Capacity building on dimensioning, design and operation of small-scale pneumatic dryers

Dr Marcelo Precoppe
Crop Postharvest Technologist | Food and Markets Department | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Background

The most suitable types of equipment available for drying cassava is a pneumatic dryer. State-of-the-art industrial pneumatic dryers are available and are used to process cassava in many tropical countries. However, in Africa, most cassava processing centres are small enterprises and their expansion have been constrained by the lack of a small-scale pneumatic dryer. The objective of this 30-days-long trip was to build capacity on an equipment manufacturer in Ghana on how to dimension, design and install small-scale pneumatic dryers. The activities were in cooperation with the Food Research Institute (FRI) of the Council for Scientific and Industrial Research (CSIR) and supported by Cassava: Adding Value for Africa, Phase II (CAVAII), plus the CGIAR Research Program on Roots, Tubers and Banana (RTB). The participants were Hormeku Engineering Works, an equipment manufacturer, and Tropical Starch Company Limited, a processing centre.

Dryer dimensioning and design

The first activity on capacity building on dryer dimensioning and design was an introductory workshop about drying fundamentals. Table 1 shows the workshop syllabus and Appendix 1 shows a selection of the slides used.

Table 1 *Syllabus of the workshop "Drying fundamentals" held at Food Research Institute, CSIR, Ghana.*

Pneumatic dryers	**Burners**	**Heat exchangers**	**Feeders' hopper**
Main components Moisture content Energy consumption Throughput capacity	Fuel sources Heating power	Heat transfer area Double-pipe, multi-pipe and shell-and-tube heat exchangers Heating power	Solid flow properties Arching Ratholing

Feeding mechanism	**Blowers**	**Drying duct**	**Cyclone separator**
Solid mass flow rate Agglomeration Uniformity Types of feeders	Types of impellers Air mass flow rate Air velocity Pressure drop	Diameter Length Solid temperature and humidity Air temperature and humidity	Standard designs Collection efficiency Parallel installation Series installation Dust control

Following the introductory workshop, the first step on dimensioning the dryer was to investigate the processing centres' desired throughput capacity. Several processing centres in Ghana were contacted and it was concluded that most of them use flatbed dryers, processing on average, 250 kg of fresh roots per hour. A workshop was thereafter, conducted helping participants to learn how to determine the correct drying conditions and the right dimensions of the drying duct. Calculation steps are shown in Appendix 2 and the results presented in Table 2.

Table 2 *Results from calculating drying conditions and dimensioning the drying duct.*

Wet solid feeding rate	**Wet solid moisture**	**Dried solid moisture**	**Water evaporation rate**
125.00 kg/h	40% (wet basis)	12% (wet basis)	39.77 kg/h

Drying air mass flow rate	**Heat input**	**Air enthalpy at dryer inlet**	**Air temperature at dryer inlet**
767.81 kg/h	195.67 MJ/h (54.35 kW)	254.84 kJ/kg	208.00 °C

Air volume flow rate	**Drying duct diameter**	**Residence time**	**Length of the drying duct**
802.08 m³/h	0.1883 m	2.48 seconds	17.37 m

After calculating the drying conditions and the size of the drying duct, it was possible to dimension the cyclone. Different cyclone standards were used for the calculations and thereafter selected based on their predicted collecting efficiency, but also considering the predicted pressure drop (Table 3). Calculation steps are presented in Appendix 3. The Stairmand standard design was chosen and its dimensions are shown in Figure 1.

Table 3 *Predicted collecting efficiency and pressure drop for different cyclone standards.*

Cyclone design standard	Predicted collecting efficiency (%)	Predicted pressure drop (Pa)
Stairmand HE	86.2	170
Lapple LE	86.1	150
Swift LE	86.1	150
Peterson/Whitby LE	85.8	160
Swift HE	85.4	160

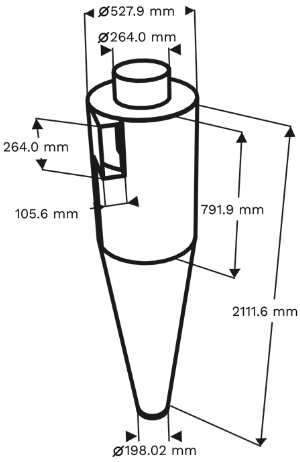


Figure 1 *Results from dimensioning the cyclone using the Stairmand standard.*

The next step was to dimension the blower. Appendix 4 shows a selection of the slides used in the workshop “Fan design fundamentals”. To make calculations easier, several online resources were used, as shown in Appendix 5. Figure 2 shows the obtained blower design.

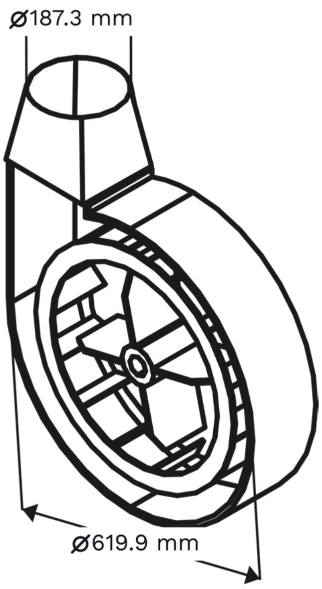


Figure 2 *Results from dimensioning the blower.*

For the feeder, a workshop was held explaining the main steps on how to design it. Some of the slides used are shown in Appendix 6. Design of feeders requires laboratory analysis of the wet solid properties, for this reason, this task was carried out in the UK by the Department of Chemical Engineering, with the support from The Wolfson Centre for Bulk Solids Handling Technology, both at the University of Greenwich. Figure 3 shows the obtained design.

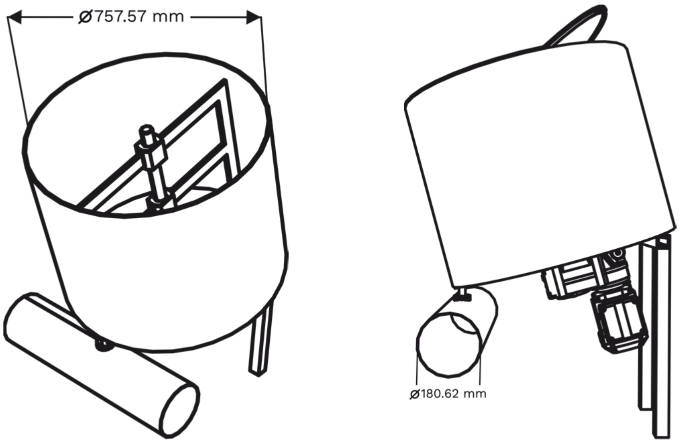


Figure 3 *Feeder designed by the Department of Chemical Engineering, with the support from The Wolfson Centre for Bulk Solids Handling Technology, University of Greenwich.*

Because of time constraints, no workshop on the design of heat exchangers was held. Instead, Arnaud Chapuis and Michel Rivier, both from CIRAD, will design a suitable shell-and-tube heat exchanger and provide the drawings. After that, the heat exchanger will be built in November by Hormeku Engineering. In the meantime, a multi-pipe heat exchanger, that has been manufactured for another dryer, will be used (Figure 4).

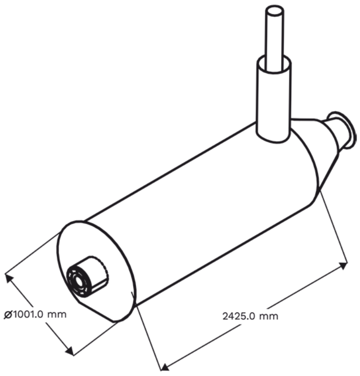


Figure 4 *Heat exchanger to be used while awaiting the design from CIRAD.*

Dryer construction

After dimensioning the dryer, the next step was choosing the construction material. All parts that contact with the drying solid will be manufactured using food-grade stainless steel. Effort was made to keep the cost low, and to use locally available resources. Table 4 shows the expected material cost, and Table 5 shows the expected manufacturing cost. Combined, the total cost is USD 11,825.00, but it does not include the heat exchanger. Final cost is expected to be USD 15,000.

Table 4 *Material cost for the construction of the pneumatic dryer (heat exchanger not included).*

Material	Quantity	Unit price (USD)	Total price (USD)
1 mm food grade stainless steel plate	6	180.00	1,080.00
2 mm food grade stainless steel plate	8	290.00	2,320.00
6 mm food grade stainless steel plate	1	880.00	880.00
6 mm low-carbon steel plate	2	90.00	180.00
1.5 mm low-carbon steel plate	3	30.00	90.00
70x70x6 mm angle iron	2	50.00	100.00
50x50x3 mm square pipe	2	30.00	60.00
60 mm stainless steel shaft	1	260.00	260.0
50 mm bearing	2	250.00	500.00
0.8 mm aluminium sheet	3	350.00	1,050.00
15 HP motor	1	380.00	380.00
1 HP geared motor	1	170.00	170.00
Diesel burner	1	1,250.00	1,250.00
Control box	1	315.00	315.00
50 mm mineral wool roll	7	40.00	280.00
		TOTAL	8,915.00

Table 5 *Manufacturing cost of the pneumatic dryer (heat exchanger not included).*

Material	Quantity	Unit price (USD)	Total price (USD)
Argon gas (tank)	2	270.00	540.00
Filler rod (package)	1	125.00	125.00
Cutting disc (unit)	10	3.00	30.00
Gasoline (litres)	10	5.00	50.00
Grinding disc (unit)	5	3.00	15.00
Paint (litres)	10	15.00	150.00
Workmanship (hours)	400	5.00	2,000.00
		TOTAL	2,910.00

Dryer installation

A visit was made to Tropical Starch, the processing centre where the dryer will be installed. Measurements of the building were taken, and it was agreed where to place the equipment. However, it was observed that the height of the roof was low, making not possible to fit the dryer inside the building. A common solution would be to make an opening through the ceiling for the drying duct to pass. However, this would require a loading crane for its installation. The availability and cost of renting such lifting equipment were investigated. It was concluded not to be feasible, particularly on regions far from Accra. The dryer was therefore redesigned, and the drying duct segmented, allowing it to be installed inside the building, without the need for a lifting equipment. Figure 5 shows the building where the dryer will be installed at Tropical Starch and Figure 6 shows the segmented drying duct, that allows assembly without a crane.

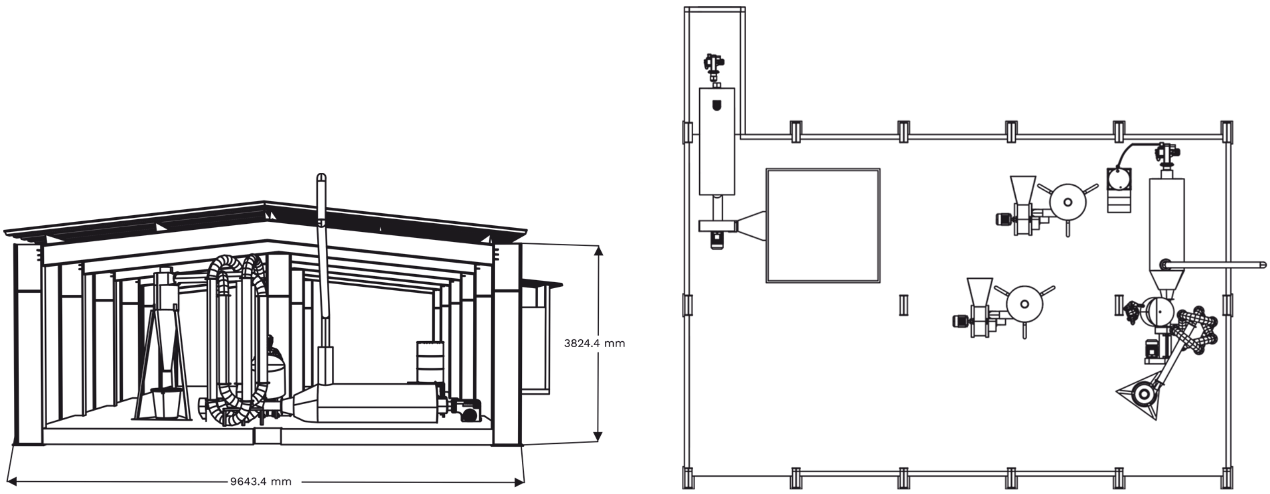


Figure 5 *Building at Tropical Starch where the dryer will be installed.*

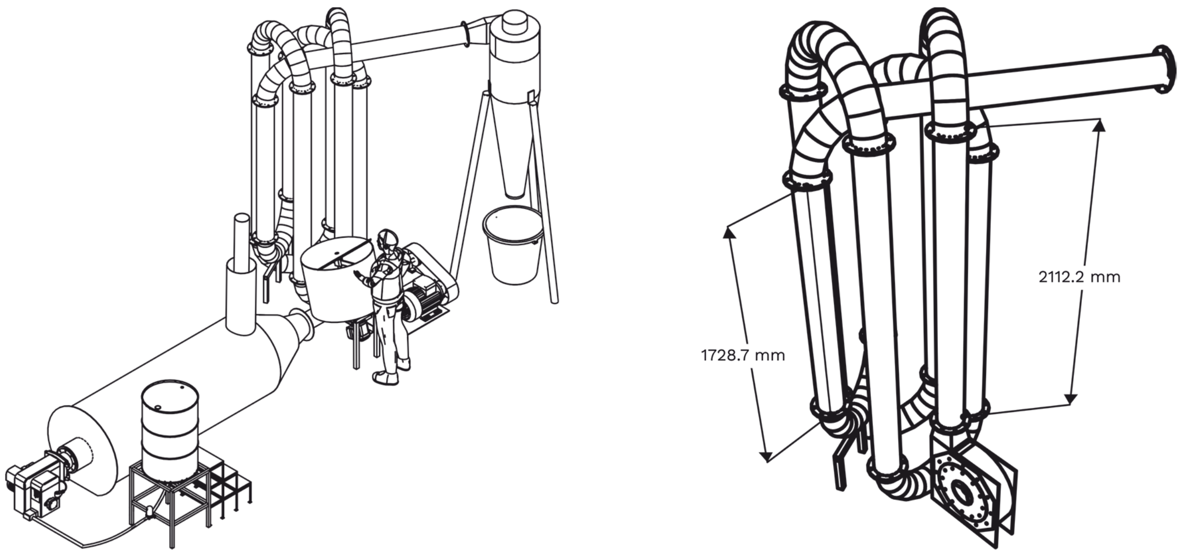


Figure 6 *Pneumatic dryer designed with a segmented drying duct for easy installation.*

For thermal insulation, to reduce costs, instead of covering each section of the drying duct with mineral wool, it was decided to use one single cover, as shown in Figure 7.

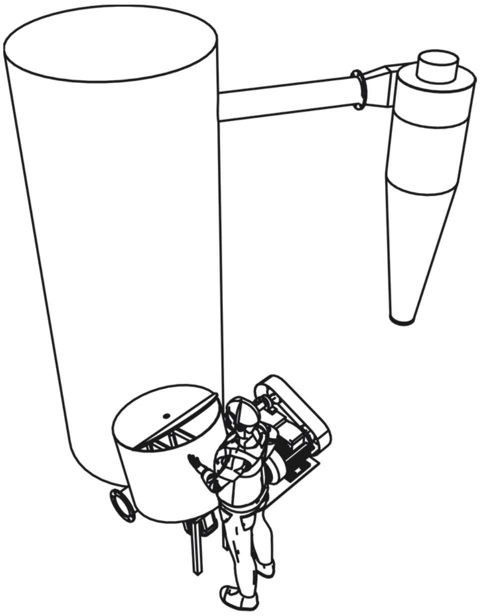


Figure 7 *Drying duct insulated with a single cover of mineral wool, shield by an aluminium sheet.*

Wrap-up and follow-up activities

A presentation summarizing the capacity building activities done and describing the next steps was made at the Food Research Institute. The presentation was attended by the CAVAII directors who have travelled to Ghana. It included a processing centre virtual tour, that can be watched in Appendix 7 (Adobe Flash Player required).

Figure 8 *Presentation summarizing the capacity building activities on dimensioning, design, and installation of pneumatic dryers.*

At the time of writing, the dryer is being manufactured at Hormeku Engineering. In October, it will be installed at Tropical Starch and in November, the users will be trained, plus the dryer will be troubleshot. The schedule of the follow-up activities is shown in Table 6. The final report will be delivered in December 2018.

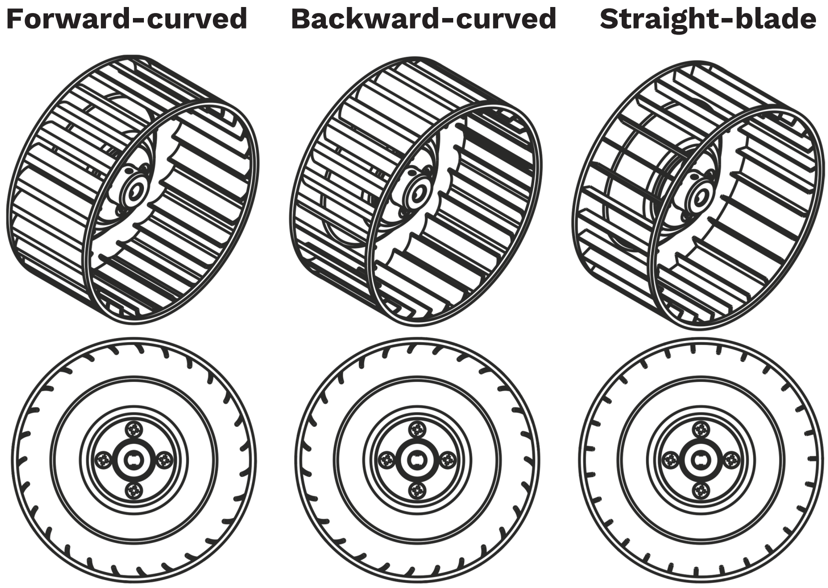
Table 6 *Schedule of the follow-up activities.*

Activities	September 2018				October 2018				November 2018			
Dryer construction	■	■	■	■								
Dryer installation					■	■	■	■				
User’s training									■	■	■	
Troubleshooting										■	■	■

Appendix 1

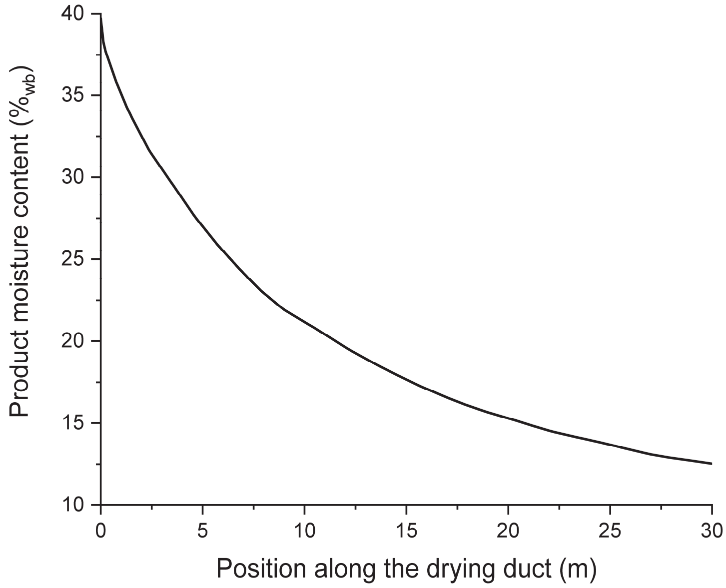
UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Blower



UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Drying duct

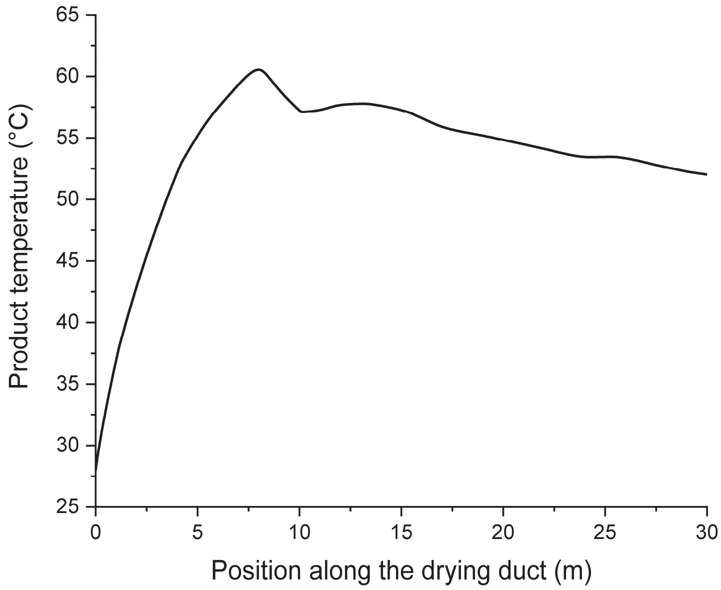


Appendix 1

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Drying duct

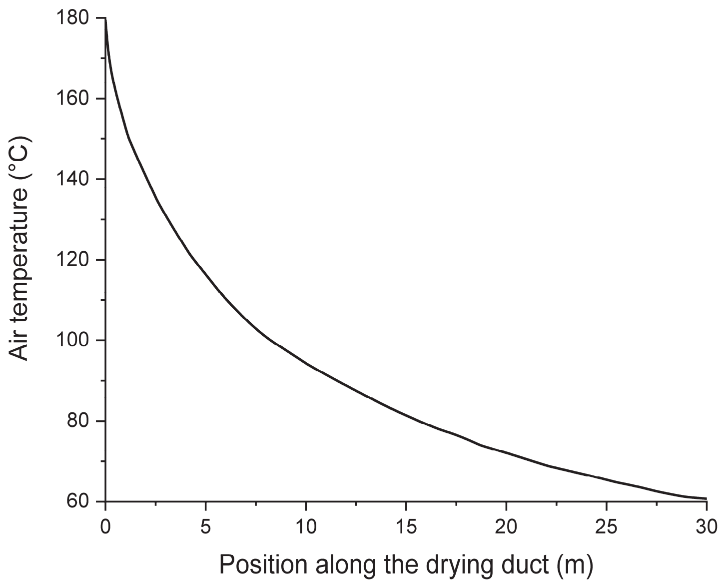


3

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Drying duct



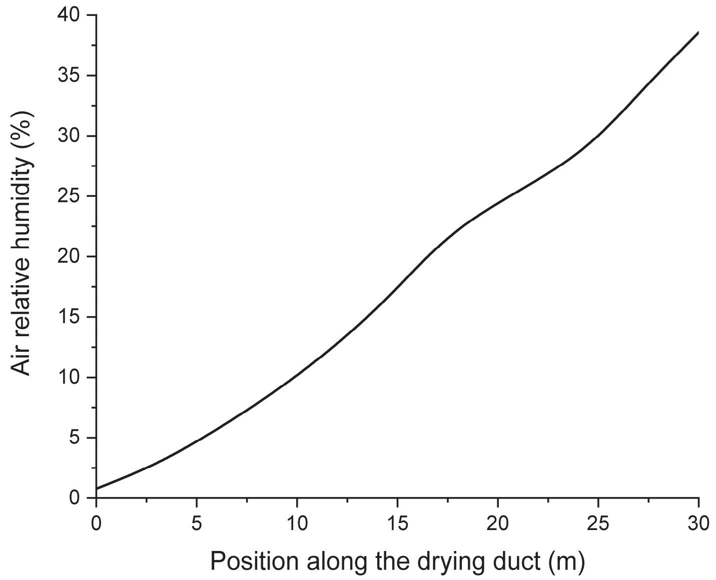
4

Appendix 1

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Drying duct



UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Cyclone separator

- Efficiency of parallel cyclones

Configuration	Efficiency, %
Individual cyclone	96.0
Seven cyclones in parallel (individual hoppers)	95.3
Seven cyclones in parallel (common hopper)	94.1
Fourteen cyclones in parallel (common hopper)	92.2

Source: Koffman (1953)

Appendix 2

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Design of small-scale pneumatic dryers for cassava processing

Dr Marcelo Precoppe | Crop Postharvest Technologist | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Determine the capacity of the processing centre:
Make sure the equipment is of suitable capacity to the user

Calculate the wet solid feeding rate:
Considering the capacity of the processing centre:
Mws=**125 kg/h**

Determine with the user the moisture content (wet basis) of the wet solid:
MCws=**40%**

Determine with the user the moisture content (wb) of the dried solid:
MCds=**12%**

Convert wet solid moisture content from wet basis to dry basis:
Xws=MCws/(100-MCws)
Xws=**0.66666666666667 kg/kg**

Convert dried solid moisture from wet basis to dry basis:
Xds=MCds/(100-MCds)
Xds=**0.13636 kg/kg**

Calculate the dry matter mass flow rate:
Mdm=Mws-(Mws*MCws)
Mdm=**75 kg/h**

Calculate dried solid mass flow rate:
Mds=Mdm+(Xds*Mdm)
Mds=**85.2273 kg/h**

Calculate water evaporation rate:
Mw=Mdm*(Xws-Xds)
Mw=**39.7727 kg/h**

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 2

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Determine the ambient air absolute humidity:
Ambient Temperature: 30 °C
Ambient relative humidity: 60%
Yamb=**16.03 g/kg**

Determine dryer outlet absolute humidity:
Dryer outlet temperature: 60 °C
Dryer outlet relative humidity: 50%
Yout=**67.83 g/kg**

Determine the required air mass flow:
Mair=Mw/(Yout-Yamb)
Mair=**767.813 kg/h**

Calculate the energy needed to evaporate 39.7727 kg of water per hour:
Use 2.5 MJ/kg as latent heat of water vaporization, based on the cassava heat of sorption:
Qw=Mw*2.5
Qw= **99.4318 MJ/h**

Calculate the heat used to increase solid temperature:
Use cassava specific heat 4.40112 kJ/kg K:
Temperature of the wet solid: 23.90 °C
Temperature of the dried solid: 52 °C
Qts=Mdm*4.40112 *(Tds-Tws)
Qts=**9.27536 MJ/h**

Calculate the required heat input:
Multiply the result by 1.8 to account for other losses
Qin=(Qw+Qts)*1.8
Qin=**195.673 MJ/h**

Calculate the dryer inlet required air enthalpy:
Hin=Qin/Mair
Hin=**254.844 kJ/kg**

Determine dryer inlet air temperature:
Enthalpy should be 254.844 kJ/kg
Absolute humidity should be 16.03 g/kg
RHin=0.139%
Tin= **208 °C**

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 2

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Determine the absolute humidity of the air at the dryer outlet:

Dryer outlet temperature: 60 °C
Dryer outlet relative humidity: 50%
Yout=**67.83 g/kg**

Calculate the humid volume of the air at the dryer outlet:

Dryer outlet temperature (Tout): 60 °C
Absolute humidity of the air at the dryer outlet (Yout): 67.83 g/kg
VH=(0.00283+0.00456*Yout)*(273+Tout)
VH=**1.04463 m^3/kg**

Calculate the air volume flow rate:

Air mass flow rate (Mair): 767.813 kg/h
VL=Mair*VH
VL=**802.080 m^3/h**

Calculate the are of the drying duct:

Air velocity of the air at the drying duct (Vair): 8 m/
IA=(VL/Vair)/3600
IA=**0.027850 m^2**

Calculate the diameter of the drying duct:

ID=2*(SQRT(IA/PI))
ID= **0.18831 m**

Determine residence time:

Water evaporation rate (Mw): 39.7727 kg/h
RT=0.03917+0.03324*exp((Mw-2.56642)/8.65914)
RT=2.48104 seconds (required residence time to evaporate 39.7727 kg/h)

Calculate the required length to the drying duct:

Velocity of the solid in the drying duct (Vs): 7 m/s
Ldc=Vs*RT
Ldc=**17.3673 m**

The Queen's Anniversary Prizes
For Higher and Further Education
2015

FS 54723 ISO 9001

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 3

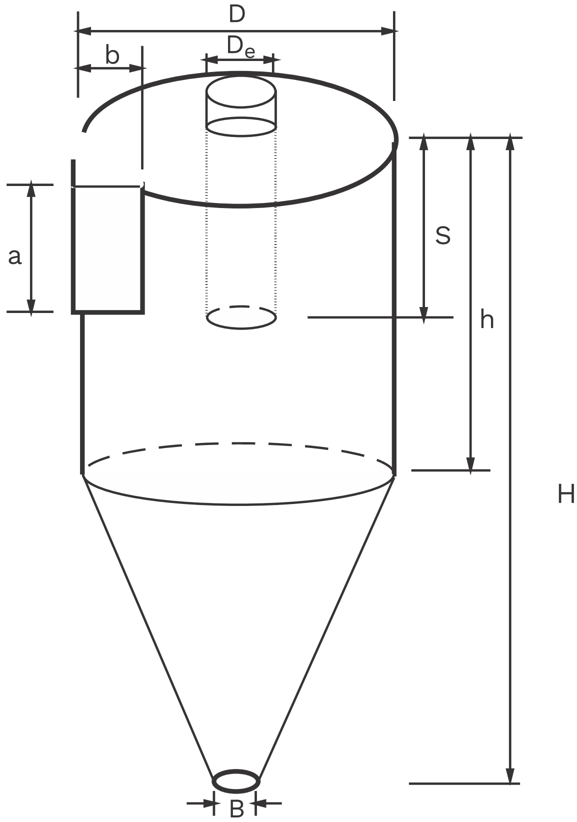
University of Greenwich
NRI | Natural Resources Institute

Design of small-scale pneumatic dryers for cassava processing

Dr Marcelo Precoppe | Crop Postharvest Technologist | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Calculate cyclone inlet area based on the dryer mass flow and air velocity:
Drying duct air volume flow rate: 802.08 m^3/h
Air velocity at the drying duct: 8m/s
IA=VL/(Vair*3600)
IA=**0.02785 m^2**

Calculate the diameter of the cyclone:
D=SQRT(IA/0.1)
D=**0.52773 m**



Calculate dimension 'a':
a=D/2
a=**0.26387 m**

Calculate dimension 'b':
bs=D*0.2
b=0.10555 m

Calculate dimension 'De':
De=D/2
De=0.26387 m

Calculate dimension 'S':
S=D/2
S=**0.26387 m**

Calculate dimension 'h':
h=D*1.5
h=**0.79160 m**

Calculate dimension 'H':
H=D*4
H=**2.11092 m**

Calculate dimension 'B':
B=D*0.375
B=**0.19790 m**

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

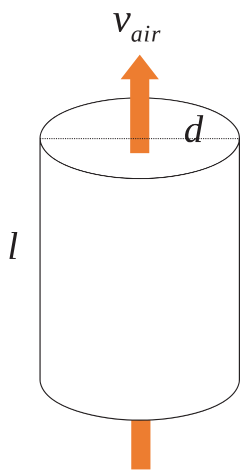
Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 4

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Pressure loss by air flow resistance

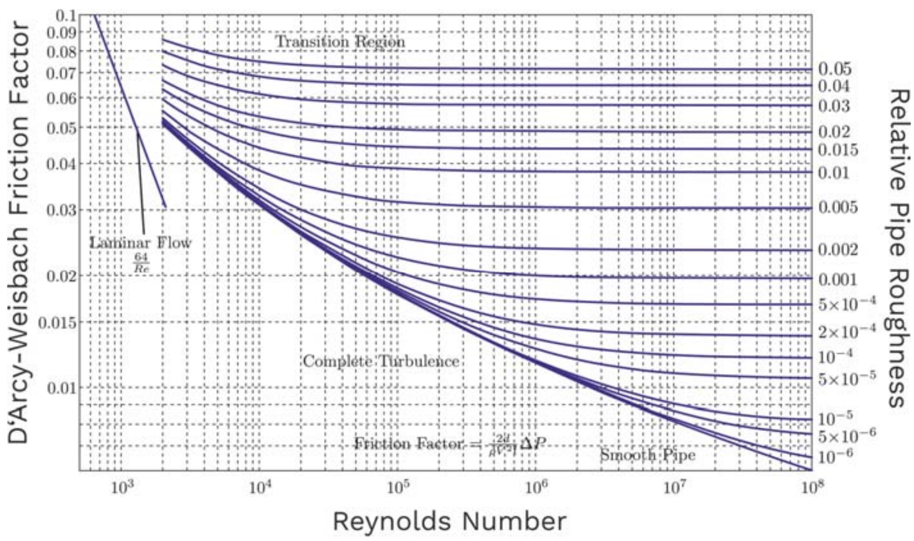
$$\Delta p = \lambda \cdot \frac{l}{d} \cdot \frac{\rho}{2} \cdot {v_{air}}^{2}$$



Δp	pressure loss
λ	D'Arcy-Weisbach friction factor
l	length of duct
d	hydraulic diameter
ρ	density of air
v_{air}	air velocity

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Moody diagram



Appendix 4

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Reynolds number

$$\mathrm{Re} = \frac{\rho \cdot v_{air} \cdot d}{\mu}$$

d	hyraulic diameter (m)
v_{air}	air velocity (m/s)
ρ	density of air (kg/m³)
μ	dynamic viscosity (Pa s)

$$\mathrm{Re} = \frac{v_{air} \cdot d}{\nu}$$

d	hyraulic diameter (m)
v_{air}	air velocity (m/s)
ν	kinematic viscosity (m²/s)

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Kinematic viscosity

$$\nu = 42.6 \cdot 10^{-10} \frac{T^{2/3}}{1 + \frac{123,6}{T}}$$

T temperature (°C)

Appendix 4

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Relative pipe roughness

$$RPR = \frac{\varepsilon}{l}$$

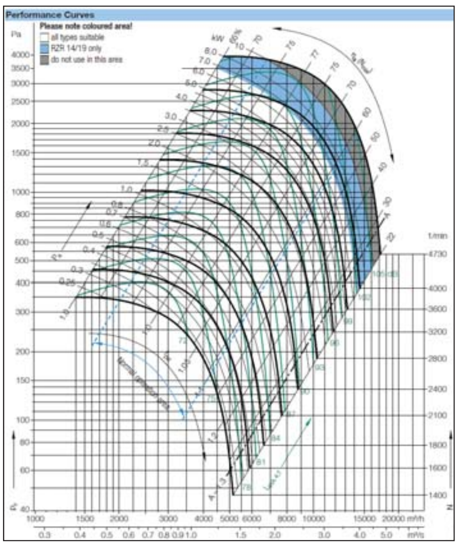
ε roughness of pipe

Material	ε (mm)
Concrete, coarse	0.25
Concrete, new smooth	0.025
Drawn tubing	0.0025
Glass, Plastic Perspex	0.0025
Iron, cast	0.15
Sewers, old	3.0
Steel, mortar lined	0.1
Steel, rusted	0.5
Steel, structural or forged	0.025
Water mains, old	1.0

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Fan performance curve



Appendix 5

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

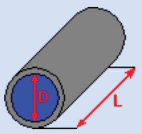
Design of small-scale pneumatic dryers for cassava processing

Dr Marcelo Precoppe | Crop Postharvest Technologist | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Calculate pressure loss at the heat exchanger:

Use the online pressure drop calculator: www.pressure-drop.com/Online-Calculator

Group: Straight pipes ▼ Subgroup: circular ▼



Diameter of pipe D: 40 mm ▼

Length of pipe L: 2 m ▼

Pipe roughness: 0.15 mm ▼

Flow medium: Air at 119 °C (Average: 30; 208)

Condition: ○ liquid ◉ gaseous

Mass flow: ▼ 19.195325 kg/h ▼

Mass flow of 767.813 kg/h divided between the 40 pipes: 19.195325 kg/h

Weight density: 0.87872 kg/m³ ▼

Density of the air at 119 °C (119 °C is the average between 30 °C and 208 °C)

Dynamic Viscosity: ▼ 22.74955 10-6 Pa s ▼

Calculate dynamic viscosity using the online calculator: www.peacesoftware.de/einigewerte/luft_e.html

Pressure: 1020 Millibar ▼

Temperature: 119 Celsius ▼

Dynamic viscosity :	22.74955	[10^{-6} (Pa s)]

Pressure (inlet, abs.):

1020 mbar ▼

Temperature (inlet):

30 °C ▼

Temperature (outlet):

208 °C ▼

Medway Campus

Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088

Web: www.nri.org

Appendix 5

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

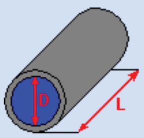
Pressure drop: 0.25 mbar

Pressure drop: 25 Pa per pipe
Number of pipes: 40
Pressure drop at the heat exchange: **1000 Pa** (25*40)

Calculate pressure loss at the straight section of the drying duct:

Use the online pressure drop calculator: www.pressure-drop.com/Online-Calculator

Group: Straight pipes ▼ Subgroup: circular ▼



Diameter of pipe D: 188.31 mm ▼
Length of pipe L: 17.3673 m ▼

Pipe roughness: 0.15 mm ▼

Flow medium: Air at 134 °C (Average: 208; 60)
Condition: liquid / gaseous (selected)

Mass flow: ▼ 767.813 kg/h ▼

Weight density: 0.84634 kg/m³ ▼

Density of the air at 134 °C (134 °C is the average between 208 °C and 60 °C)

Dynamic Viscosity: ▼ 23.38855 10-6 Pa s ▼

Calculate dynamic viscosity using the online calculator: www.peacesoftware.de/einigewerte/luft_e.html

Dynamic viscosity : 23.38855 [10^{-6} (Pa s)]

Pressure: 1020 Millibar ▼
Temperature: 134 Celsius ▼

Pressure (inlet, abs.):
1020 mbar ▼
Temperature (inlet):
208 °C ▼
Temperature (outlet):
60 °C ▼

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 5

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

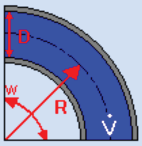
Pressure drop: 0.62 mbar

Pressure loss at the straight section of the drying duct: **62 Pa**

Calculate pressure loss at the bends of the drying duct:

Use the online pressure drop calculator: www.pressure-drop.com/Online-Calculator

Group: Bends Subgroup: Circular bend



Diameter of pipe D:	188.31	mm
Radius R:	192.31	mm
Angle w in degree:	180	

Very small radius, each section of the drying duct touching each other to reduce heat losses

Pipe roughness:	0.15	mm

Flow medium:	Air at 134 °C (Average: 208; 60)	
Condition:	liquid / gaseous (selected)	
Mass flow:	767.813	kg/h
Weight density:	0.84634	kg/m³
Dynamic Viscosity:	23.38855	10-6 Pa s

Pressure (inlet, abs.):	
1020	mbar
Temperature (inlet):	
208	°C
Temperature (outlet):	
60	°C

Pressure drop: 0.16 mbar

Pressure drop per 180° bend: 16 Pa
The dryer will probably have 2 bends of 180° and one bend of 90°
Pressure loss at the bends of the drying duct: **40 Pa** (16*2.5)

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 5

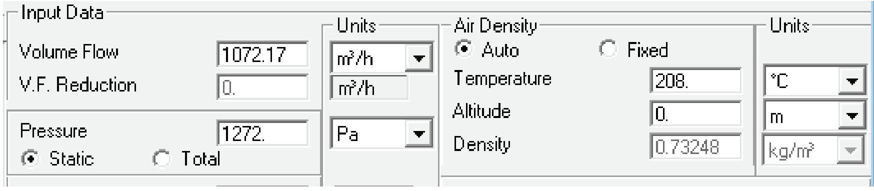
UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Calculate total pressure loss

Pressure loss at the heat exchange: 1000 Pa
Pressure loss at the straight section of the drying duct: 62 Pa
Pressure loss at the bends of the drying duct: 40 Pa
Pressure loss at the cyclone separator: 170 Pa
Total pressure loss: **1272 Pa**

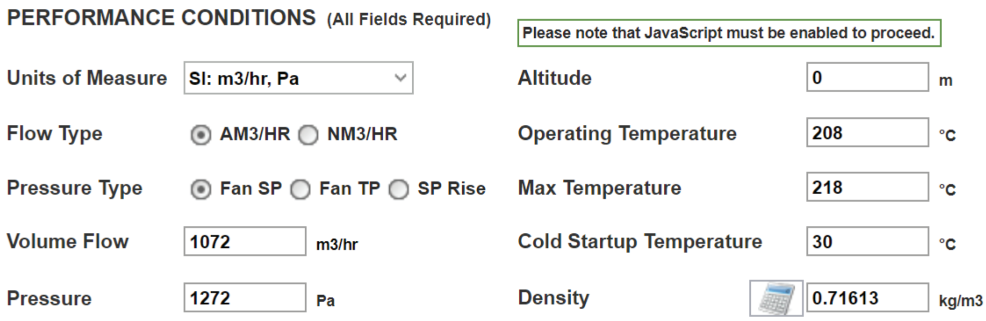
Select suitable blower design using the software Ventil

Download the software Ventil from: www.nicotra-gebhardt.com/images/content/Infocenter/proselecta/Ventil_330.zip



Select suitable blower design using the online tool from New York Blower

Go to: https://apps.nyb.com/FanToSize/ProductSelection.aspx



The Queen's Anniversary Prizes
For Higher and Further Education
2015

FS 54723 ISO 9001

Medway Campus
Central Avenue,
Chatham Maritime,
Kent ME4 4TB
United Kingdom

Tel: +44 (0)1634 880088
Web: www.nri.org

Appendix 6

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

- Hopper
- Feeding mechanism

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Determine material flow properties

- Cohesive Strength
- Wall friction
- Compressibility
- Density and porosity
- Particle shape and size

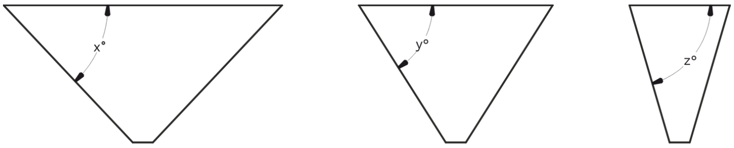
Appendix 6

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Hopper design

- Dimensions are calculated based on the material characteristics

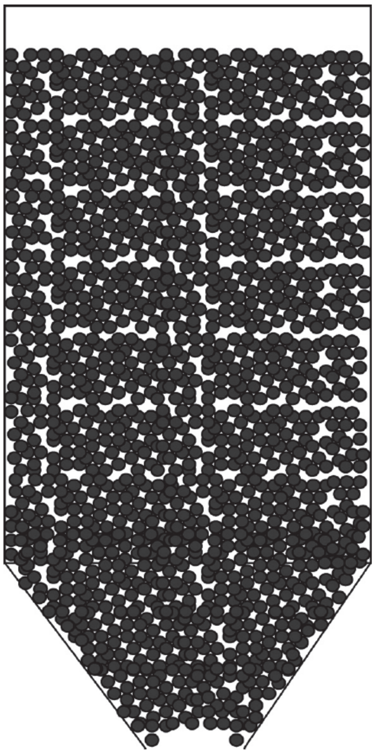


UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Hopper design

- No flow due arching



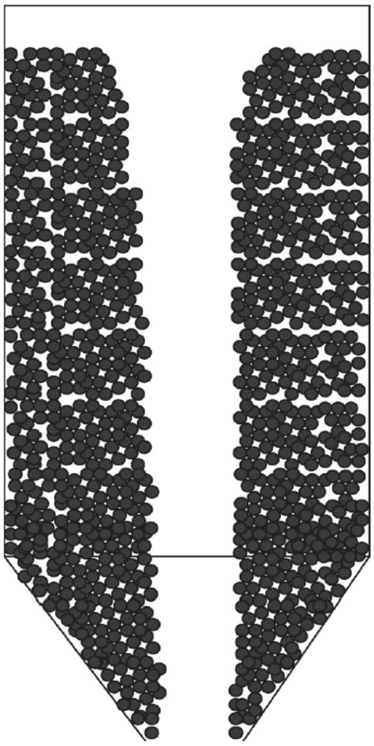
Appendix 6

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Hopper design

- No flow due ratholing



UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Feeding mechanism

- Based on the material characteristics
- Based on the feeding rate
- Based on the dryer requirements

Appendix 6

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Feeding mechanism

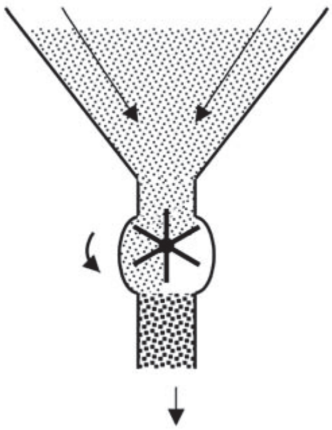
- Uniform and controlled feeding rate
- Full dispersion of the wet solids in the air stream
- No lumps

UNIVERSITY of GREENWICH
NRI | Natural Resources Institute

Feeder

Feeding mechanism

- Rotary feeders



Appendix 6

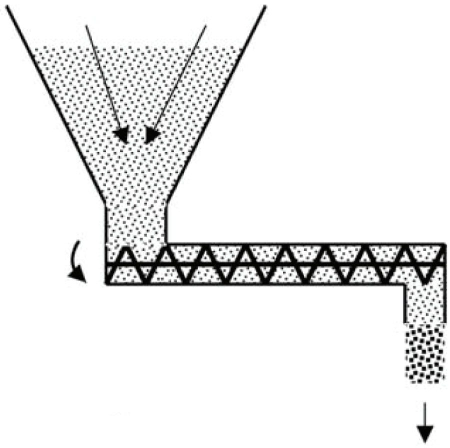
UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Feeder

Feeding mechanism

- Screw feeder



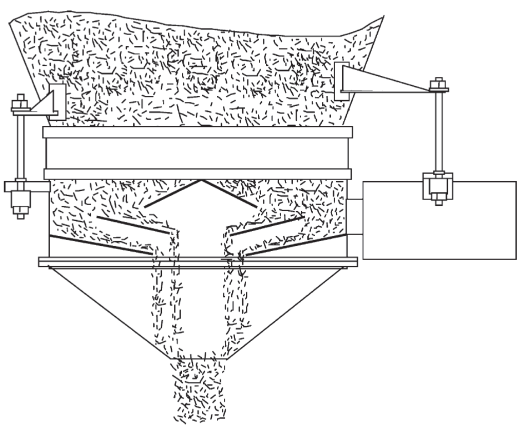
UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

Feeder

Feeding mechanism

- Louvered feeder



Appendix 7