11].

2.7. Calculating the Rotational Speed

Rotational speed is a measurement that expresses the rotational velocity of the rotary dryer.

$$N_r = \frac{60s}{\pi D} \quad (9)$$

Where:

N_r = Rotational speed per minute (rpm)

D = Diameter of rotary dryer (m)

s = Peripheral speed (m/s)

(Source: W. L. McCabe 1993)

2.8. Calculating of Residence Time

The time referred to in this parameter represents the duration for which the material will be inside the rotary dryer, from the inlet to the outlet.

$$\theta = \frac{0{,}23L}{S{N_r}^{0{,}9}D} \pm 0{,}6\frac{BLG}{F} \quad (10)$$

Where:

θ = Residence time (minutet)

N_r = Rotational speed per minute (rpm)

D = Diameter of rotary dryer (ft)

 P-ISSN : 2598-1277
E-ISSN : 2621-3966

S = Slope of rotary dryer (ft/ft)

L = Length of rotary dryer (ft)

G = Mass velocity of hot air (kg/m^2.h)

B = Material contanst

d_p = Particle size of the material (μm)

F = Feed rate material to the *dryer* (lb/h.ft^2)

(Source: W. L. McCabe 1993)

2.9. Calculating the Shell Thickness

The shell thickness is calculated to determine the minimum thickness of the dryer to accommodate the capacity of the material to be dried.

$$t_s = \frac{SD}{2S_w e - S} + C \quad (11)$$

Where:

t_s = Shell Thickness (mm)

S_w = Work pressure material (MPa)

D = Diameter of rotary dryer (mm)

S = Design pressure in rotary dryer (Mpa)

C = Corrosion Allowance (mm)

e = longitudinal joint efficiency

(Source: ASME B31.3 1992)

2.10. Calculating the Insulation Thickness

The insulation of the shell serves to prevent conduction heat and minimize heat loss from the hot air.

$$t_i = e^{\left(\left(\left(\frac{2\pi L(T_i - T_o)}{Q_k}\right) - \left(\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_s}\right) + \left(\frac{\ln(r_2)}{k_i}\right)\right) \times k_i\right)} - r_2 \quad (12)$$

Where:

t_i = Insulastion thickness (m)

Q_k = Conduction heat allowance (kJ/h)

T_o = Surface temperature of shell (^{o}C)

r_2 = Outer radius of the shell (m)

r_1 = Inner radius of the shell (m)

k_i = Insulation material thermal conductivity (W/m.^{o}C)

k_s = shell material thermal conductivity (W/m.^{o}C)

(Source: Yunus A. Cengel 2007)

 P-ISSN : 2598-1277
E-ISSN : 2621-3966

2.11. Calculating the BHP of motor

This parameter is used to determine the size of the motor required to drive the rotary dryer.

$$BHP = \frac{N_r(4{,}75D_tW_m + 0{,}1925dW_t + 0{,}33W_t)}{100000} \quad (13)$$

Where:

BHP = The motor capacity/power required. (HP)

d = Diameter of riding ring (ft)

D_t = The total outer diameter of the shell and insulation (ft)

W_t = The total load (lb)

W_m = Load from the material (lb)

N_r = Rotational Speed (rpm)

(Source: R. H. Perry 1999)

3. RESULT AND DISCUSSION

The designed rotary dryer is a direct heat, counter-current flow type. This choice is based on the lower cost of direct heat and the easier design complexity compared to indirect heat and co-current flow types. Additionally, the counter-current flow type offers higher efficiency compared to co-current flow. The heat for the dryer will be obtained by installing pipes along the ESP (Electrostatic Precipitator) to the rice husk storage. The heat extraction process will be done through the ESP chimney, which aims to maintain the ESP operation by minimizing resistance and preventing additional load caused by the percentage of pollutants present in the hot air.

Based on the research methodology regarding the design of the rotary dryer above, this study obtained the design results of the rotary dryer, as illustrated in **Figure 1.**

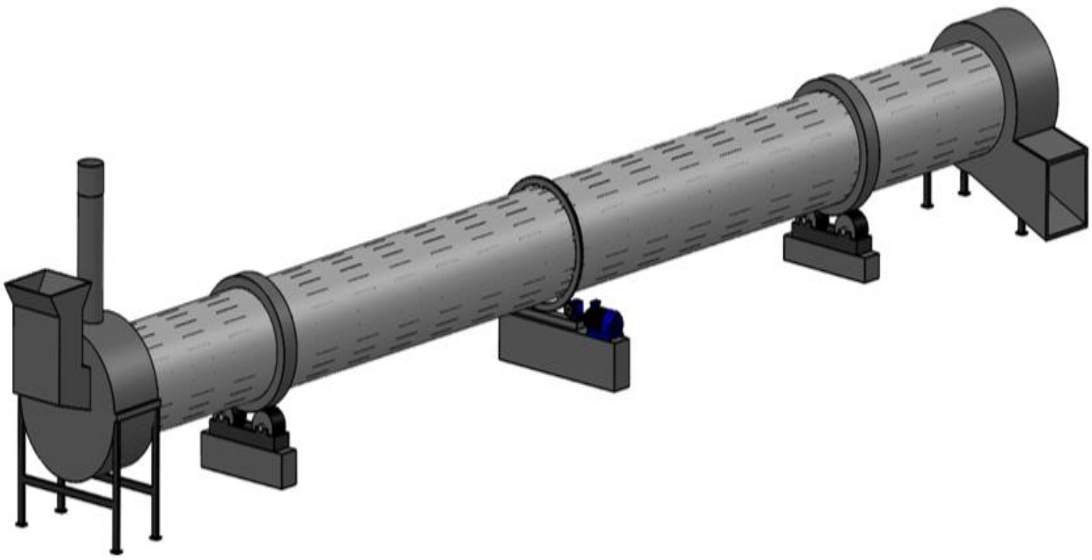

Figure 1. Rotary Dryer

The specifications of the rotary dryer are described in the following Table 3.

 P-ISSN : 2598-1277
E-ISSN : 2621-3966

Table 3. Rotary Dryer Spesification

No.	Parameters	Value	Unit
1.	Length of Shell	41.58	m
2.	Diameter of Shell	2.914	m
3.	Area of Shell	6.667	m^2
4.	Volume of Shell	332.7	m^3
5.	Shell Thickness	8.76	mm
6.	Insulation Thickness	15.6	mm
7.	Residence Time	125.4	menit
8.	Rotational Speed	3.277	rpm
9.	Number Flights in a Circle	23	buah
10.	Number Flight rows	21	buah
11.	Height of Flight	0.364	m
12.	Type of Lips	90	^{o}
13.	Length of Lips	0.273	m
14.	Motor Capacity	103.1	kW

Source: Result Analysis, 2023.

The rotary dryer design utilizes ASTM 283 Grade C carbon steel for the shell material, with a thickness of 8.81 mm. This material is commonly used and offers higher strength compared to stainless steel. Given the large capacity of the designed rotary dryer, it requires a stronger material to withstand high loads, temperatures, and pressures. However, due to the high thermal conductivity of carbon steel, thermal insulation is necessary. The selected insulation for this rotary dryer is aluminum foil insulation. It has a low thermal conductivity of 0.12 W/m·°C and lower density compared to mineral wool insulation, while providing similar thermal insulation properties. This choice aims to minimize heat loss and enhance energy efficiency in the rotary dryer.

According to standards, materials like rice husk are suitable for using a radial flight type of dryer with 90-degree angled lips and a lip-to-flight height ratio of 0.75. This design aims to ensure thorough mixing and even drying of the material within the dryer's capacity. Rice husk belongs to the category of free-flowing materials, meaning it easily moves and has relatively small particle sizes. Therefore, the chosen radial flight design with the specified lip-to-flight ratio is appropriate to facilitate proper agitation and uniform drying of the rice husk.

Table 4. Comparison of Resulte with the Design Criteria

No.	Parameter	Result	Design Criteria	Description
1.	Dryer Capacity (t/h)	21.6	> 18	Fulfilled
2.	Temperature Output *Dryer* (^{o}C)	80	< 90	Fulfilled
3.	Final Water Content of Rice Husk (%)	14.73	9 - 15	Fulfilled

Source: Result Analysis, 2023

Table 4 shows that the rotary dryer, operating with an input temperature of 275°C and a heat supply of 20,000 kg/h, is capable of drying 18 t/h of rice husk. This capacity aligns with the designed dryer

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capacity of 21.6 t/h, resulting in a reduction of the paddy husk's moisture content from an initial value of 25% to 14.73%. Moreover, the drying process, which achieves this moisture reduction, ensures that the exhaust air temperature remains below the standard limit of 90°C. Hence, the design satisfies all three criteria necessary to determine its feasibility. Based on the comparison results, this design is deemed suitable and can be considered as an alternative solution for utilizing waste gas to dry paddy husk, which serves as an alternative fuel source.

4. CONCLUSSION

The design specifications of the rotary dryer in this research include the following details: the material used is ASTM 283 Grade C with a diameter of 2.914 m, a width of 41.58 m, an area of 6.67 m², and a volume of 332.7 m³. The shell thickness is 8.76 mm. The insulation used is aluminum foil with a thickness of 15.6 mm. Inside the shell, radial flights with a lip angle of 90 degrees are installed, totaling 23 flights with a height of 0.364 m and a lip length of 0.273 m around the circumference of the shell. The design requires 21 rows of flights along the length of the shell. The rotary dryer is designed to operate at a rotational speed of 3.277 rpm, and the residence time of the material is 125.4 minutes. The motor required for this design has a capacity of 103.1 kW.

The input process parameters for the rotary dryer are as follows: the hot air from the ESP is supplied at a rate of 20,000 kg/h with an input temperature of 275°C and an output temperature of 80°C. The input material, which is rice husk, is fed into the dryer at a rate of 18,000 kg/h. The purpose is to dry the rice husk and reduce its moisture content from 25% to 14.73%.

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