Drying Basics and Principles

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Content

• Drying process
• Moisture gradient
• Tempering
• Heated air drying and low temperature drying
Drying process

- **I Preheating period**
  - drying rate is slowly increasing
  - only a very slight change in MC

- **II Constant-rate period**
  - drying rate is constant in time
  - removal of surface water
  - grain temperature is constant
  - energy used to evaporate water

- **III Falling-rate period**
  - drying rate declines over time
  - transfer of internal moisture to the surface
  - drying rate declines
  - grain heats up (danger)
  - for paddy grain starts at 18%

-> **Temperatures for drying paddy**

- **Seeds**
  - Maximum of 43 ºC

- **For milling**
  - During constant-rate period: > 100ºC
  - During falling-rate period: < 55 ºC
    (depends on drying system)
Drying rate

- Stated in percent moisture removed per hour
- Affected by:
  - Temperature and relative humidity of the drying air
    - Seeds: max. 43°C
    - Fist stage drying: max. 120°C
    - Second stage drying: max. 55°C
  - Air velocity
    - Too low -> air is saturated before leaving the dryer
    - Too high -> faster drying but wast of energy
    - Low-temperature drying: 0.1 m/s
    - Heated air drying: 0.15-0.25 m/s
    - Fluidized bed drying: 2.3 m/s
Uniform drying

**Moisture gradient**
- grain at the air inlet dries faster
- moisture gradient
- unloading - dry grains are mixed with wet grains
- Re-wetting -> cracks in dry grains

**For even drying**
- sun drying: stir every 30 minutes
- mix grain in fixed bed dryers
- use re-circulating batch dryers
- use low temperature for more even drying
Tempering

- Temporary stopping of drying (tempering)
  - moisture will equalize inside the grains
  - moisture between grains will equalize (reduces the moisture gradient)
- Re-start drying
  - drying rate will be higher
  - reduced energy requirement
- Application
  - re-circulating batch dryers, grain goes through cycles of drying followed by tempering
  - tempering bins in continuous flow dryer plants
Mechanical drying Methods

Heated-air drying

- Drying air temp.: 43°C
- Air velocity: 0.15-0.25 m/s
- Airflow rate per t grain: >0.7 m³/s
- Power requirement: 1.5-2.5 kW/t grain
- Layer depth: < 40 cm
- Drying time: 6-12 h
- Initial MC: up to 30%+

Advantages:
- Simple management
- Fast drying
- Affordable
- Low level of integration

Disadvantages:
- 3-4% moisture gradient in final product, requires mixing or reduced layer depth
- Reduction in milling yield
- Danger of killing seeds

Low-Temperature Drying

- Drying air temperature: \( \Delta T = 0-6 \ ^\circ K \)
- Air velocity: 0.1 m/s
- Airflow rate per t grain: >0.05-0.4 m³/s
- Power requirement: 0.05-0.15 kW/t grain
- Layer depth: < 2 m
- Drying time: days to weeks
- Initial MC: 18% (28%)

Advantages:
- Very energy efficient
- Bins can be filled at harvest rate
- Maintains grain quality optimally
- Drying in storage structures

Disadvantages:
- Increased risk with poor power supplies
- Requires bulk handling system (high level of integration in postharvest system)
- Long drying time
Sun drying

- **Advantages**
  - Free energy
  - Low capital investment

- **Disadvantages**
  - Weather risk
  - Temperature control difficult
  - High qualitative and quantitative losses
  - High labor requirement
## IRRI Flat-bed dryer

<table>
<thead>
<tr>
<th><strong>Capacity</strong></th>
<th>1 – 2 metric tons/batch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price</strong></td>
<td>US$ 1000-2000</td>
</tr>
<tr>
<td><strong>Drying time</strong></td>
<td>6-8h</td>
</tr>
<tr>
<td><strong>Grain Quality</strong></td>
<td>Medium quality, uneven drying of bottom and top layer</td>
</tr>
</tbody>
</table>
| **Heater** | Drying air temperature: 43°C  
A.) Kerosene burner, 2.0 l kerosene/h  
B.) Rice hull furnace, 3-4 kg rice hull/h |
| **Fan** | Axial flow fan, 2200 rpm  
1800 cfm at 20mm H2O  
A.) Electric motor, 2.5 kW  
B.) Gasoline engine, 0.75l gasoline/h |
| **Dimensions** | L: 3.2m; W: 2.5m; H: 1m;  
bin: 220 kg; furnace: 290kg |
| **Advantage** | Simple design, can be locally made, can handle very wet crop |
| **Disadvantage** | Moisture gradient, mixing necessary, dust when unloading, kerosene smell |

![Kerosene burner](image1.png)  
![Rice hull furnace](image2.png)
Vietnam: Reversible airflow flat bed dryer..
Vietnamese 4t Flat Bed Dryer in Battambang, Cambodia
Vietnamese type
Flat Bed Dryer in Myanmar
4-6t capacity
Drying rate: 1%/h
Cost: US$ 3,000
Rice husk furnace
Vietnamese Low-cost dryer

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>1 t/batch</td>
</tr>
<tr>
<td>Price</td>
<td>US$ 150-200</td>
</tr>
<tr>
<td>Drying time</td>
<td>2-4 days</td>
</tr>
<tr>
<td>Grain Quality</td>
<td>Good, low temperature drying principle</td>
</tr>
<tr>
<td>Heater</td>
<td>Drying air temperature: 6°C above ambient, if weather is bad</td>
</tr>
<tr>
<td></td>
<td>A.) Coal stove, 0.9-1 kg/h</td>
</tr>
<tr>
<td></td>
<td>B.) Electric heater, 1 kW</td>
</tr>
<tr>
<td>Fan</td>
<td>Axial flow fan, 1750 rpm blowers from automotive coolers</td>
</tr>
<tr>
<td></td>
<td>Electric motor, 0.5 kW</td>
</tr>
<tr>
<td>Advantage</td>
<td>Very cheap, simple design, can be locally made, can utilize traditional</td>
</tr>
<tr>
<td></td>
<td>storage structures, highly mobile</td>
</tr>
<tr>
<td>Disadvantage</td>
<td>Small moisture gradient, long drying time</td>
</tr>
</tbody>
</table>
# Low-cost seed dryer

<table>
<thead>
<tr>
<th><strong>Capacity</strong></th>
<th>100-250 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price</strong></td>
<td>US$ 150-200</td>
</tr>
<tr>
<td><strong>Drying time</strong></td>
<td>6-9h (initial MC of 22%)</td>
</tr>
<tr>
<td><strong>Grain Quality</strong></td>
<td>Good seed quality</td>
</tr>
<tr>
<td><strong>Heater</strong></td>
<td>Drying air temperature: 43°C</td>
</tr>
<tr>
<td></td>
<td>Rice hull stove, 1-1.5 kg rice hull/h</td>
</tr>
<tr>
<td><strong>Fan</strong></td>
<td>Centrifugal fan, 3200 rpm</td>
</tr>
<tr>
<td></td>
<td>0.11 m³/s</td>
</tr>
<tr>
<td></td>
<td>Electric motor, 220W</td>
</tr>
<tr>
<td><strong>Advantage</strong></td>
<td>Simple design, can be locally made, affordable, mobile</td>
</tr>
<tr>
<td><strong>Disadvantage</strong></td>
<td>Moisture gradient</td>
</tr>
</tbody>
</table>
Re-circulating batch dryer

<table>
<thead>
<tr>
<th>Capacity</th>
<th>10 metric tons/batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>US$ 10,000</td>
</tr>
<tr>
<td>Drying time</td>
<td>6-8 h, 55 min circulation period</td>
</tr>
<tr>
<td>Grain Quality</td>
<td>Best quality, continuous mixing, tempering – drying cycles</td>
</tr>
<tr>
<td>Heater</td>
<td>Drying air temperature: adjustable, Kerosene burner, 15.4 l/h</td>
</tr>
</tbody>
</table>
| Fan            | 2 axial flow fans, 1730 rpm  
1800 cfm at 20mm H2O 
A.) Electric motor, 2.5 kW  
B.) Gasoline engine, 0.75l gasoline/h |
| Dimensions     | L: 3.5 m; W: 2.5 m; H: 8.3 m; 2,110kg |
| Electricity cons. | 7.2 kW for blower, conveyors, electronic control |
| Advantage       | Automatic operation, excellent quality, Automatic safety features |
| Disadvantage   | Problems with very wet crop (>30%) |
## Agridry seed dryer

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>0.6 t/batch (1m³)</td>
</tr>
<tr>
<td><strong>Price</strong></td>
<td>US$ 1,350</td>
</tr>
</tbody>
</table>
| **Drying time** | 3.5 hours from 21.5% to 12.5%  
Drying rate: 2.3%/h |
| **Grain Quality** | See quality analysis |
| **Heater**      | LPG gas, 20 MJ/h |
| **Fan**         | Centrifugal fan  
Electric motor, 1.5 kW |
| **Advantage**   | Mobile, convenient operation,  
automatic temperature control,  
high drying rate |
| **Disadvantage** | Uneven grain bed thickness  
Bin needs to be totally filled  
Inconvenient unloading |
Components of a flat bed dryer

- Furnace
- Fan
- Drying bin

- Air
- Flue gas
- Heated air
Components of a dryer and their function

• **Main components**
  – **Drying bin** - holds the grain
  – **Air distribution system** – provide drying air, remove water
  – **Fan** – create pressure and air flow
  – **Air heater** – reduce relative humidity of air

• **Optional**
  – **Conveyors** – loading and unloading

• **Accessories**
  – **Moisture meter** – monitor drying process
  – **Dust separator** – clean exhaust air
Drying bin and plenum chamber

- **Flat bed dryer**
  - ☑ Cheap and simple
  - ☒ Labor intensive

- **Inclined bed dryer**
  - ☑ Easy unloading
  - ☒ More expensive

- **Circular bin dryer**
  - ☑ Compact and cheap
  - ☒ Uneven airflow inside and outside

Air flow direction and drying chamber types.
Circular drying bin

- Advantages
  - Self supporting structure
  - Simple plenum chamber
  - Short air delivery pathways

- Disadvantage
  - Uneven air velocity
  - Air velocity highest at the inlet
Reversible air flow dryer

- Reversal of air flow
- Reduced moisture gradient
- No mixing needed
- Increased capacity
Air distribution system
Re-circulating batch dryers

• Cross flow
  - Grain moves downwards, air across
  - Less hindrance of grain flow, works better with wet paddy with high amount of straw and chaff

• Mixed flow
  - Air flows from inlet to outlet ducts
  - Ducts are shaped so that they mix the grain
  - Better mixing leads to better quality
## Fans

<table>
<thead>
<tr>
<th>Fan type</th>
<th>Axial flow</th>
<th>Centrifugal, forwards curved</th>
<th>Centrifugal, backwards curved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Cheap</td>
<td>more expensive</td>
<td>most expensive</td>
</tr>
<tr>
<td>Characteristics (^1)</td>
<td>non-overloading</td>
<td>overloading</td>
<td>Non-overloading</td>
</tr>
<tr>
<td>Pressure creation</td>
<td>10-15 cm water</td>
<td>0-15 cm water</td>
<td>0-30 cm water</td>
</tr>
<tr>
<td>Unstable region of operation</td>
<td>At high pressure</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Construction</td>
<td>Sturdy</td>
<td>Light</td>
<td>Sturdy</td>
</tr>
<tr>
<td>Noise level</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Typical use</td>
<td>Aeration, recirculation</td>
<td></td>
<td>In-store dryers</td>
</tr>
<tr>
<td></td>
<td>batch dryer, batch dryer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Air distribution system

<table>
<thead>
<tr>
<th>Type of dryers</th>
<th>Pressure system</th>
<th>Suction system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed bed batch</td>
<td>Fixed batch can be made airtight easily, large outlet</td>
<td>Moving mechanical parts make sealing difficult</td>
</tr>
<tr>
<td>Air tightness of bin</td>
<td>Before fan</td>
<td>Before dryer inlet</td>
</tr>
<tr>
<td>Heater</td>
<td>High temperature resistance needed, sometimes exposed to flames</td>
<td>Lower temperature resistance</td>
</tr>
<tr>
<td>Fan</td>
<td>Stays mainly in fixed bed, set free when unloading</td>
<td>Sucked out with the drying air</td>
</tr>
<tr>
<td>Dust</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Air distribution system

### Options for batch dryers

<table>
<thead>
<tr>
<th>System</th>
<th>Air ducts</th>
<th>Perforated false floor</th>
<th>Air-sweep floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Medium</td>
<td>High (grill shaped metal plus fan)</td>
</tr>
<tr>
<td>Air distribution</td>
<td>Uneven</td>
<td>Optimal</td>
<td>Optimal</td>
</tr>
<tr>
<td>Requirements</td>
<td>Sealed floor</td>
<td>Stable support structure needs withstand walking on it</td>
<td>Support structure Strong fan for conveying</td>
</tr>
<tr>
<td>Constraints</td>
<td>Manual unloading</td>
<td>Manual unloading</td>
<td>Dust creation</td>
</tr>
<tr>
<td></td>
<td>Uneven drying at high MC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strong fan for conveying</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Air distribution systems
Air ducts for batch dryers

Air ducts with plenum chamber outside the drying bin
Air ducts with central plenum chamber
Protecting the grain bulk from ground moisture. Figure a: False floor. Figure b: Insulation
Air distribution systems
Air sweep floors
Heating systems
## Heating Systems

<table>
<thead>
<tr>
<th>Application</th>
<th>Kerosene / Diesel burner</th>
<th>Small Rice Hull Furnace</th>
<th>Automated Rice Hull Furnace</th>
<th>LPG burner</th>
<th>Electricity</th>
<th>Solar energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Capital cost</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Operating cost</strong></td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Medium-High</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>• Easy fuel handling</td>
<td>• Cheap fuel</td>
<td>• Cheap fuel</td>
<td>• Easy</td>
<td>• Convenient</td>
<td>• CO2 neutral</td>
</tr>
<tr>
<td></td>
<td>• Automatic operation</td>
<td>• CO2 neutral</td>
<td>• CO2 neutral</td>
<td>handling of</td>
<td>• Easy to control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High energy content</td>
<td></td>
<td></td>
<td>fuel</td>
<td>• Clean</td>
<td></td>
</tr>
<tr>
<td><strong>Constraints</strong></td>
<td>• Smell</td>
<td>• Labor intensive</td>
<td>• High capital cost</td>
<td>• Availability</td>
<td>• Expensive</td>
<td>• Low heat generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Material difficult to convey</td>
<td>• Wear of components.</td>
<td>• Cost of fuel</td>
<td>• Limited power load</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bulky fuel</td>
<td>• Bulky fuel</td>
<td></td>
<td>• Highest energy form</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Accessories: Pre-cleaner

- Fines in rice create dust during the loading and drying process and reduce airflow through the rice grain.
- Pre-cleaners usually consist of:
  - scalper that lets through the grain but retains straw
  - a smaller second screen that removes small stones and other impurities
  - air aspirator for sucking out dust and light empty grains
Accessories: Elevators and Conveyors

- For horizontal and vertical transport of grains:
  - Loading
  - Circulation
  - Discharge
- Need to be matched to the capacity of the dryer.
  - A properly designed bucket elevator for a re-circulating batch dryer can easily reach capacities of 10t/h.
• Monitoring grain moisture to avoid
  – over drying
  – incomplete drying

• Over drying
  – Unnecessary weight loss
  – Reduced milling yields

• Incomplete drying causes qualitative and quantitative losses from
  – fungal growth
  – insect activity
  – respiration
Accessories: Dust collection system

• Grain handling will create dust, making working around a grain drying hazardous.

• Need for dust collection systems
  – Cyclone
  – Need to be properly sized depending on the dryer specifications.
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