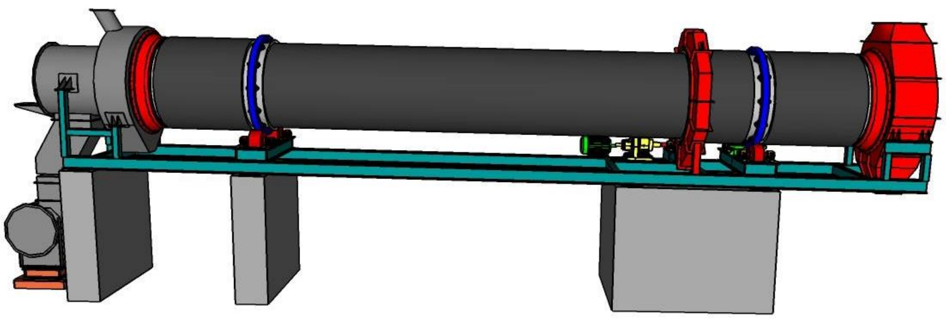
D-01 ROTARY DRYER

Objective: *To reduce the moisture content of filter cake from 25.0 % to 0.9%.*

EQUIPMENT SPECIFICATION



ROTARY DRYER DATA SHEET	EQUIPMENT NO. (TAG): D-01 DESCRIPTION (FUNCTION): To reduce the moisture content of filter cake from 25.0 % to 0.9%
Dimensions	
Material of Construction	Carbon Steel (SA 285, Grade C)
Inclination	5 degrees
Inside Diameter	1.31 m
Total Diameter	1.39 m
Length	8.02 m
Shell Thickness	8.17 mm
Insulation Thickness	32.30 mm
Technical Data	
Rotational Speed	4.60 rpm
Number of Flights	13
Flight Depth	0.16 m
Motive Power Requirement	3.23 kW
Blower Power Requirement	3.97 kW
Dryer Power Requirement	1.61 kW

PROCESS CONDITIONS

	Feed			Air
Component	$CaHPO_4 \cdot 2H_2O$	$Ca(H_2PO_4)_2$	H_2O	
Mass Flow Rate	407.41 kg/hr	5.51 kg/hr	137.64 kg/hr	6,712.60 kg/hr
Inlet Temperature	30 °C			170 °C
Outlet Temperature	105 °C			105 °C

DESCRIPTION OF DRYER CLASSIFICATION CRITERIA

1. **Form of Feed:** Wet Filter Cake
2. **Mode of Operation**: Continuous operation
3. **Heating System:** Steam-heated air
4. **Gas Flow Pattern in Dryer:** Cocurrent gas flow

CALCULATION OF HEAT DUTY

Using Ambient Temperature of 30 ˚C and RH = 93% (Weather Past 2 Weeks in Manila, Philippines, 2015)

From Psychometric chart of Perry's Handbook: Humidity = 0.0252 kg of water per kg of dry air

Taking the humid heat of Air:

$$C_s = 1.005 + 1.88H = 1.005 + 1.88(0.0252)$$

$$C_s = 1.0524\ \frac{kJ}{kg-k}$$

Calculating for the amount of air needed:

$$m_a = \frac{Q}{Cs\Delta T} = \frac{382{,}642.7525\frac{kJ}{hr}}{1.0524\frac{kJ}{kg-K}(443.15-378.15)K} = 5{,}593.83\,\frac{kg}{hr}$$

To find humidity of outlet Air:

$$H = \frac{m_{vapor}}{m_{air}} + H_{30°C}$$

$$H = \frac{133.8868\ kg\ water}{5{,}593.8292\ kg\ dry\ Air} + 0.0252\ \frac{kg\ water}{kg\ dry\ Air} = 0.05\ \frac{kg\ water}{kg\ air}$$

To find the relative humidity of outlet Air:

P° at 105 °C = 120,701.0447

$$P_{H_2O} = \frac{0.0491\ kg\ water \times \frac{1\ kmol}{18.02\ kg}}{\left(0.0491\ kg\ water \times \frac{1\ kmol}{18.02\ kg}\right) + (1\ kg\ dry\ Air \times \frac{1\ kmol}{28.84\ kg})} \times 101{,}325\ Pa$$

$$P_{H_2O} = 7{,}387.04\ Pa$$

$$RH = \frac{P_{H_2O}}{P°} \times 100\% = \frac{7{,}387.0354\ Pa}{120{,}701.0447\ Pa} \times 100\% = 6.12\ \%$$

Thus the outlet air does not exceed the capacity of the air to carry vapor since RH<100%

Allotting an allowance of 20%, for the possible heat losses and due to startup, shutdown and cleaning. (van't Land, 2012)

$$m_a = (1.20)(5{,}593.8292)\frac{kg}{hr}$$

$$m_a = 6{,}712.60\frac{kg}{hr}$$

CALCULATION OF INSIDE DIAMETER & LENGTH

The allowable mass velocity of the air ranges from 2000 kg/hr-m^2 up to 25,000 kg/hr-m^2 (McCabe, Harriot, & Smith, 1993). Assuming that the mass velocity of air = 5,000 kg/hr-m^2

Then, the area of dryer,

$$A = \frac{6{,}712.5950\frac{kg}{hr}}{5{,}000\frac{kg}{hr - m^2}} = 1.34\ m^2$$

$$D_i = \sqrt{\frac{4(\ 1.3425\ \ m^2)}{\pi}}$$

$$D_i = 1.31\ m$$

Drying diameter ranges from 1 to 3 m (McCabe, Harriot, & Smith, 1993), thus the computed drying diameter is accepted.

The following empirical equation is used to calculate for the overall heat transfer coefficient from Perry's Handbook with the index n = 0.67 (McCormick, 1962). The k value falls in the range 3.75 ≤ k ≤ 5.25 as suggested by AICHE for SI unit (van't Land, 2012). Assuming k = 4.75:

$$U_a = \frac{kG^n}{D}$$

$$U_a = \frac{4.75(5{,}000\frac{kg}{hr - m^2})^{0.67}}{1.3074\ m}$$

$$U_a = 1{,}092.92\ \frac{kJ}{hr - m^3 - k}$$

For the calculation of wet bulb temperature, the most economical operation of rotary dryer can be achieved for N_t is in general between 1.5 and 2.5 (Mujumdar, 2014). Assuming the value of N_t = 2.

$$N_t = \ln\left(\frac{T_{A_{in}} - T_w}{T_{A_{out}} - T_w}\right)$$

$$2 = ln\left(\frac{443.15 - T_w}{378.15 - T_w}\right)$$

$$T_w = 367.98\ K$$

Calculating the logarithmic mean temperature difference:

$$(\Delta T)_{lm} = \frac{(T_{A_{in}} - T_w) - (T_{A_{out}} - T_w)}{ln\frac{(T_{A_{in}} - T_w)}{(T_{A_{out}} - T_w)}} = \frac{(443.15 - 367.98) - (378.15 - 367.98)}{ln\frac{(443.15 - 367.98)}{(378.15 - 367.98)}}$$

$$= 32.5\ K$$

To calculate the length of the drier:

$$Q = U_a AL(\Delta T)_{lm}$$

$$L = \frac{Q}{U_a A(\Delta T)_{lm}} = \frac{382{,}642.7525 \frac{kJ}{hr}}{1{,}092.9196 \quad \frac{kJ}{hr - m^3 - K}(1.3425\ m^2)(32.5\ K)}$$

$$L = 8.02\ m$$

Checking L/D ratio:

$$\frac{L}{D_i} = \frac{8.0242\ m}{1.3074\ m} = 6.14$$

L/D ratio is most efficient between 4 and 10 for industrial dryers (Mujumdar, 2014), therefore the above diameter and length can be accepted.

CALCULATION OF RPM, FLIGHT DESIGN & RESIDENCE TIME

Speed values ranges 0.1 to 0.5 m/s (van't Land, 2012). Assuming the peripheral speed of rotation to be 0.1 m/s.

To calculate the speed of rotation of the drier:

$$RPM = \frac{peripheral\ speed}{Diameter}$$

$$RPM = \frac{0.1 \frac{m}{s} \times \frac{60\ s}{1\ min}}{1.3074\ m} = 4.59\ rpm$$

The revolution of a drier varies between 2-5 rpm. Therefore, the above value can be accepted.

Flight Design:

$No.\ of\ flights = 3D$, (D in feet)

$$No.\ of\ flights = 3\left(1.3074\ m \times \frac{1\ ft}{0.3048\ m}\right) = 12.87 \approx 13$$

Flight Depth:

$$F_d = \frac{D}{8} = \frac{1.3074\ m}{8}$$

$$F_d = 0.16\ m$$

Using the following empirical equation for the residence time (in minutes) in dryer as recommended by AICHE (van't Land, 2012):

$$B = 5{d_p}^{-0.5} = 5(210)^{-0.5} = 0.3450$$

$$\tau = \frac{0.23L}{SN^{0.9}D} + \frac{2BLG}{F} = \frac{0.23(8.0242)}{(5)(4.5892)^{0.9}(1.3074)} + \frac{2(0.3450)((8.0242)(5{,}000)}{(\frac{416.67}{1.3425})}$$

$$\tau = 89.28\ min$$

Residence time of rotary dryer typically ranges at 5-90 minutes (Couper, Penney, Fair, & Walas, 2005), therefore the computed value is acceptable.

CALCULATION OF SHELL DRYER THICKNESS & OUTER DIAMETER

Considering the material to be used is Carbon Steel (SA 285, Grade C) because it can withstand up to 343.33 °C. For operating pressure of 0 psig (14.7 psia), the design pressure is 10 psig (24.7 psia) or 170,253.5714 Pa (Hesse & Rushton, 1975)

Using the following formula for working stress:

$$S_w = S_u \times F_m \times F_a \times F_r \times F_s$$

where: S_u: minimum specified tensile strength, 380 MPa (ASME SA285 Grade C, n.d.)

F_m: material factor, 0.92 for Grade C material

F_a: radiographing factor, 1.00 since radiographing is not employed

F_r: stress relieving factor, 1.00 since relieving is not employed

F_s: factor of safety, 0.25 for temperature less than 315.56 °C

$$S_w = 380\ MPa \times 0.92 \times 1.00 \times 1.00 \times 0.25$$

$$S_w = 87.4\ MPa$$

Using the following equation to calculate shell thickness with a corrosion allowance of 6.35 mm (Hesse & Rushton, 1975) and efficiency of the joint 0.70 for double-welded butt joint since radiographing is not employed (Sinnot, 2005):

$$t_s = \frac{PD}{2S_w e - P} + C$$

$$t_s = \frac{170{,}253.5714\frac{N}{m^2} \times 1.3074\ m \times \frac{1000\ mm}{1\ m}}{(2 \times 87{,}400{,}000\frac{N}{m^2} \times 0.70) - 170{,}253.5714\frac{N}{m^2}} + 6.35\ mm$$

$$t_s = 8.17\ mm$$

The minimum shell thickness of equipment vessel with 1.0668 - 1.524-m diameter is 8.128 mm (Couper, Penney, Fair, & Walas, 2005), therefore above value can be accepted.

To calculate the outer diameter of the dryer:

$$D_o = D_i + 2t_s = 1.3074\ m + 2(8.1717\ mm \times \frac{1\ m}{1000\ mm})$$

$$D_o = 1.32\ m$$

CALCULATION OF THE INSULATION THICKNESS

To limit heat loss an insulation is to be given to the dryer. The chosen insulating material is brick. From literature, its thermal conductivity equals to 0.72 W/m·K. Mild steel however has a thermal conductivity of 51.9220 W/m·K.

$$Q = \frac{2\pi L(T_2 - T_1)}{\frac{\ln(\frac{r_2}{r_1})}{k_A} + \frac{\ln(\frac{r_3}{r_2})}{k_B}}$$

$$106{,}289.6535\ W = \frac{2\pi(8.0242\ m)(443.15\ K - 303.15\ K)}{\frac{\ln(\frac{0.6619}{0.6537})}{51.9220\frac{W}{m \cdot K}} + \frac{\ln(\frac{0.6619 + t_i}{0.6619})}{0.72\frac{W}{m \cdot K}}}$$

$$t_i = 0.0323\ m = 32.30\ mm$$

To calculate the total diameter of the dryer:

$$D_t = D_o + 2t_i = 1.3238\ m = 1.3238\ \ m + 2(32.2966\ mm \times \frac{1\ m}{1000\ mm})$$

$$D_t = 1.39\ m$$

CALCULATION OF THE LIVE LOAD & ROTATING LOAD

To calculate the volume of shell material:

$$V_{SM} = \frac{\pi(D_o^2 - D_i^2)L}{4} = \frac{\pi(1.3238^2 - 1.3074^2)m^2 \times 8.0242\ m}{4}$$

$$V_{SM} = 0.27\ m^3$$

To calculate the volume of insulating material:

$$V_{IM} = \frac{\pi(D_t^2 - D_o^2)L}{4} = \frac{\pi(1.3884^2 - 1.3238^2)m^2 \times 8.0242\ m}{4}$$

$$V_{IM} = 1.10\ m^3$$

To calculate the weight of unloaded dryer using the density of mild steel 7850 kg/m^3:

$$W_{dryer} = 0.2710\ m^3 \times 7{,}850\ \frac{kg}{m^3}$$

$$W_{dryer} = 2{,}127.43\ kg$$

To calculate the weight of insulating material using the density of brick 2165 kg/m^3:

$$W_{insulation} = 1.1040\ m^3 \times 2{,}165\ \frac{kg}{m^3}$$

$$W_{insulation} = 2{,}390.26\ kg$$

To calculate the weight of the material in the dryer:

$$W_{material} = \left(550.5535\ \frac{kg}{hr}\right) \times 89.2775\ min \times \frac{1\ hr}{60\ min}$$

$$W_{material} = 819.20\ kg = 1{,}806\ lbs$$

To calculate the total weight of the loaded dryer:

$$W_{total} = 2{,}127.4269\ kg + 819.2001\ kg + 2{,}390.2589\ kg$$

$$W_{total} = 5{,}336.89\ kg = 11{,}765.62\ lbs$$

CALCULATION OF BLOWER POWER, MOTIVE POWER & POWER TO DRIVE A DRIER

Using the equation in (van't Land, 2012) for the calculation of motor power for rotation for rotary dryers:

$$P_m = \frac{0.3\pi {D_i}^2 L}{4} = \frac{0.3\pi}{4} \times (1.3074)^2 \times (8.0242)$$

$$P_m = 3.23\ kW$$

To calculate the power requirement for blower:

$$Q_{inlet\ air} = \frac{nRT}{P} = \frac{(6{,}712.5950\frac{kg}{hr})(\frac{1\ kmol}{28.5740\ kg})(8{,}314\ \frac{Pa \cdot m^3}{kmol \cdot K})(378.15\ K)}{101{,}325\ Pa}$$

$$Q_{inlet\ air} = 7{,}289.15\ \frac{m^3}{hr}$$

$$P_b = 2.72 \times 10^{-5} Q_{inlet\ air} p = 2.72 \times 10^{-5}(7{,}289.1505\ )(20)$$

$$P_b = 3.97\ kW$$

Using the following equation proposed by CE Raymond Division, Combustion Engineering Inc., to calculate the power to drive a dryer with flights (Mujumdar, 2014):

$$P_D = \frac{N(4.75 D_i W_{material} + 0.1925 D' W_{total} + 0.33 W_{total})}{100{,}000}$$

where: N: expressed in rpm; D': D + 2

$W_{material}$, W_{total}: expressed in lbs; D_i: expressed in feet

$$P_D = \frac{4.75\big((4.75 \times 4.29 \times 1{,}806) + (0.1925 \times 6.29 \times 11{,}765.62) + (0.33 \times 11{,}765.62)\big)}{100{,}000}$$

$$P_D = 2.52\ bhp \times \frac{0.75\ kW}{1\ bhp}$$

$$P_D = 1.89\ kW$$

REFERENCES

ASME SA285 Grade C. (n.d.). Retrieved from Join-Win Steel Website: http://www.steel-jw.com

Capitaine, S. L., & Carlson, C. (n.d.). Rotary Kiln Refractory: The Working Layer vs. The Insulating Layer. *FEECO International*.

Capitaine, S. L., & Carlson, C. (n.d.). *Rotary Kiln Refractory: The Working Layer vs. The Insulating Layer.* Retrieved from FEECO International: file:///C:/Users/NeilPatrick/Downloads/feeco.com-Rotary-Kiln-Refractory-The-Working-Layer-vs-The-Insulating-Layer%20(1).pdf

Couper, J. R., Penney, W. R., Fair, J. R., & Walas, S. M. (2005). *Chemical Process Equipment: Selection and Design, Second Edition.* Oxford: Elsevier Inc.

Geankoplis, C. J. (1995). *Transport Processes and Unit Operations, 3rd Ed.* Singapore: Prentice Hall.

Hesse, H. C., & Rushton, J. H. (1975). *Process Equipment Design.* New York: D. Van Nostrand Co.

McCabe, W. L., Harriot, P., & Smith, J. C. (1993). *Unit Operations of Chemical Engineering, 5th Edition.* Singapore: McGraw-Hill, Inc.

Mujumdar, A. S. (2014). *Handbook of Industrial Drying, Fourth Edition.* Florida: CRC Press.

Perry, R. H., & Green, D. W. (2008). *Perry's Chemical Engineering Handbook, Eight Edition.* New York: McGraw-Hill.

Peters, M. S., & Timmerhaus, K. D. (1991). *Plant Design and Economic for Chemical Engineers, Fourth Edition.* New York: McGraw-Hill.

Rotary Dryers, Cooler and Calciners. (n.d.). Retrieved from www.gea.com

Sinnot, R. K. (2005). *Coulson and Richardson's Chemical Engineering Vol. 6, 4th Edition.* Oxford: Butterworth-Heinemann.

van't Land, C. (2012). *Drying in the Process Industry.* New Jersey: John Wiley & Sons, Inc.

Weather Past 2 Weeks in Manila, Philippines. (2015, August 26). Retrieved from Time and Date: http://www.timeanddate.com/weather/philippines/manila/historic