มหาวิทยาลัยราชภัฏนครปฐม

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

9673204
Drying and Storage

rse Description

eory of drying, sun drying, principles of air flow, drying gricultural products by heated air, moisture content rmination, relationship of moisture and temperature, ibrium moisture content, design of dryers storage

sional Interest Statement:

onitoring CO_2/O_2 concentrations to assess biological activity and reduce post-rvest losses
tablishing verification criteria for unacceptable insect infestation levels
pporting fumigation and grain storage management decisions
eveloping agricultural product drying and intelligent drying systems

Assistant Professor Dr. Chukiat Cho

Office: ETB 101 - Industrial Educat
Faculty of Science and Tec

Webpage: https://pws.npru.ac.th/chukia

NPR

Lecture 8 – General Principles of Dryer Design

Study Questions – Lecture 8

1. *What factors must be considered when selecting a dryer?*
2. *How is airflow rate determined in bulk drying?*
3. *What components contribute to total pressure loss?*
4. *How is fan power calculated?*
5. *What are the main components of heat energy in drying systems?*

Lecture 8 – Importance and Theory of Drying

Outline – Lecture 8

1. *Importance of Dryer Design*
2. *Criteria for Selecting Dryers*
3. *Design Factors and Airflow Calculation*
4. *Pressure Drop in Drying Systems*
5. *Fan Selection and Power Requirement*

Why is Importance of Dryer Design?

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

✓ Different dryers use distinct heat transfer methods:

- Convection: Hot air dryers
- Radiation: Infrared and microwave dryers
- Mixed (Convection & Radiation): Bin dryers, cross-flow, concurrent-flow, count flow, spray dryers, and fluidized bed dryers

✓ Dryer selection depends on the product type, whether the material is solid or wet, the required batch capacity, and hot air temperature conditions

Methods for Selecting Dryer Types:
1. Material Properties

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

- Consider the physical state (solid/wet), size, and weight of the material
- Porosity & Penetration:
  - For solid materials like cereal grains with low porosity, pure infrared drying is unsuitable as it cannot penetrate thick layers
  - Forced hot air with material movement (e.g., cross-flow) is required
- Heat Sensitivity: High temperatures can negatively impact quality, such as causing cracks or altering chemical composition, color, and odor
- Drying Time: This is determined by the rate of moisture reduction under specific temperatures and air velocities, which can be obtained from lab tests or literature

Methods for Selecting Dryer Types:

2. Production Costs

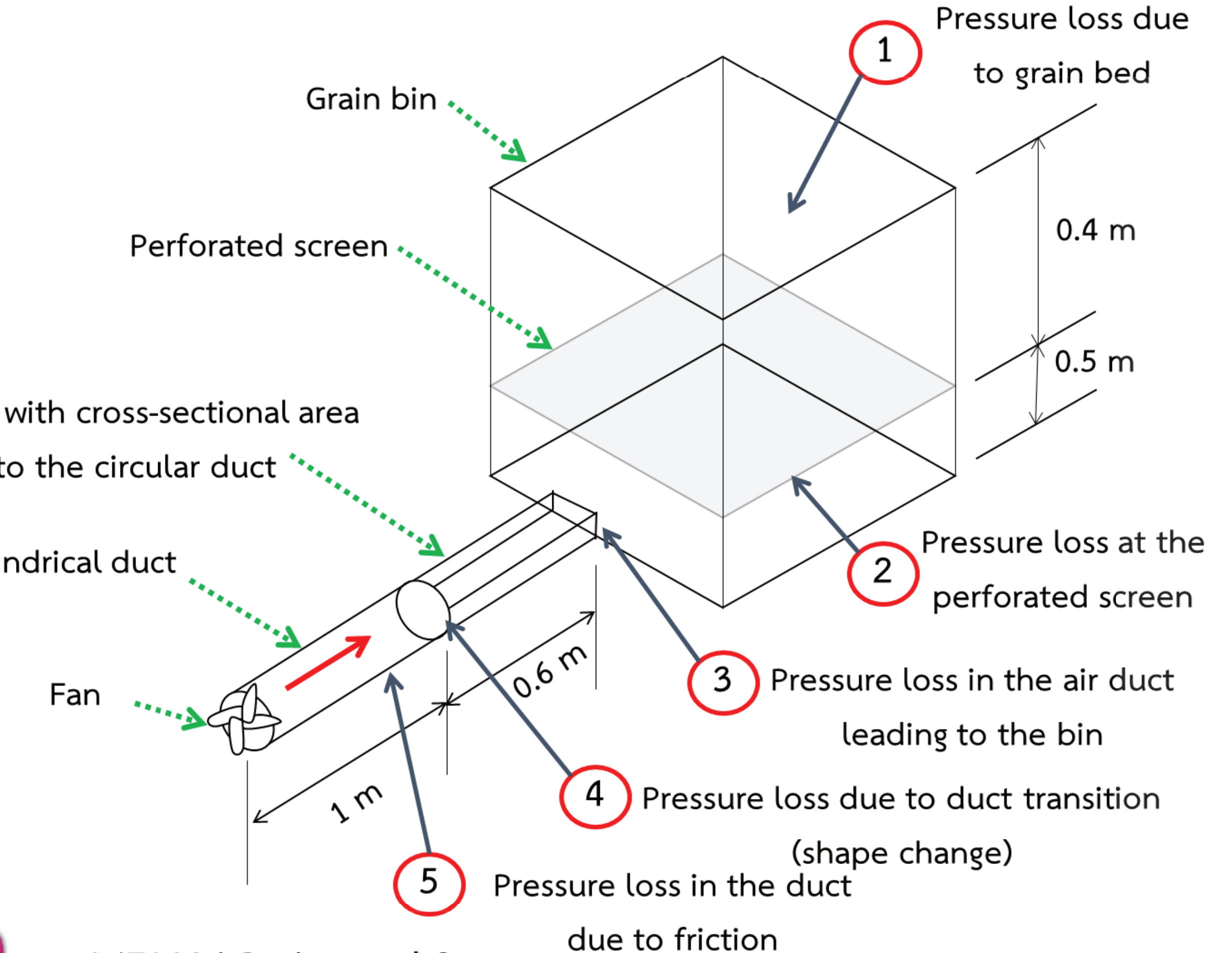
มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

- ✓ The chosen dryer must have a cost suitable for the dried product, ensuring a fast payback period
- ✓ Design must account for maintenance and the availability of replacement parts in the market
- ✓ Case Study (Heat Pump Dryer for Chrysanthemum): Initial investment: 150,000 Baht
  - Despite the high initial cost, selling the high-value dried product yielded an estimated payback period of just 3 months and 17 days

Example 1

Fan Horsepower Calculation

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University



Calculate the appropriate fan horse
for a bin dryer structure

Given Data:

- Capacity of corn: 5,000 kg
- Density: 550 $kg{\cdot}m^{-3}$
- Air velocity in duct: 15 $m{\cdot}s^{-1}$
- Inlet airflow rate range:
  30 - 40 $m^3{\cdot}(min^{-1}){\cdot}(m^{-3})_{bulk}$

Example 1 (Cont.)
Volume and Area Calculations

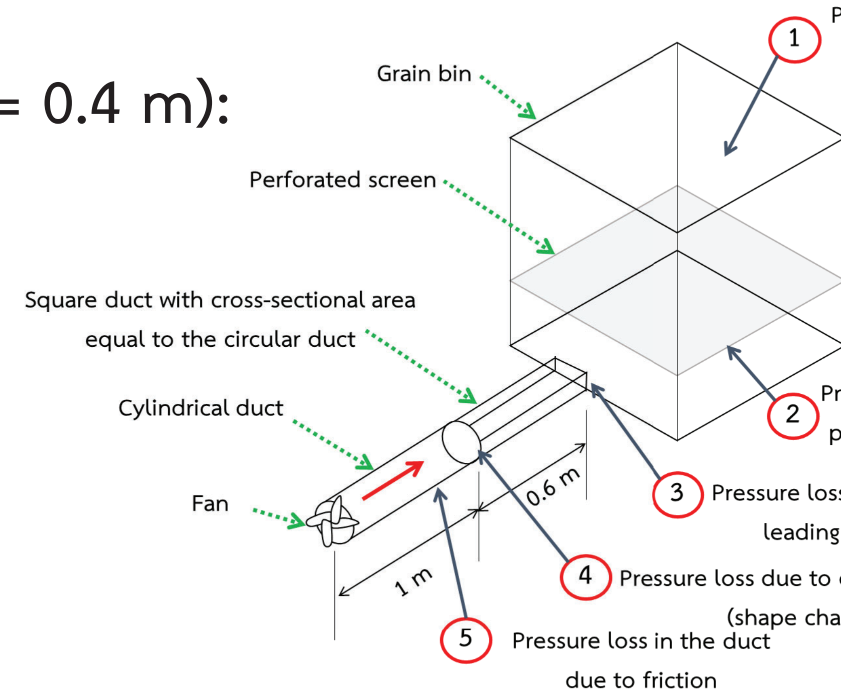
determine the physical volume and area required for the corn

ne of Corn:

$$V_{bulk} = \frac{m}{\rho} = \frac{5,000\,kg}{550\,\frac{kg}{(m^3)_{bulk}}} = 9.09\ (m^3)_{bulk}$$

-sectional Area of Bin (Assuming bed depth L = 0.4 m):

$$A = \frac{V_{bulk}}{L} = \frac{9.09\ (m^3)_{bulk}}{40\ cm} = 22.725\ m^2$$



มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

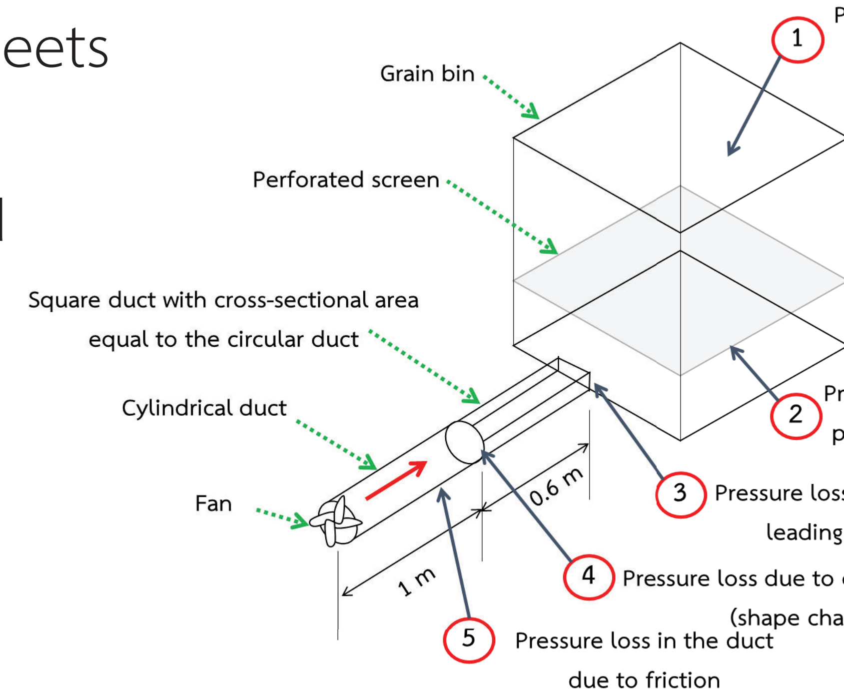
Example 1 (Cont.)

Number of Perforated Screen Sheets

ross-sectional area of the drying structure is used to determine the required of perforated screen sheets

the standard commercial size of a perforated sheet available on the market **× 2.438 m² (or 4 × 8 ft²),** the number of sheets required can be calculated ws: $22.725\ m^2 \div (1.219 \times 2.438\ m^2) = 7.646$ sheets

efore, approximately <u>8 sheets</u> must be purchased

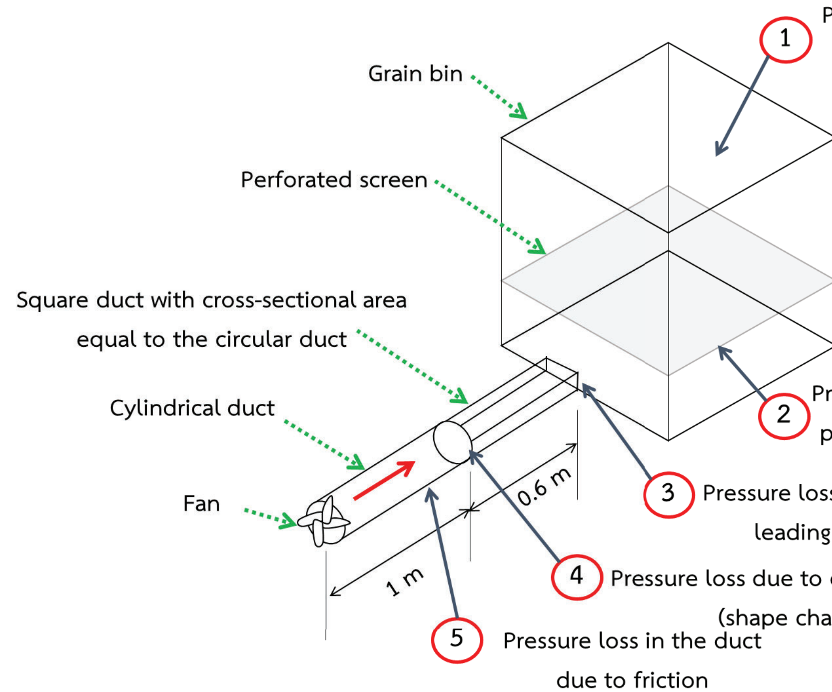


Example 1 (Cont.)
Required Airflow

ming that the approximate value is selected based on
nimum inlet airflow rate
g the minimum rate of 30 $m^3 \cdot (min^{-1}) \cdot (m^{-3})_{bulk}$

$$30\ m^3 \cdot (min^{-1}) \cdot (m^{-3})_{bulk} \times 9.09\ (m^3)_{bulk} = \underline{272.7\ m^3 \cdot (min^{-1})}$$

$$\boxed{V_{bulk} = \frac{m}{\rho} = \frac{5{,}000\,kg}{550\,\frac{kg}{(m^3)_{bulk}}} = 9.09\ (m^3)_{bulk}}$$



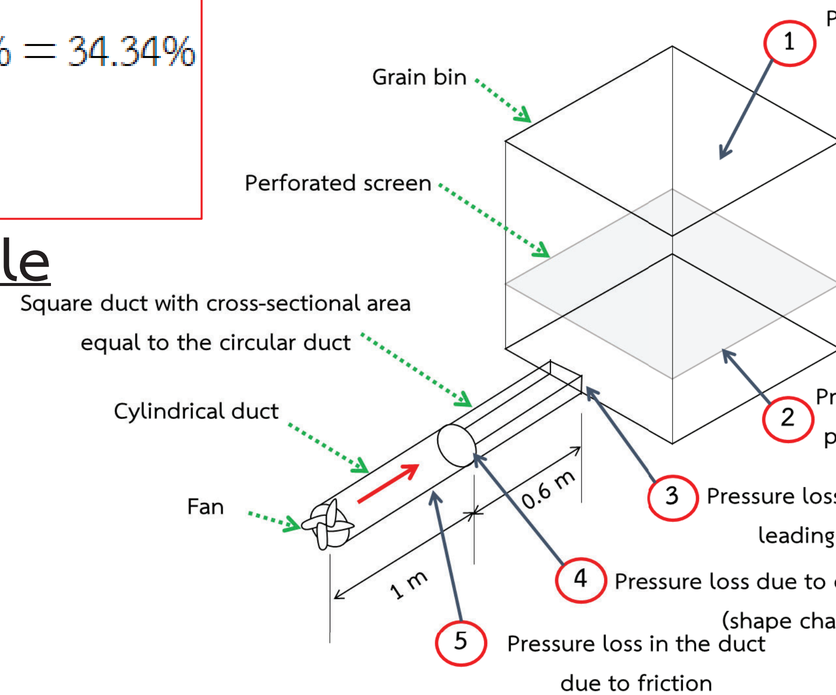
Example 1 (Cont.)
Screen Pressure Loss

en Pressure Loss: Standard screen (No. 14, 1.40 mm hole diameter) yields

en area ratio (O_f) **of 34.34%**

$$\frac{\textit{tal area of all holes}}{\textit{urface area of plate}} \times 100\% = \frac{\dfrac{\pi \times (1.4\ mm)^2 \times 144\ \dfrac{hole}{inch^2}}{4}}{\left(\dfrac{25.4 \times 25.4\ mm^2}{inch^2}\right)} \times 100\% = 34.34\%$$

O_f) **< 10%,** pressure loss at the screen is **negligible**



Example 1 (Cont.)
Duct Sizing

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

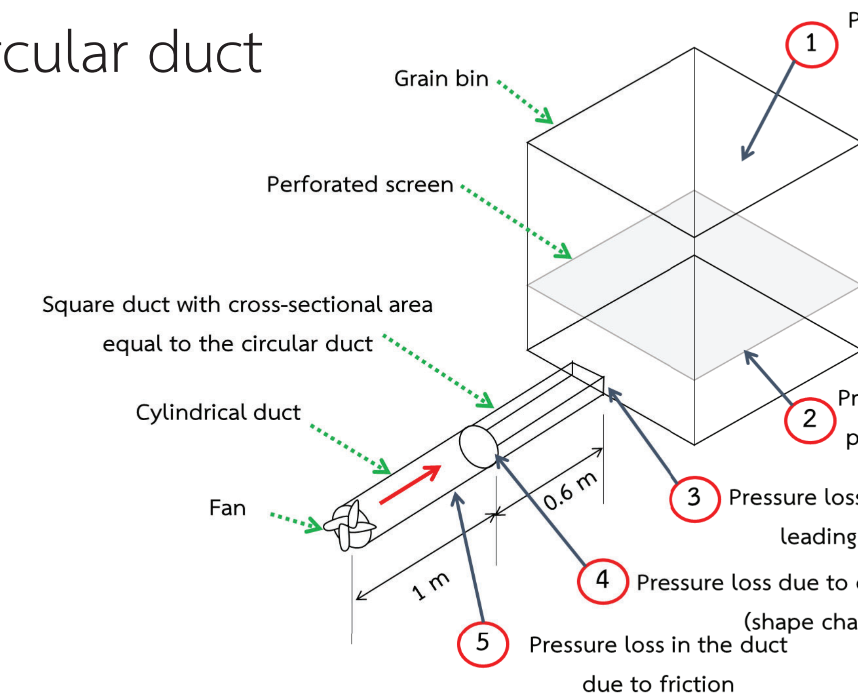
Dimensions:

$$A_{pipe} = \frac{Q_{air}}{V} = \frac{272.7 \frac{m^3}{min}}{15 \frac{m}{s}} = 0.303\ m^2$$

re duct with cross-sectional area **equal** to the circular duct

$$width = \sqrt{0.303\ m^2} = 0.55\ m$$

$$diameter = \sqrt{\frac{0.303\ m^2 \times 4}{\pi}} = 0.62\ m$$



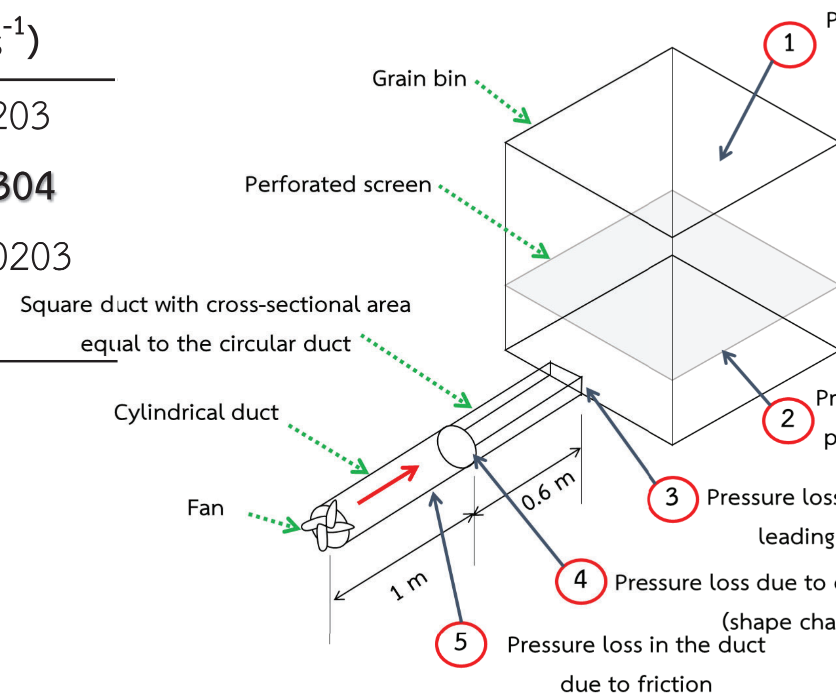
Example 1 (Cont.)
Total Static Pressure

ure Drops: Higher airflow rates result in significantly higher pressure drops across t
ed, duct transitions, and friction

ssure loss due to grain bed

$$\frac{aQ^2}{\ln(1+bQ)}$$

Grain	a (Pa·s²·m⁻³)	b (m²·s·m³)	Q (m³·m⁻²·s⁻¹)
Barley	2.14×10^4	13.2	0.0056-0.203
Shelled corn	**2.07×10^4**	**30.4**	**0.0056-0.304**
Shelled corn (low airflow)	9.77×10^3	8.55	0.00025-0.0203



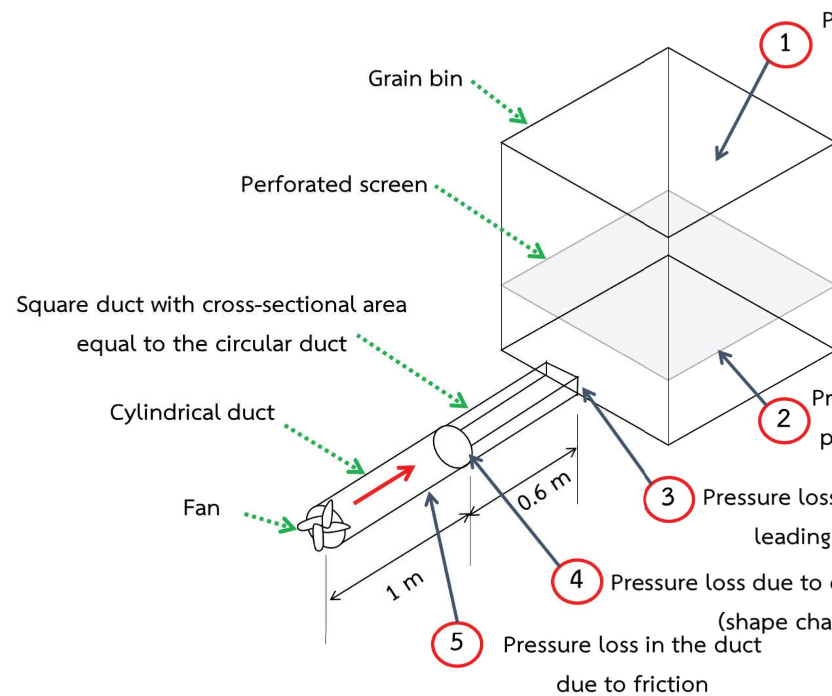
Example 1 (Cont.)
Total Static Pressure

ssure loss due to grain bed (Cont.)

sition 1, the airflow rate must be simulated within the range of $m^3 \cdot (min^{-1}) \cdot (m^{-3})_{bulk}$ based on a corn bed cross-sectional area of m^2 and a bed height of 0.40 m, respectively

$_r$ (s^{-1})	A (m^2)	Q ($m^3 \cdot m^{-2} \cdot s^{-1}$)	ΔP ($Pa \cdot m^{-1}$)	L (m)	ΔP (Pa)
60	22.725	0.165	314.06	0.40	125.62
60	22.725	0.220	491.20	0.40	196.48
60	22.725	0.275	699.97	0.40	279.99

high airflow rate in the system will result in a correspondingly essure loss



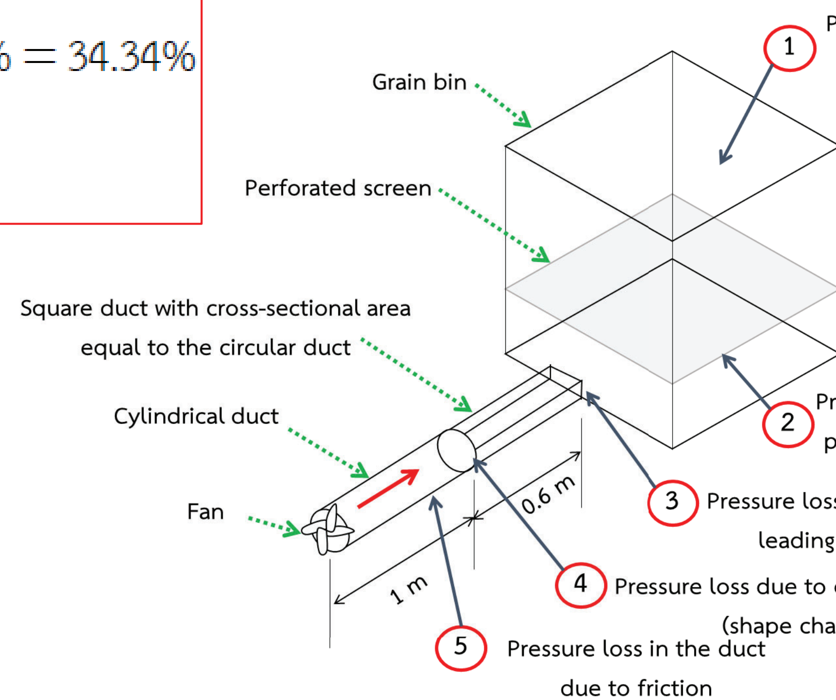
Example 1 (Cont.)

Total Static Pressure

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

ressure loss at perforated screen: Since (O_f) **< 10%,** pressure the screen is **<u>negligible</u>**

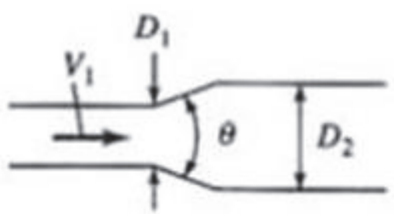
$$\frac{\textit{tal area of all holes}}{\textit{urface area of plate}}\times 100\% = \frac{\dfrac{\pi \times (1.4\ mm)^2 \times 144\ \dfrac{hole}{inch^2}}{4}}{\left(\dfrac{25.4\times 25.4\ mm^2}{inch^2}\right)}\times 100\% = 34.34\%$$



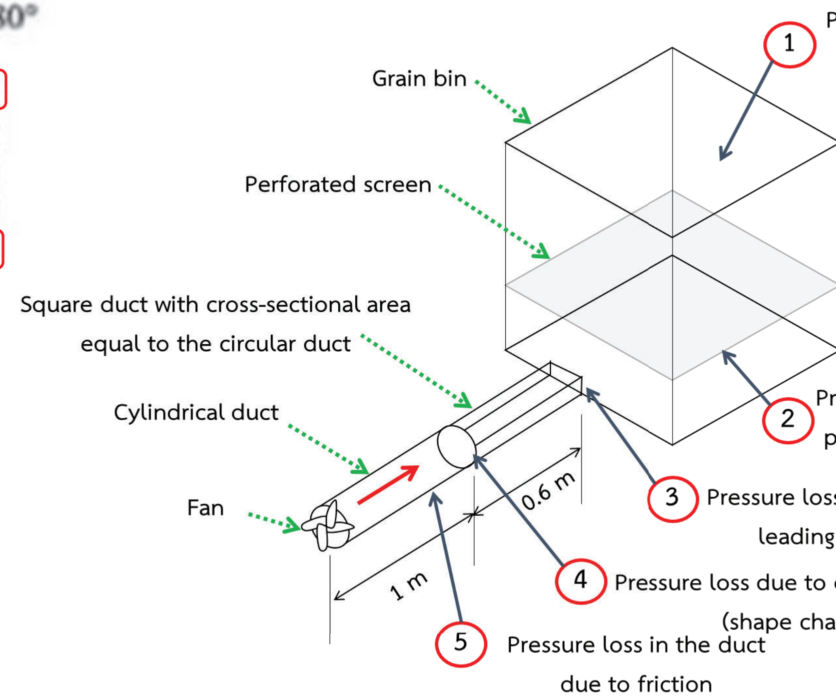
Example 1 (Cont.)
Total Static Pressure

ressure loss in the air duct leading to the bin & **4.** duct transition (shape change)

$$\Delta P = K\left(\frac{V}{1.29}\right)^2$$



D_1/D_2	K_E $\theta = 10°$	K_E $\theta = 180°$
0.0		1.00
0.20	0.13	0.92
0.40	0.11	0.72
0.60	0.06	0.42
0.80	0.03	0.16



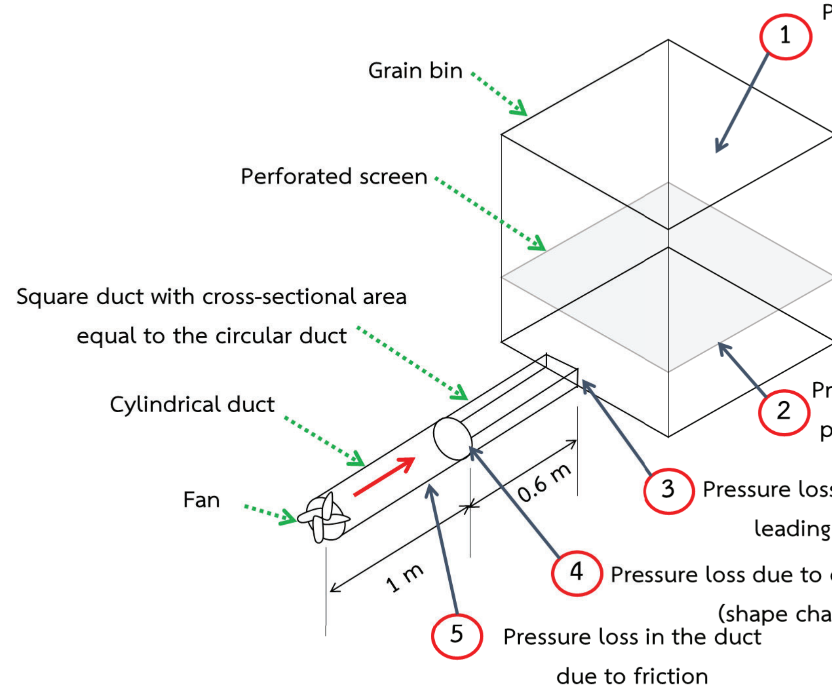
Example 1 (Cont.)
Total Static Pressure

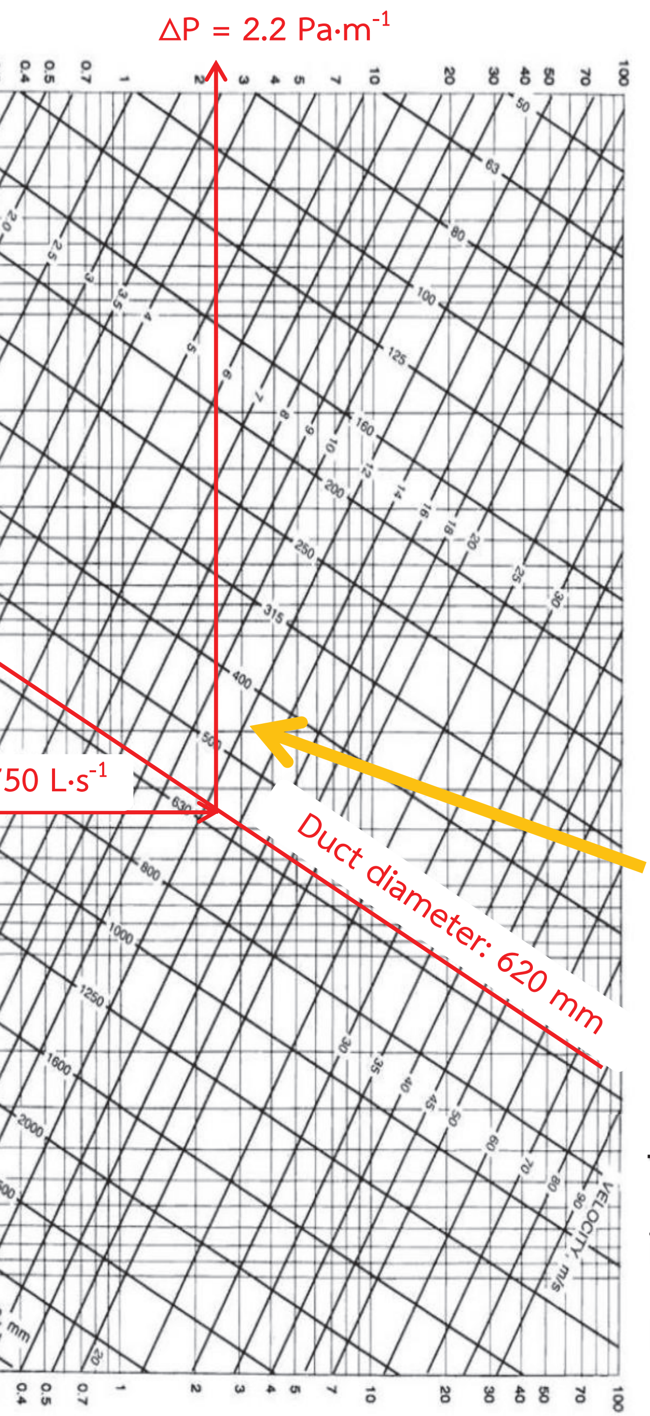
มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

ressure loss in the air duct leading to the bin & **4.** duct transition (shape change)

$$\Delta P = K\left(\frac{V}{1.29}\right)^2$$

Q_{air} (n^3·s^{-1})	A_{pipe} (m^2)	$V = Q_{air} / A_{pipe}$ (m·s^{-1})	ΔP (Pa) Position 3	ΔP (Pa) Position 4
3.75	0.303	12.38	92.04	14.73
5.00	0.303	16.50	163.63	26.18
6.25	0.303	20.63	255.68	40.91





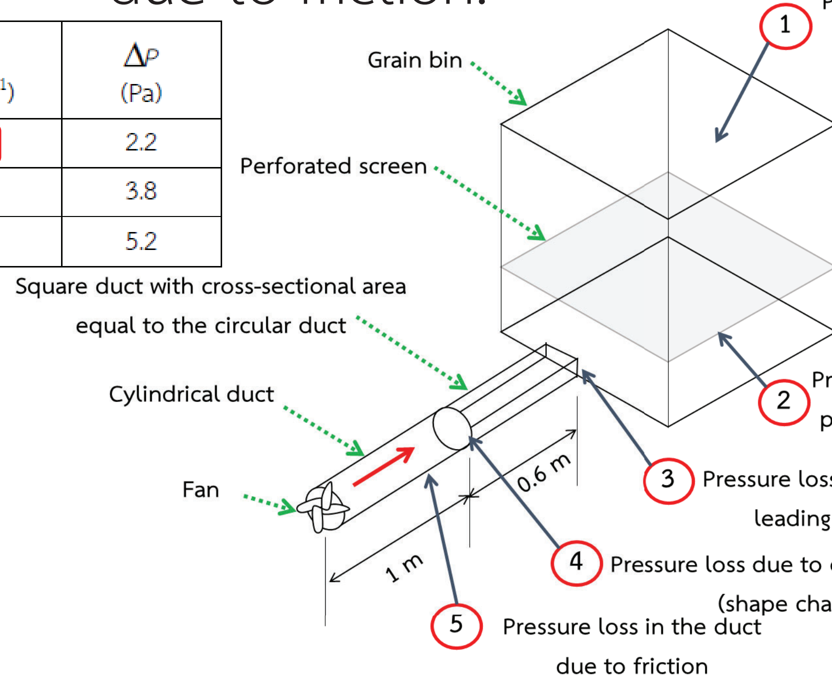
Example 1 (Con

Total Static Press

5. Pressure loss in the due to friction:

The duct has a diameter of 0.62 m and a length of 1 m

Q_{air} ($m^3 \cdot s^{-1}$)	A_{pipe} (m^2)	$V = Q_{air} / A_{pipe}$ ($m \cdot s^{-1}$)	ΔP ($Pa \cdot m^{-1}$)	ΔP (Pa)
3.75	0.303	12.38	2.2	2.2
5.00	0.303	16.50	3.8	3.8
6.25	0.303	20.63	5.2	5.2



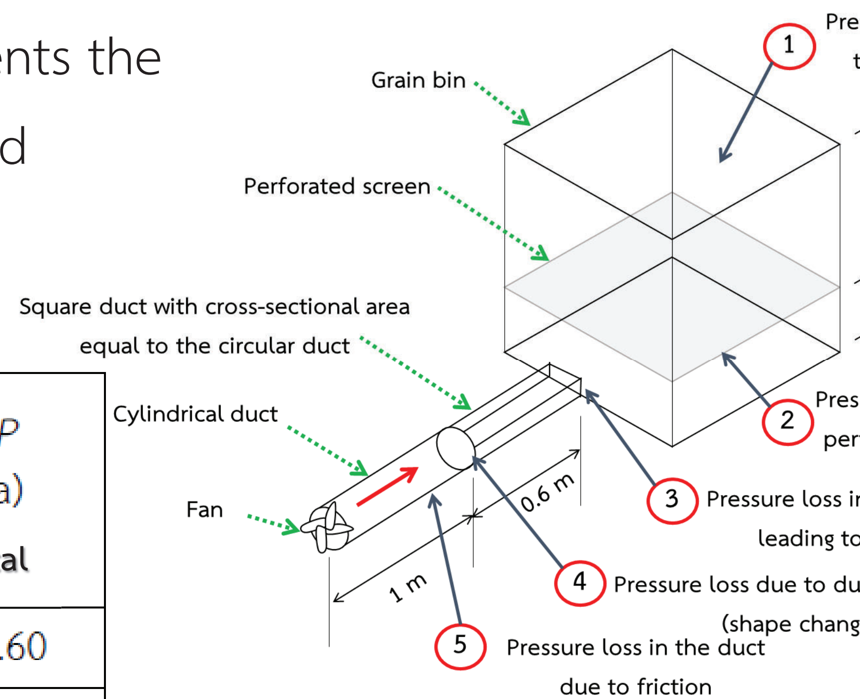
The pressure loss in the straight duct per 1 m length

References: Captiveair, n.d.

Example 1 (Cont.)
Total Static Pressure

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

al pressure loss is presented in the table, which represents the the pressure losses at positions 1–5 under the simulated range of 30–40 $m^3 \cdot (min^{-1}) \cdot (m^{-3})_{bulk}$



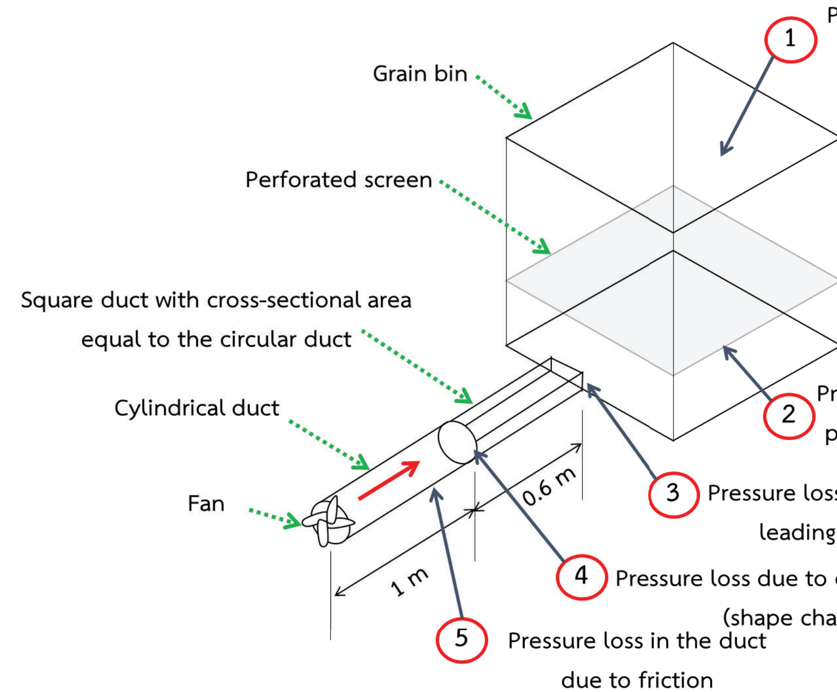
ΔP (Pa) Position 1	ΔP (Pa) Position 2	ΔP (Pa) Position 3	ΔP (Pa) Position 4	ΔP (Pa) Position 5	ΔP (Pa) Total
125.62	Negligible	92.04	14.73	2.2	234.60
196.48		163.63	26.18	3.8	390.10
279.99		255.68	40.91	5.2	581.77

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

Example 1 (Cont.)
The Static Pressure Loss

atic pressure loss can be calculated as the sum of
essure losses at <u>positions 1 and 5</u>

ΔP (Pa) ที่ตำแหน่ง 1	ΔP (Pa) ที่ตำแหน่ง 5	ΔP (Pa) ความดันสถิต
125.62	2.2	127.82
196.48	3.8	200.28
279.99	5.2	285.19



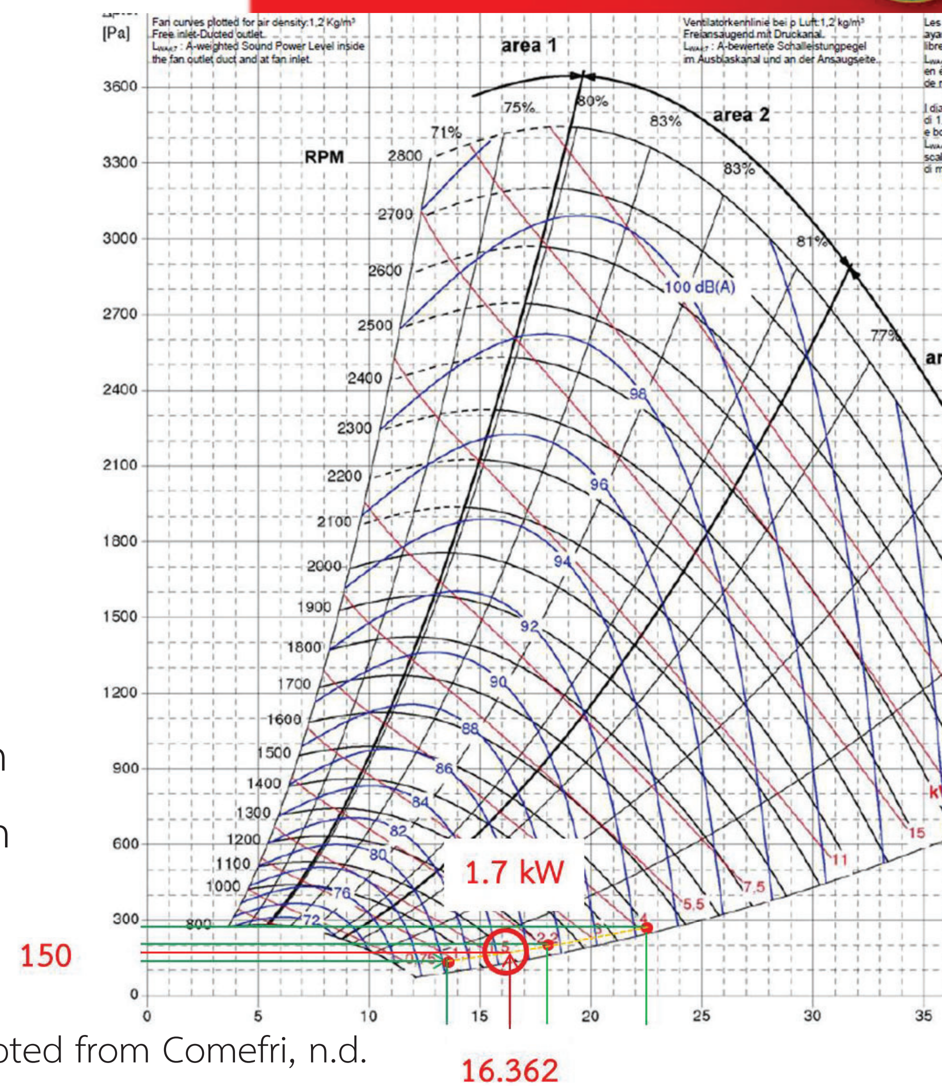
Example 1 (Cont.)

The Electrical Power of the Fan

tic pressure value is then used to determine **<u>the electrical</u>** of the fan, as shown in the figure

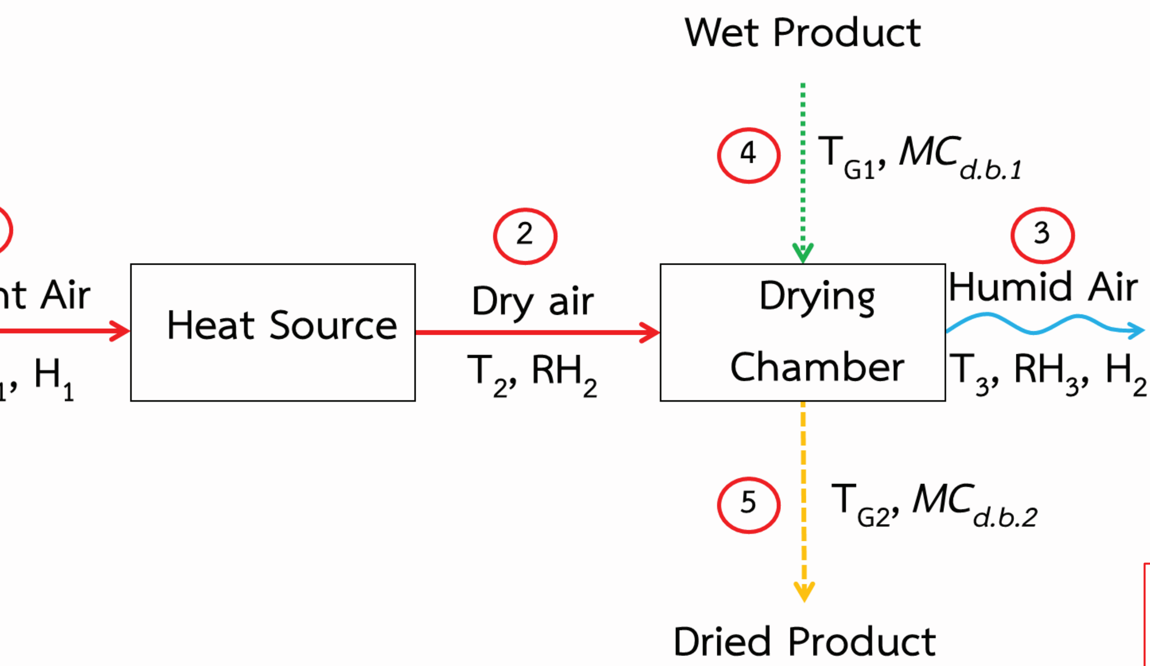
ΔP (Pa) ที่ตำแหน่ง 1	ΔP (Pa) ที่ตำแหน่ง 5	ΔP (Pa) ความดันสถิต	W_s (kW)
125.62	2.2	127.82	1.1
196.48	3.8	200.28	2.2
279.99	5.2	285.19	4.0

n inlet airflow rate of 30 $m^3 \cdot (min^{-1}) \cdot (m^{-3})_{bulk}$, as calculated the required electrical power can be determined as shown in re. The result indicates <u>a power requirement of 1.7 kW</u> with <u>onal speed of 1,100 rpm.</u>



References: Adapted from Comefri, n.d.

Calculation of Airflow, Heat, and Fuel



Total Heat Required (q_t):

$$q_t = m_{dry\ air} \times c_h \times (T_2 - $$

$$c_h = c_d + (c_v \times H_1)$$

$$\boxed{q_t = m_{dry\ air} \times \left[c_d + (c_v \cdot H_1) \right] \times (T_2 -}$$

the mass flow rate of dry air or airflow rate $(kg^{-1})_{dry\ air} \cdot h^{-1}$

specific heat of humid air $(kJ \cdot (kg^{-1})_{dry\ air} \cdot °C)$

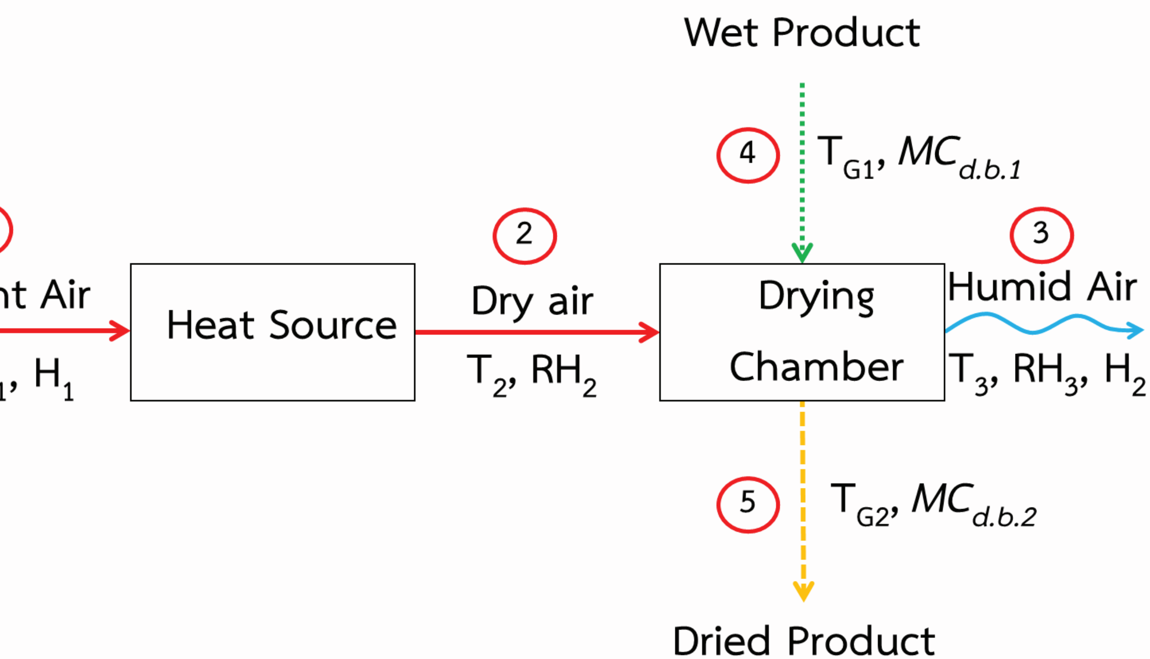
specific heat of dry air $(kJ \cdot (kg^{-1})_{dry\ air} \cdot °C)$, which has an approximate value of 1.01 $kJ \cdot (kg^{-1})_{dry\ air} \cdot °C$

specific heat of water vapor $(kJ \cdot (kg^{-1})_{water} \cdot °C)$, which has an approximate value of 1.88 $kJ \cdot (kg^{-1})_{water} \cdot °C$

rying time (h)

References: Prommas et al., 2010, p.1,110;
Adapted from Dincer & Sahin, 2004, p.647

Calculation of Airflow, Heat, and Fuel



The heat used for water evaporation:

$$q_e = G_d \times \left(MC_{d.b.1} - MC_{d.b.2}\right) \times h_g$$

- **The sensible heat** is the amount of heat r to raise the temperature of the grains to the temperature of the drying chamber (T_{G2})
- **This amount of heat** can be calculated us following equation:

$$q_s = \left(G_d \times c_d \times \left(T_{G2} - T_{G1}\right)\right) + \left(G_d \times c_w \times \left(T_{G2} - T_{G1}\right) \times\right.$$

$$q_t = q_e + q_s$$

lry mass of the material (kg)

atent heat of vaporization of water (kJ· (kg^{-1})) = 2,280 kJ· (kg^{-1})

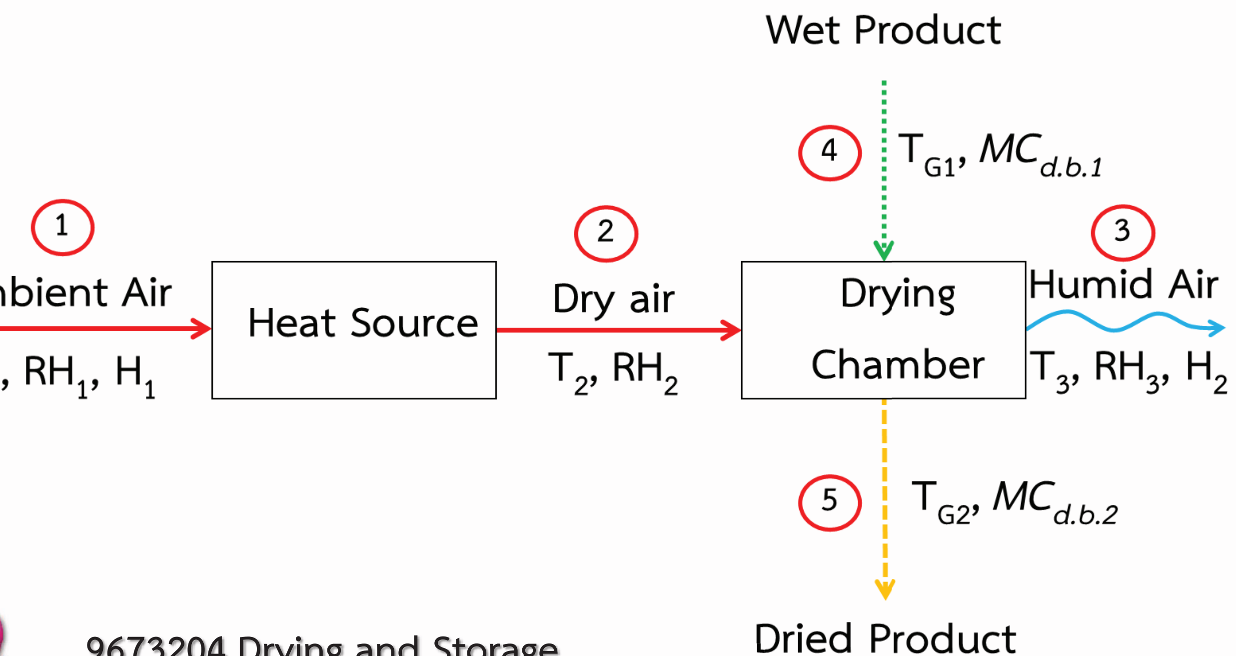
pecific heat of water (kJ· (kg^{-1})·°C) = 4.19 kJ· (kg^{-1})·°C

References: Prommas et al., 2010, p.1,110

Calculation of Airflow, Heat, and Fuel

quired mass flow rate of dry air, or airflow rate, can be
ned from the following equation:

$$\frac{(G_d h_g (MC_{d.b.1} - MC_{d.b.2})) + (G_d c_d (T_{G2} - T_{G1})) + (G_d c_w MC_{d.b.1} (T_{G2} - T_{G1}))}{(c_d + (c_v H_1))(T_2 - T_1)t}$$



มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

In cases where drying reli
fuel energy, the fuel consum
rate (F, kg·h^{-1}) can be calculat
from the following equation:

$$F = \frac{q_t}{\eta \eta_e c_f}$$

η is the thermal efficiency of the heatin

η_e is the thermal efficiency of the heat e

c_f is the heating value of the fuel (kJ· (kg^{-1})

References: Prommas et al., 2010, p.1,110

Example 2

paddy rice at 60°C. Air is blown into the drying chamber at a mass flow rate of kg$_{dry\ air}$·(kg^{-1})$_{dry\ solid}$·s^{-1}, and the drying time is 20 h. Given that the dry mass of rice is 6 kg$_{dry\ solid}$, calculate the total heat supplied to the air. The ambient air tions are 30°C and 65% relative humidity.

ept: The problem states that the air has a temperature of 30°C and a relative dity of 65%. By plotting these values on the psychrometric chart, the ponding humidity ratio can be obtained (H) = 0.0175 kg$_{water}$·(kg^{-1})$_{dry\ air}$

irflow rate can be determined from the following equation:

$$\dot{m}_{dry\ air} = 0.052\ kg_{dry\ air}\cdot(kg^{-1})_{dry\ solid}\cdot s^{-1} \times 6\cdot kg_{dry\ solid} \times 3{,}600\ s\cdot h^{-1} = 1{,}123.2\ kg_{dry\ air}\cdot h^{-1}$$

otal heat supplied to the air can be calculated from the following equation:

$$q_t = 1{,}123.2 \times \left[1.01 + \left(1.88 \times 0.0175\right)\right] \times \left(60 - 35\right) \times 20 = 585.69$$

Summary

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

1. Basic dryer design calculations involve selecting duct size, fan size, require
airflow, electrical power, and heat quantity.

2. Selecting a fan with excessively high airflow may not be beneficial due to t
high pressure losses generated across different system parts (e.g., grain bed, duc
screens).

3. In practical operations, other factors such as initial moisture content and th
specific type of agricultural product must also be considered.

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

Thank you very much for your kind attention.

Questions?

mail: chukiat@webmail.npru.ac.th

Office: ETB 101 - Industrial Education, Faculty of Science and Technology

Study Questions – Lecture 8

What factors must be considered when selecting a dryer?

How is airflow rate determined in bulk drying?

What components contribute to total pressure loss?

How is fan power calculated?

What are the main components of heat energy in drying systems?

Assignment – Lecture 8

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

1. When drying cereal grains, ambient air (15.6°C, 70% RH) is heated to 26.6°C. A fan supplies an airflow of 0.4 $m^3 \cdot min^{-1}$ into the drying chamber for 8 h. If the dry weight of the cereal grains is 8 $kg_{dry\ solid}$, calculate the required thermal values.

2. Calculate the appropriate fan horsepower for the structure in Example 1, given 6,000 kg of paddy (bulk density 750 $kg \cdot m^{-3}$) in a bin, a duct air velocity of 10 $m \cdot s^{-1}$, and an inlet airflow of 20 - 30 $m^3 \cdot (min^{-1}) \cdot (m^{-3})_{bulk}$

3. Based on your calculation in Question 2, compare the fan horsepower with Example 1 and explain the reasons for the differences.

มหาวิทยาลัยราชภัฏนครปฐม
Nakhon Pathom Rajabhat University

References

Captiveaire. (n.d.). **Designing air flow systems**. Retrieved April 3, 2022, from ttp://www.captiveaire.com/manuals/airsystemdesign/designairsystems.htm

Comefri. (n.d.). **Double inlet centrifugal fans with backward curved blades**. Retrieved une 19, 2022, from http://www.comefri.com/sitoweb/images/catalogues/AMCA_C-0077_NTHZ_03-15.pdf

Dincer, I. & Sahin, A. Z. (2004). "A new model for thermodynamic analysis of a drying rocess." **International Journal of Heat and Mass Transfer**, 47 (4), 645-652.

Prommas, R., Keangin, P. & Rattanadecho, P. (2010). "Energy and exergy analyses in onvective drying process of multi-layered porous packed bed." **International Communications in Heat and Mass Transfer**, 37 (8), 1106-1114.

มหาวิทยาลัยราชภัฏนครปฐม