Masaganang ANI
Mataas na KITA

RICE COMPETITIVENESS ENHANCEMENT FUND (RCEF)
MECHANIZATION PROGRAM

04

Reference Manual on

Grain Drying

A Compilation of Resources

Philippine Center for Postharvest Development and Mechanization (PHilMech), 2020

Published by:
Department of Agriculture
Philippine Center for Postharvest Development and Mechanization (PHilMech)
CLSU Compound, Science City of Muñoz,
Nueva Ecija, Philippines

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2020

ISBN: 978-971-9947-14-1

Cover Design by:
Jett Molech G. Subaba

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RM NO. 4

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FOREWORD

The Philippine Center for Postharvest Development and Mechanization (PHilMech) is mandated to generate, extend and commercialize appropriate and problem-oriented agricultural and fishery postharvest and mechanization technologies and systems.

With this mandate, PHilMech works diligently at mechanizing the production or postproduction operations of all agricultural commodities available in the country. Rice is one of the major programs of PHilMech in terms of mechanization especially in the advent of free trade and the passing of the Rice Tariffication Law or the RA 11203. Through this law, the Rice Competitiveness Enhancement Fund or RCEF was funded where farmers are groomed to be as competent as its neighboring countries.

As stated in the law, PHilMech will receive 50 percent of the 10 billion peso-fund each year for RCEF Mechanization Program to facilitate the distribution of the machinery grants to qualified rice-producing farmers' cooperatives and associations (FCAs).

To support and make sustainable the program in mechanization, extension services like training courses, enterprise development and communication support have also been funded to educate, train and empower these FCAs.

In the area of communication support, the project aims at increasing the knowledge and interest of the farmers to adopt and utilize rice mechanization technologies in their production to postharvest operations.

One way to increase their knowledge is by producing helpful and comprehensive references on rice production and postharvest systems that can guide them toward the path of competitiveness. Thus, PHilMech compiled reliable and comprehensive sources of information both from other agencies and from our experts to come up with this manual.

The series of reference manuals for FCAs include topics on the different farm operations from land preparation, plant establishment, harvesting and threshing, grain drying and up to rice milling. Each includes principles, knowledge and practices to effectively mechanize farm operations. This will not only educate the farmers but also reach even the new generation of farmers among the different FCAs in the country.

Baldwin G. Jallorina, Ph.D.
Director IV

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GRAIN DRYING

1. **Why is grain drying important?**

   - Drying is one of the most important operations towards the preservation of grain quality. Delays in drying, incomplete drying, or uneven drying will result in qualitative and quantitative losses.

2. **What happens if grains have high moisture?**

   - This promotes the development of insects and molds that are harmful to the grain.
   - High moisture in grain also lowers the germination rate of rice, causes yellowing or discoloration of grains due to mold development and heat built-up from respiration.
   - Also, based on studies, insects are most active at higher moisture content level which may cause damage to the grain.

3. **What is the purpose of drying?**

   - Drying reduces the moisture content of grains to a level safe for storage. Thus, rice grain must be dried as soon as possible after harvest (ideally within 12 hours).
   - Storage of incompletely dried grain with a higher than acceptable moisture content will lead to failure regardless of what storage facility is used. In addition, the longer the desired grain storage period, the lower the required grain moisture content must be.
   - Drying temperature also affects the milling quality of rice. Higher temperatures result in lower head rice yield and increased fissure formation.

4. **What are the technical terms used in drying?**

   - **Airflow rate -** volume of air delivered to the mass of grains per unit time
   - **Ambient air –** surrounding air; an encompassing atmospheric air
   - **Dry matter –** bone dry material; water-free matter; it is the resulting product of removing all moisture from a certain matter
   - **Burner efficiency -** furnace efficiency; ratio of the heat supplied by the burner/furnace, to the heat released by the fuel
   - **Combustion efficiency -** ratio of the heat released by the fuel, to the theoretical heat available from the fuel
   - **Conventional energy source -** source of energy which includes petroleum-based fuels such as kerosene, gasoline, diesel oil and bunker fuel oil

- **Damaged grains -** grains which are heat damaged, weather damaged, sprouted or distinctly damaged by insects, water, fungi and/or any other means
- **Drying air temperature -** mean temperature of the air used for drying the grain, measured at a number of points as close as practicable to its entry to the grain bed
- **Moisture reduction rate -** ratio of the average percent moisture content removed from the grain, to drying time, expressed in percent per hour (%/hr.).
- **Drying rate -** amount of water removed per unit of time, expressed in kilogram per hour
- **Drying system efficiency -** ratio of the total heat utilized for drying, to the heat available in the fuel expressed in percent
- **Foreign matter -** all matters other than rice/corn grains such as sand, gravel, dirt, pebbles, stones, lumps of earth, clay, mud, chaff, straw, weed seeds and other crop seeds.
- **Grain holding capacity –** continuous flow – weight of grain in the dryer after a period of stable operation: batch-type – weight of grain required to fill the dryer at the input moisture content
- **Heat utilization -** total amount of heat utilized to vaporize moisture in the material, expressed in kJ/kg of H2O
- **Humidity –** the amount of water vapor in the air; pounds of moisture per pound of dry air
- **Hygroscopic –** the property to absorb or give off moisture
- **Immature grains -** palay which are light green and chalky with soft texture

  Moisture content – the amount or quantity of water contained in a material such as grain, soil, fruits and other hygroscopic materials.
- **Non-conventional energy source -** source of energy that includes non-petroleum based fuels such as biomass and solar energy
- **Purity -** percentage of grains free of foreign matter
- **Psychometrics or psychrometry –** determination of physical and thermodynamic properties of gas-vapor mixtures
- **Static pressure -** pressure build-up in the plenum chamber to maintain uniform distribution of air flow through the grain mass
- **Tempering -** temporarily holding the grain between the drying passes, allowing the moisture content in the center of the grain and that on the surface of the grain to equalize

PRINCIPLES AND SYSTEMS

1. **What is the anatomy of the paddy grain?**

   Anatomy refers to the study of the structure and parts of an organism, in this case, grain.

   It is important because understanding the anatomy of the rice grain will clarify the reasons why rice kernels break so easily on mechanical impact during the physical operations of threshing and milling, and under thermal stress during drying.

2. **How does a grain paddy looks like, internally and externally?**

   The grain has the following anatomy:

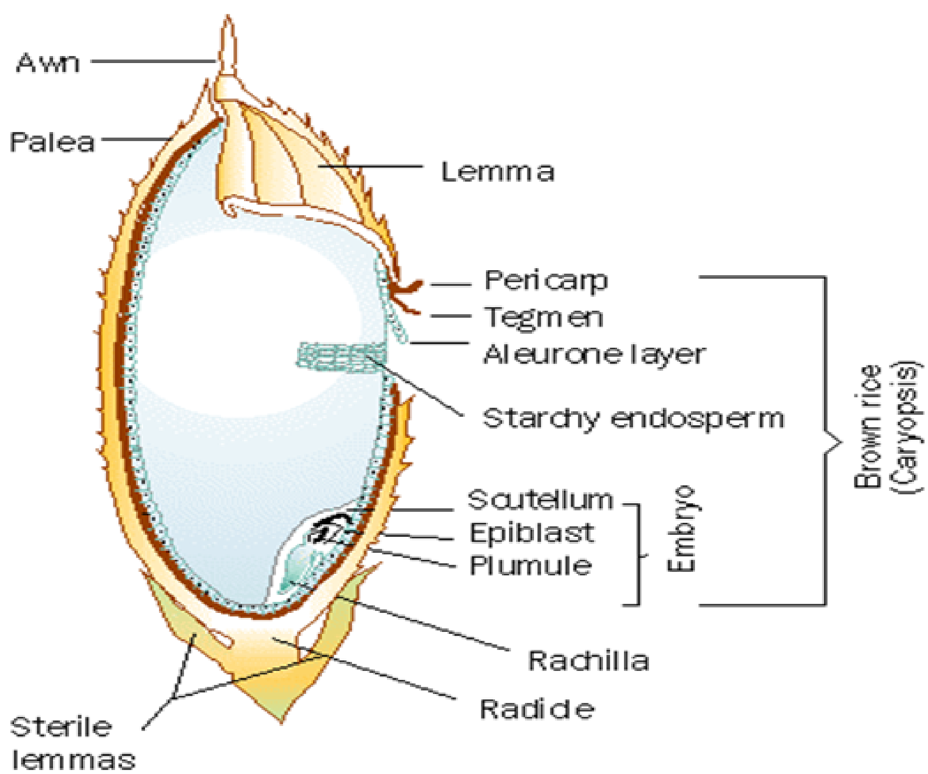


Figure 1. *Anatomy of paddy grain*

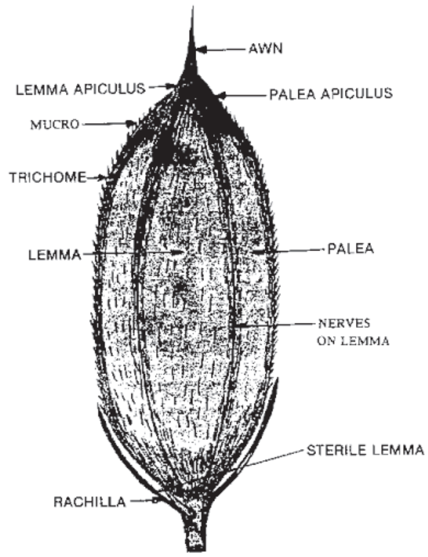


Figure 2. External parts of paddy grain

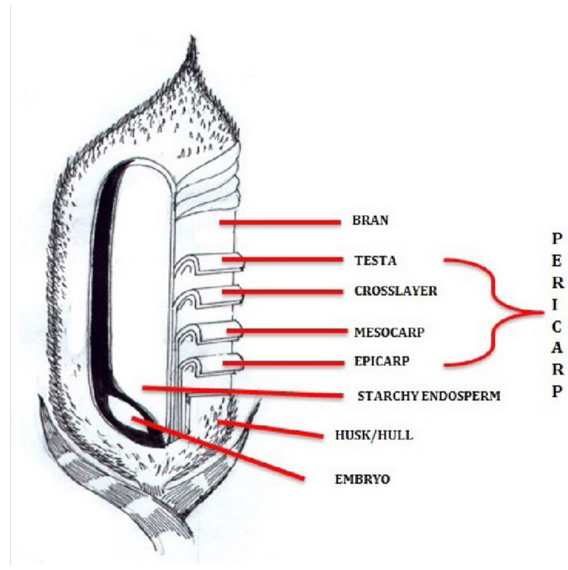


Figure 3. Internal parts of paddy grain

3. What are the parts of the paddy grain?

- *Hull*
    - o Also known as husk. which is the most visible part or a rough rice grain.
    - o Formed from the two leaves of the spikelet namely the palea covering the ventral part of the seed and the lemma covering the dorsal portion.
    - o The upper end of the two hull sections transfers into the apiculus sections and finally ends in the pointed awn.
    - o The caloric value to the hulls is rather high and ranges from 13 to 18 MJ/kg making hulls an important source of energy in agriculture.
    - o Rice hull has high proportion of silica which causes considerable damage to processing equipment through excessive wear of machine parts and interconnecting transfer facilities.
- *Pericarp*
    - o When the hull is removed, a thin fibrous layer can be seen. This is called the pericarp, frequently known as the "silver skin".
    - o It is usually translucent or greyish in color. When the pericarp is not translucent, but in color the grain is referred to as red rice. It is considered as an integral part of the brown rice kernel (caryopsis) can be easily removed in the whitening process.

- o The pericarp consists of three layers namely epicarp, mesocarp and cross layer. Immediately under the pericarp layer is the testa or sometimes called tegmen layer which is only a few cells in thick ness but with less fibrous than the pericarp layer. This pericarp is rich in oil and protein but its starch content is very low.
- o This layer serves as an additional protective layer against molds and quality deterioration through oxidation and enzymes due to the movements of oxygen, carbon dioxide and water vapor.
- o Sometimes this layer is considered as part of the seed coat but because of its oil content, it is normally considered as the outermost layer of the bran.

- *Bran*
    - o Under the testa or tegmen layer is the bran layer or aleurone layer, the main part removed in the whitening stage during milling.
    - o Has very low starch content but has a high percentage of oil, protein, vitamins and minerals.
    - o When rice is fully milled the vitamins (A complex), protein, mineral, and oil contents are lessened. This explains why persons with beri-beri (Vitamin A deficiency) are advised to eat brown rice.
    - o The vitamins in the grain can be retained by parboiling before milling. This allows the movement of nutrients from the bran layer to the inner part of the grain thus, making the vitamins available in the milled rice.

- *Embryo*
    - o The embryo is located at central bottom portion of the grain.
    - o this is the living organism in the grain which develops into a new plant. The embryo respires by taking in oxygen in the air, consumes food which comes from the starch in the grain itself while simultaneously releasing moisture and heat. This explains why grains during storage have the tendency to decrease in weight as a result of the loss in moisture and dry matter content in the endosperm.
    - o During milling, the embryo is removed resulting in an indented shape at one end of the milled rice grain.

- *Endosperm*
    - o when the husk, the pericarp, the bran and the embryo are removed, what remains is the endo sperm.
    - o it mainly consists of starch with only a small concentration of protein and hardly any, minerals vitamins or oil. Because of its high percentage of carbohydrates, its energy value is high.

4. **What are the paddy physical properties/characteristics?**

- *Length*
  - o The length of the paddy grain is variable, even within a variety, because of variation in the length of the awn and the pedicel.
  - o The type of paddy is not determined by the length of the paddy grain but by the length of the brown rice kernel.
- *Husk surface*
  - o The husk surface is rather rough and abrasive because of its high silica content.
    It is for this reason that rubber-rolls of the hullers wear so fast, that precleaning machines have many parts which frequently need to be replaced.
    In rice mill equipment, the rough surface of the paddy grain compared with the smooth surface of the brown rice, plays an important role in the determination of specific design criteria.
- *Free space between the husk and the brown rice kernel.*
  - o When the grain is dried, there is a distinct space between the rice hull and the kernel. This enables minimal pressure against the grain when dehulling and thus minimises breakage and losses.
- *Tight Interlocking fold of the husk*
  - o The husk sections consisting of the lemma and the palea, are tightly seamed together through a double fold. It requires force to open these folds of dehulling which make the design of hullers rather difficult in order to avoid breakage of the grain.
- *Awn*
  - o The awn sometimes is very long on certain varieties, that special machine is required to break and remove the awns prior to the dehulling of the paddy.
  - o awners are expensive, energy consuming and slightly increase the amount of breakage resulting to a less profitable, and less efficient conversion of paddy into milled rice.
- *Pericarp*
  - o When damaged, it allows oxygen to penetrate into the bran layer which leads to an increase of the free fatty acid (FFA) content of the oil in the bran. The oxidation process makes the bran rancid and will cause in serious quality deterioration of the brown rice kennel.
  - o It's mainly the abrasive disc huller which damages the pericarp. However, the abrasions in the pericarp pose no problem if the brown rice is immediately milled and the bran is removed.

- *Longitudinal Starchy Cells*
  - o The outermost starch cells of the endosperm are elongated in shape.
  - o These long cells are positioned with the long side directed towards the center of the grain making the grain vulnerable to thermal stresses that leads to fissures and cracks. The grain can easily break under the impact of force either when it is thre shed, conveyed, cleaned or dehusked.
  - o This characteristic gives the grain the potential to break when incorrect drying procedures are followed.

3. What other physical properties related to the physical composition of the grain?

- *Angle of Repose*
  - o Paddy forms a complete cone when it is vertically unloaded on a flat surface. The angle of the side of this cone-shaped mass of grain, measured after the flow of grain has completely stopped, is the angle of repose.
  - o This angle differs from each type of grain and depends much on the moisture content and smoothness of the surface of the grain.
  - o The angle of repose is directly dependent on the moisture content of the grain. At a moisture content level of 20 the angle of repose for paddy will be greater than for dry paddy at 14 MC.
  - o This property is important in the construction of bulk storage facilities and the calculation of the dimensions of intermediate holding bins of a given capacity. wet grain and rough surface is greater as compared to angle of friction of smooth surface and dry grain.
- *Angle of Friction*
  - o When grains are placed on a surface of any flat material where one end is slowly lifted, there is a certain angle wherein grains will start to move after overcoming the friction offered by the surface with gravity discharging the grains. This angle measured from the horizontal is called the angle of friction.
  - o The angle of friction varies with the characteristics of the surface and MC of the grain.
- *Bulk Density*
  - o The bulk density refers to the ratio between weight and volume of grains. It is normally expressed in kg per HL, lbs per ft^3 or kg/m^3.
  - o The density data are important in the calculation of the dimension of bulk storage facilities and intermediate holding bins of given capacity. It also indicates the puritydegree of the grain since the presence of light foreign matter reduces the grain density.

- *Grain Dimensions*

  - The dimension of the paddy grain and milled rice kernel play an important role in the determination of grain standards and throughout the processing cycle.

  - The grain dimension is classified according or in relation to the following.

The type of paddy-classified according to the length of the whole brown rice grain:

- **Extra-long:** 80 percent of the whole brown rice kernels havie a length of 7.5 mm or more.

- **Long:** 80 percent of whole brown rice kernels have a length of 6.5 mm or more but shorter than 7.5 mm.

- **Medium:** 80 percent of the whole brown rice kernels have a length between 5.5 mm. to 6.5 mm.

- **Short:** 80 percent of the whole brown rice kernels have shorter than 5.5 mm.

The sub-type of paddy - this refers to the ratio of length and width of the whole brown rice kernel

- **Slender:** the brown rice grain has a length-width ratio of 3.0 or more.

- **Bold:** the brown rice grain has a length/width ratio of 2.0 or more but smaller than 3.0

- **Round:** the brown rice grain has a length-width ratio smaller than 2.0

The type of milled rice-milled rice is classified according to the length of the whole grain.

- **Extra-long:** 80 percent of the whole milled rice kernels have a length of 7.0 mm or more.

- **Long:** 80 percent of the whole milled rice kernels have a length of 6.0 mm. or more but shorter than 7.0 mm.

- **Medium:** 80 percent of the whole milled rice kernels have a length of 5.0 mm. or more but shorter than 6.0 mm.

- **Short:** 80 percent of the whole milled rice kernels are shorter than 5.0 mm.

The sub-type of milled rice: this refers to the length/width ratio of the whole milled rice grain. It is defined in the same manner as that for paddy as slender, bold and round.

Brokens in milled rice: generally based on the length of the rice particle and is referred to in units 118 of the length of the whole unbroken milled rice grain. These are categorized as:

- **Head Rice:** a milled rice particle with a length of 75 percent or more of the length of the whole unbroken milled rice kernel.
- **Large Broken:** a milled rice particle with length ranging from 3/8 to 6/8 of the whole length of the grain.
- **Small Broken:** a milled rice particle with length ranging from 1/8 to ¼ of the whole length of the unbroken grain.
- **Brewer's Rice:** a milled rice particle which will pass through a sieve with a round perforation of 1.4 mm but the length of the grain is shorter than 3/8 of the whole unbroken milled rice kernel.

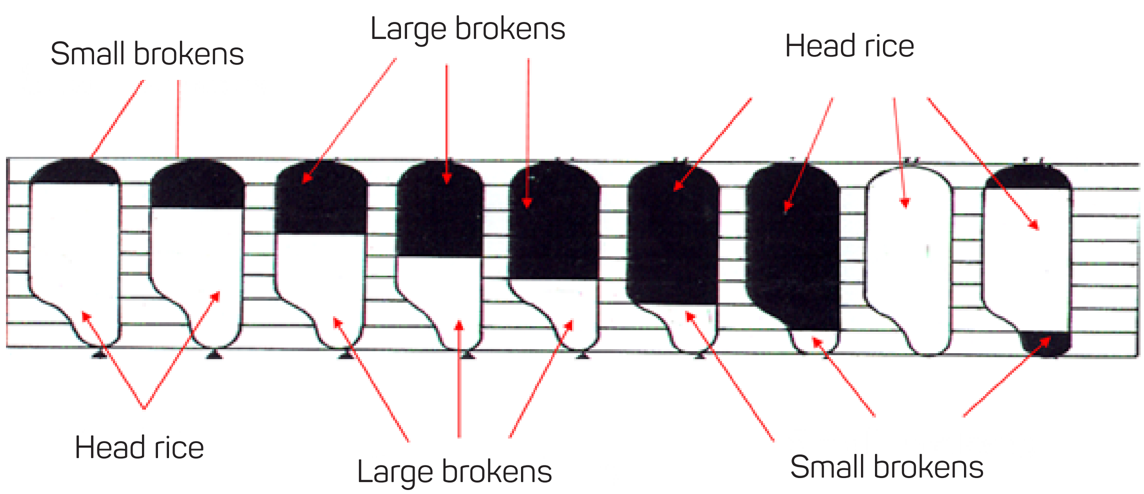


Figure 4. *Interpretation of brokens in milled rice*

4. What are the principles of drying?

- Drying consists of two fundamental processes, the heat and mass transfer. Moisture in the grain evaporates and diffuses out of the grain kernel. To evaporate this moisture, heat energy must be flowing into the grain kernels to cause moisture to change from liquid to gas.

5. What are the two fundamental processes in drying?

- Moisture in the grain evaporates
- Moisture of the grain out of the grain kernels

6. What are the influencing factors of the drying rate?

Drying rate is influenced by the:

- temperature of the drying air;
- the relative humidity of the drying air;
- grain moisture content; and
- the velocity of the air moving through the grain mass.

7. What is the minimum amount of energy to evaporate moisture?

- The minimum amount of energy required is about 2.4 MJ/kg of water.
- In-heated air dryers, the amount of energy required usually more than this.
- Drying in-bin with air and near-ambient conditions require less than this because the thermal energy in the air due to heating by the sun is used more efficiently than in heated air dryer.

8. What are the fundamental modes of heat transfer?

- Conduction

    - o Transfer of heat as a result of the direct contact of rapidly moving atoms through a medium or from one medium to another, without movement of the media.
    - o Materials that allow heat to travel through them in this way are called conductors. Metals are good conductors of heat.
    - o Non-metals such as plastic, clay, wood and paper are poor conductors of heat; they are also called insulators.

- Convection

    - o Transfer of heat by the physical movement of the heated medium itself. Convection occurs in liquids and gases but not in solids. It occurs when a liquid gas is in contact with a solid body at a different temperature and is always accompanied by the motion of the liquid or gas.

- Radiation

    - o Transfer of heat in the form of waves through space (vacuum). Dull black surfaces are better than white shinning ones at absorbing radiated heat. The sun cannot transfer heat to earth by conduction (because there is no physical contact with the earth) or convection (because there is no liquid or gas between them). The sun heats the earth by radiation which does not require contact or the presence of any matter between them.

9. What is equilibrium moisture content?

Grains are hygroscopic in nature, meaning it will lose or gain moisture until equilibrium moisture content (EMC) is reached with the surrounding air. If the vapor pressure of the moisture within the grain is higher than that of the moisture in the atmosphere, the grain will lose its moisture to the surrounding air. In effect, the grain undergoes a drying process. Conversely, if the grain is dry and the surrounding atmosphere is wet, the grain will absorb moisture.

The equilibrium moisture content (EMC) is dependent on the relative humidity and the temperature of the air; EMC's for paddy and milled rice are shown in table 1.

Table 1. Equilibrium moisture content for milled rice

Grain	Relative Humidity							
	30	40	50	60	70	80	90	100
	Equilibrium Moisture Content (wb) at 25 Degree Celcius							
Paddy	7.90	9.40	10.80	12.20	13.40	14.80	16.70	
Millled Rice	9.00	10.30	11.50	12.60	12.80	15.40	18.10	23.60

The data in table 1 shows, for example, that paddy can only be dried to a moisture content of 16.7 percent when exposed to air at 25 ^{0}C and 90 percent relative humidity. If paddy at moisture content less than 16.7 is required, either the temperature of the drying air has to be increased or its humidity reduced.

10. What is relative humidity?

- The actual vapor pressure of the air relative to saturation is called relative humidity (RH). Relative humidity is express as percentage.
- In the common convection drying, the air must have a relative humidity low enough to absorb moisture from the grain. Lowering the relative humidity can be done by heating. Increasing the temperature by 11^{0}C will reduce the relative humidity to half its original value.

11. What is the vapor pressure of the air?

- Energy in the form of heat must be supplied to evaporate moisture from the grain. The latent heat of vaporization, Lh, for a grain depends on its moisture content and temperature and is appreciably greater than the latent heat of evaporation of water.

12. What is the latent heat of vaporization for paddy at selected moisture contents and temperatures?

Table 2. Latent heat of vaporization of paddy

Temperature ^{0}C	Latent Heat of Variation (kj/kg)					
	Moisture Content % (wb)					
	Free water	14	16	18	20	22
25	2,443	2,605	2,518	2,483	2,464	2,453
30	2,431	2,593	2,506	2,471	2,452	2,441
35	2,419	2,580	2,493	2,458	2,440	2,429
40	2,407	2,567	2,482	2,447	2,428	2,417
45	2,395	2,555	2,469	2,434	2,416	2,405
50	2,383	2,542	2,456	2,422	2,404	2,393
55	2,371	2,529	2,444	2,410	2,391	2,381
60	2,359	2,516	2,432	2,398	2,379	2,369

Source: Brooker et al. (1974)

13. What is moisture content (MC) and how is it determined?

- The amount of water present in the grains is represented by moisture content of the grain. Moisture content of grain is one of the most important indices for determining whether the grain should be harvested, is dry enough for safe storage, or can be milled with maximum recovery.
- In postharvest handling, moisture content (MC) of grains are usually measured on a wet basis, i.e., the mass of moisture per unit mass of wet grain and written as percent wet basis % (wb). There are several methods used in determining grain moisture content (MC) of any product expressed in percentage by weight and may be represented either on a wet or dry basis. Dry basis moisture content is used mainly in scientific research.

14. What are the two ways of expressing moisture content?

Wet Basis Formula:
$MC_{wb} = (W_i – W_f/W_i) \times 100$
Where:
MC_{wb} = Moisture Content wet basis, %
W_i = Initial Weight, kg
W_f = Final Weight, kg

Dry Basis Formula:
$MC_{db} = (W_i – W_f/W_f) \times 100$ Where:
MC_{db} = Moisture Content dry basis, %
W_i = Initial Weight, kg
W_f = Final Weight, kg
Weight Loss during Drying Formula:
$W_f = W_i \times (100 – MC_i/100 – MC_f)$
Where:
W_i = Initial Weight, kg
W_f = Final Weight, kg

Sample Computation:

A 6,000 kg of paddy is harvested at 24 percent MC, and dried down to 14 percent MC, what is the final weight of the dried grain?
$W_f = W_i \times (100 – MC_i/100 – MC_f)$
$W_f = 6000 \text{ kg} \times (100 – 24/ 100 – 14)$
$W_f = 6000 \text{ kg} \times (76/86)$
$W_f = 5{,}302.32 \text{ kg}$

15. What are the categories of moisture content determination methods?

- Methods that determine MC are categorized as primary (direct) and secondary (indirect).

- The primary or direct methods involve the actual removal of moisture from the sample, and getting the initial and final weights of the sample, the difference being the amount of moisture removed.

- The secondary method makes use of the electrical property of the material which is directly related to MC. The secondary method is calibrated against the primary method which is the standard and official method.

- Although direct measurement is more accurate, the procedure is time consuming and cumbersome. The secondary method which usually takes less than three minutes to operate is preferred in commercial trading and field operations.

16. What are the methods which commercially available moisture meters employ?

- Primary method
  - o Air-oven
  - o Vacuum oven
  - o Brown-Duvel fractional distillation o Infra-red o

- Secondary method
  - o Electrical resistance (Universal, Gann)
  - o Electrical capacitance (Motomco, Steinlite, Dole)
  - o Other indirect methods – chemical, hygrometric, and neutron scattering.

17. What is the drying process curve?

Drying process can be presented by a curve known as the drying curve as shown figure 2. The transverse axis (x – axis) represents the drying time and the longitudinal axis (y-axis) for moisture content.

The drying curve shows the grain moisture content changes over time and how grain temperature changes. As can be seen in the chart, the drying rate is not constant but changes over time. The temperature of the grain equally changes over time.

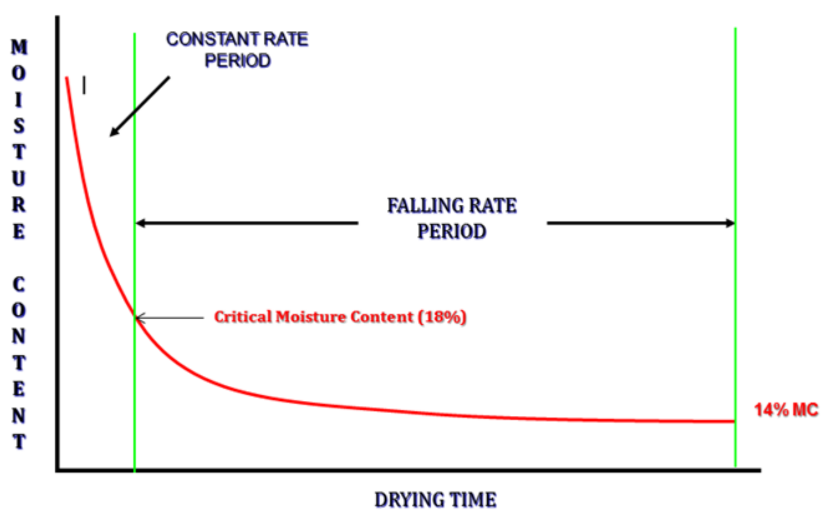


Figure 5. *Grain drying characteristics*

18. **What are the three different periods which will occur consecutively in time during drying?**

- **Constant-rate period** (drying rate is constant in time)
  - o Occurs when there is a rapid diffusion of moisture in the grain being dried. The drying rate is determined by the evaporation of water from the surface of the grain. During this period, all the heat from the drying air is used to evaporate surface moisture and the amount of moisture removed from the grain is constant in time. It is therefore called the constant-rate period, because of the constant drying rate.

- **Falling-rate period** (drying rate declines over time)

  - o As time passes, it becomes difficult for a sufficient amount of moisture to be transported from the inside to the surface of the grain to maintain evaporation at a constant rate. As a result, grain temperature starts to rise, and the drying rate decreases until an equilibrium moisture content is reached. For paddy grain, the falling-rate period typically occurs at around 18 percent grain moisture content.

19. **What is the critical moisture content?**

The moisture content at the turning point from the constant rate drying to the first-stage falling rate drying is said to be the critical moisture content.

20. **What is the relationship between drying rate and temperature?**

Using the drying curve as a guideline, above 18 percent MC the grain drying rate can be:

- Increased by providing a higher temperature without major changes in grain temperature.

- Below 18 percent MC increase in drying air temperature will not only increase the drying rate but will increase grain temperatures and potentially damage the grain.

- Therefore, higher drying air temperatures can be used to dry grain quickly down to 18 percent MC to remove "grain surface moisture" but lower temperatures should be used to remove internal moisture from the grain.

- For seed purposes, drying air temperatures should never exceed 43°C, regardless of the MC, to avoid overheating of the grain which kills the germ. Exposing paddy to 60°C for one hour can reduce the seed germination rate from 95 percent to 30 percent. Two hours at 60°C can reduce the germination rate to 5 percent.

21. **What are the major factors determining the removal of moisture in the air?**

The properties of the air flowing around the drying grain are a major factor in determining the rate of removal of moisture. The capacity of air to remove moisture is principally dependent upon its initial temperature and humidity; the greater the temperature and lower the humidity, the greater the moisture removal capacity of the air.

22. What is the psychrometric chart?

A psychrometric chart simplifies the measurement of air properties and eliminates many time-consuming and tedious calculations that would otherwise be necessary. It is simply a graphic presentation of the conditions or properties of the air that include dry-bulb and wet-bulb temperatures, relative humidity, humidity ratio, specific volume, dew point temperature, and enthalpy. Only two properties are needed to characterize air because the point of intersection of any two property line defines the state-point of air on a psychrometric chart. Once this point is located on the chart, the other air properties can be read directly. Air properties at 101.325 kPa standard atmospheric pressure can be found using the psychrometric chart.

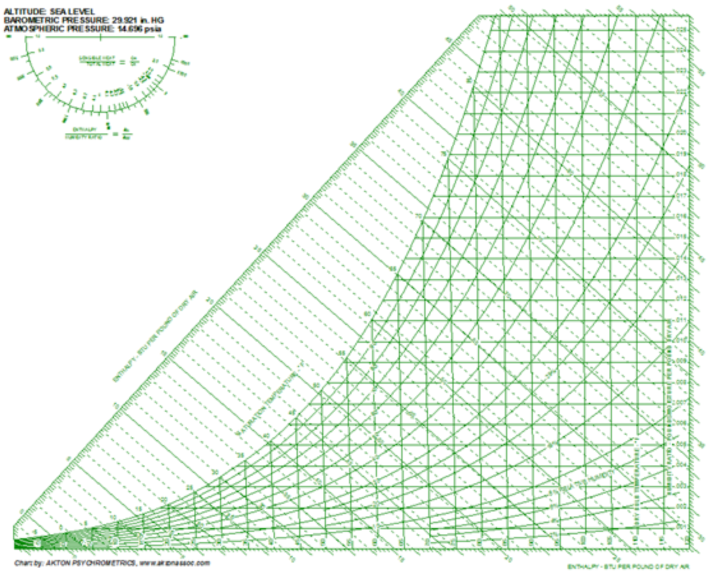


Figure 6. *Psychrometric chart*

23. What are the physical properties of air?

- Dry-bulb temperature
  - o This is usually referred to simply as air temperature, the most familiar air property. Dry-bulb temperature, Tdb, can be measured using a standard thermometer or more sophisticated sensors. This temperature is an indicator of heat content and is shown along the bottom axis of the psychrometric chart. The vertical lines extending upward from this axis are constant temperature line.
- Relative humidity, RH
  - o This the ratio of the actual water vapor pressure, Pv, to the vapor pressure of saturated air at the same temperature, Pvs, expressed as a percentage. Relative humidity is a relative measure, because the moisture-holding moisture level of the air compared to the air's moisture-holding capacity. Relative humidity lines are shown on the chart as curved lines that move upward to the left in 10 percent increments. The line representing saturated air (RH= 100%) is the uppermost curved line on the chart.

- Wet-bulb temperature, Twb
  - o This represents how much moisture the air can evaporate. This temperature is often measured with a common mercury thermometer passing over the wick. On the chart, the wet-bulb lines slope a little upward to the left, and this temperature is read at the saturation line.
- Dew point, Tdp
  - o This is the temperature at which water vapor starts to condense out of the air that is cooling. Above this temperature, the moisture stays in the air. This temperature is read by following a horizontal line from the state-point (found earlier) to the saturation ine.
- Specific volume
  - o This represents the space occupied by a unit weight of dry air, usually expressed in m^3/kg dry air, and is equal to 1.205 kg/m^3 air density. Specific volume is shown along the bottom axis of a psychrometric chart, with constant-volume lines slanting upward to the left..
- Humidity ratio, w
  - o This is the dry-basis moisture content of air expressed as the weight of water vapor per unit weight of dry air. Humidity ratio is indicated along the right-hand axis of a psychrometric chart.
- Enthalpy, h
  - o This is the measure of air energy content per unit weight (kJ/kg). Wet-bulb temperature and enthalpy are related intuitively. So, enthalpy is read from where the appropriate wet-bulb line crosses the diagonal scale above the saturation curve

Sample Computations

Calculate from the dry-bulb and wet bulb temperature the relative humidity.

Given: Dry- bulb Temperature = 30^0C
Wet-bulb Temperature = 20^0C

Find: Relative Humidity

Solution:

1. Locate 30^{0}C on dry-bulb scale at bottom chart;

2. Draw a straight line up the 30^{0}C line to the curve line at the instep;

3. Follow down the instep (wet-bulb scale) to 20^{0}C;

4. Draw a line diagonally along the 20^{0}C wet-bulb line until it crosses the 30^{0}C dry-bulb line; and

5. Read 40% relative humidity at the intersection of the dry-bulb and wet-bulb lines.

Example 2

Calculate from the dry-bulb and wet-bulb temperatures the dewpoint.

Given: Dry- bulb Temperature = 40^{0}C

Wet-bulb Temperature = 30^{0}C

Find: Dewpoint

Solution:

1. Find the intersection of the 40^{0}C dry-bulb line and 30^{0}C wet-bulb

2. Proceed horizontally to the instep line; and

3. Read 27.5^{0}C dewpoint temperature. At 40^{0}C dry-bulb and 30^{0}C we-bulb, the dewpoint temperature is 27.5^{0}C.

What are the three groups of factors affecting drying efficiency?

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task.

- Those related to the environment, in particular, ambient air conditions;
- Those specific to the crop; and
- Those specific to the design and operation of the dryer.

What are the performance parameters for evaluation of dryers?

- Drying Capacity (kg/h) = $\frac{\text{Initial weight of grain, kg}}{\text{drying time, h}}$

- Moisture reduction per hour = $\frac{\text{Total moisture removed, kg}}{\text{Drying time, h}}$

- Heating system efficiency = $\frac{\text{Heat supplied to the dryer}}{\text{Heat available in the fuel}}$

Heat supplied to the dryer = (h2-h1) x Q x 60/v

Where:

h2 = enthalpy
h1 = enthalpy of ambient air, kJ/kg
v = specific volume of ambient air, m^3/kg dry air
Q = airflow rate, m^3/min

Heat available in the fuel = fuel feed rate, kg/min x heating value of fuel, kJ/kg

- Heat utilization, kJ/kg = $\frac{\text{heat supplied, kJ/h}}{\text{total Moisture removed, kg}}$

- Drying efficiency = $\frac{\text{Heat required to evaporate moisture from grain}}{\text{Heat supplied to the dryer}}$

  Heat required to evaporate moisture from the grain =
  Heat of vaporization of water x moisture reduction per hr

- Drying system efficiency = $\frac{\text{Heat required to evaporate moisture from grain}}{\text{Heat available in the fuel}}$

Sample Computation:

Given:

Ave. ambient air temperature = 30^0C
Relative humidity = 80%

Average drying temperature =60^0C

Fan's casing = =2 ft

Ave. air velocity = 2000 ft/min

Rice hull heating value (Hv) = 12,000 kj/kg

Fuel consumption = 30 kg/hr

Drying time = 8 hr

Initial grain weight (Wi) = 6,000 kg

Initial moisture content = 24%

Final moisture content = 14%

Compute for:

1. Drying capacity, kg/hr
2. Final weight of paddy, (Wf), kg
3. MC reduction per hr, (by weight), kg/hr
4. Heating system efficiency (HSE)
5. Heat utilization, kJ/kg
6. Drying system efficiency, %

Solutions:

1. Drying Capacity = Initial Weight (Wi) ÷ Drying Time
   = 6000 kg ÷ 8 hrs
   = 750 kg/hr

2. Final Weight of Paddy = Initial Weight (100 – MCi) /(100 – MCf)

= 6000 kg (100 – 24%) / (100 – 14%)
= 6000 kg (76/86)
= 5 ,302.32 kg

3. Moisture Content Reduction per Hour = Initial Weight – Final Weight / Drying Time
= 6000 kg – 5302.32 kg / 8 hr
= 87,21 kg/hr

4. Heating System Efficiency = Heat Supplied to the Dryer x 100 % Heat Available in the Fuel

Heat Supplied to the Dryer = (Enthalpy2 – Enthalpy1) x Airflow rate / Specific Volume

Where:

Enthalpy 1(h_1) = 85 kJ/kg

Enthalpy 2 (h_2) = 117.5 KJ/kg

Specific Volume = 0.975 m3/kg

Figure 8: Show Chart for h_1 and h_2

Figure 9 : Show chart of specific volume, v

Airflow Rate, Q = Area x Air Velocity

Area = d2 ÷ 4 = 3.1416 x (22/4) = 3.1416 ft2

Q = 3.1416 ft2 x 2000 ft/min = 6283.2 ft3 x (m/3.28 ft) 3 = 178.04 m3/ min

Heat Supplied to the Dryer = $\frac{(117.5 - 85)\ kJ/kg \times 178.04\ m^3/min}{0.975\ m^3/kg}$

= 5934.67 kJ/min

Heat Available = fuel rate x heating value of fuel

= 30 kg/hr x 12000 kJ/kg

= 360,000 kJ/hr x hr/60 min

= 6000 kJ/min

Heating System Efficiency = (Heat Supplied / Heat Available) x 100%

= (5934.67 kJ/min / 6000 kJ/min) x 100%

= 98.9%

5. Heat Utilization, kJ/kg = $\frac{\text{Heat Supplied (kJ/h)} \times 8\ hr \times 60\ min/hr}{697.68\ kg}$

= 4,083.02 kJ/kg

6. Drying system efficiency, % = $\frac{\text{Heat required to evaporate moisture from grain}}{\text{Heat available in the fuel}}$

Given:

MC reduction rate = 697.68 kg/8 hr = 87.21 kg/hr

Latent of vaporization of water in grain = 2502 kJ/kg + 15% water in grain = 2627.1 kJ/kg

Drying System Efficiency, % = $\frac{87.21\ kg/hr \times 2627.1\ kJ/kg}{360{,}000\ kJ/hr}$

Drying System Efficiency = 63.64 %

METHODS AND SYSTEMS OF DRYING

1. What are the drying methods for paddy?

There are many different drying methods for paddy. These are various drying technologies with different scales and complexities. There is no ideal dryer for drying paddy grain since each drying method has its own inherent advantages and disadvantages.

- Sun Drying

  o Sun drying is a natural method of drying since it relies mainly on solar energy and natural air movement. The process is cheaper and requires no special skills. o Sun drying usually use drying underlays such as nets, mats, plastic sheet or concrete pavements. Occasional mixing and turning of the grain is necessary to maintain grain quality.

  o Sun drying has some limitations :

  it is not possible during rainy season and at night;

  delay leads to excess respiration and fungal growth causing losses and yellowing;

  it is labor intensive and has limited capacity; and

  with unstable temperature that may cause overheating or re-wetting of grains that can lead into low milling quality as a result of cracks developing i n the kernels.

Table 3. Overview on different drying methods and technologies

Method	Crop Flow	Drying Technology	Advantages	Disadvantages
Sun drying	Batch	Drying pavements or mats/ underlays	😊 Cheap	☹ Labor intensive ☹ Typically poor milling quality
Heated air drying	Batch	Fixed bed dryer	😊 Inexpensive, small scale operation possible 😊 Local construction from various materials 😊 Operation with unskilled labor	☹ High moisture gradient ☹ Labor intensive
		Re-circulating batch dryer	😊 Mixing of grain 😊 Large capacity range 😊 Good quality	☹ Skilled laborers required ☹ Medium capital investment ☹ After-sales service requirement ☹ Rapid wear & tear of moving components
	Continuous	Continuous flow dryer	😊 Large capacity 😊 Economics of	☹ High capital investment ☹ Not feasible for small batches of different varieties ☹ Complicated operation
In-Store Drying	Batch	Storage bin with aeration components and pre-heater for adverse weather and night time operation	😊 Excellent grain quality 😊 Large capacity range	☹ Pre-drying of high moisture grain (flash drying) 😊 Risk of spoilage during power failure 😊 Longer drying time

2. **What are the recommendations for sun drying?**

Proper management of sun drying is necessary to ensure good quality grain. The following general guidelines are recommended for proper sun drying:

- Spread the grains in thin layers, ideally 2 to 4 cm. Too thin layers tend to heat up very quickly with negative effect on the head rice recovery. If layers are too thick a large moisture gradient develops with dry grains on the top and wet grains on the bottom, which re-adsorbs moisture after mixing, thus resulting in cracked grains. The optimum layer thickness is somewhere between 2 to 4 cm.

- Mixing or turning the grain every 30 minutes to achieve uniform moisture content, is the most important activity for maintaining good quality.

- To avoid accumulation of water in case of rain, drying pavement should be constructed with a sloping contour with drainage canals around. Plastic sheets or canvass may be useful in protecting the spread paddy from sudden downpours.

- Prevent contamination of grain with other materials and keep animals off the grain;

- Monitor grain moisture content and grain temperature.

- For large drying requirements, mechanical dryers are recommended.

Besides layer depth and mixing interval, the drying rate of sun drying depends on other factors which could not control the operator:

- Temperature and humidity of ambient air: the rate at which rice dries is affected significantly by the temperature and humidity of the air that moves over or through the grain For this reason, in most tropical, humid climates sun drying is only successful during a few hours in the mid-day.

- Initial moisture content of grain: wet grains dry at a higher drying rate than comparatively dry grains.

- Air velocity: natural convection is usually not enough to transport large amounts of evaporated moisture away from the grain. Therefore, drying rates of sun drying are higher on windy days compared to days without wind.

3. **What is heated air drying?**

Heated air drying employs high temperatures for rapid drying and the drying process is terminated when the average MC reaches the desired final MC.

Unlike sun drying, heated air drying or mechanical drying has the advantage that suitable drying air conditions can be set, and that drying can be carried out any time of the day or night. Use of mechanical drying may also reduce the labor costs, especially if some form of mechanical turning or stirring of grain is practiced, as in the case of re-circulating dryers.

4. **What are the basic components of a mechanical dryer?**

A dryer typically consists of three main components and often has some additional accessories. The main components are: the drying bin for holding the grain; the fan for moving the air through the dryer and the grain; the air distribution system; and the heating system for pre-heating the drying air.

- **Drying Bin**

The function of the drying bin is to hold the grain for drying and in in-store drying also to serve as the storage bin after drying. Drying bins come in different shapes according to the requirements of the design of the dryer . Depending on the model of dryer and locally available materials they can be made from different materials such as metal, wood, concrete, bricks, woven bamboo mats etc.

- **Fans and Air Distribution System**

The function of fan is to move the drying air through the drying system. Depending on the required airflow rate and the needed pressure creation either axial-flow or centrifugal fans are used. The purpose of the air distribution system is to deliver the drying air to the drying chamber in the dryer and to remove the moisture that was extracted from the grains. Major elements of the air distribution system are a plenum chamber, air channels, and air ducts or false floors.

- **Heating System**

Depending on the availability and cost, different heating system can be used for heating the drying air such as kerosene, diesel, LPG, biomass like rice hull, or electricity.

In Southeast Asia kerosene burners are most common because of their simple design, availability and easy handling of the fuel. In the Philippines, biomass furnace using rice hull or corn cobs is commonly used in heating the drying air.

5. **What is the difference between direct and indirect heating?**

Heating system can be direct or indirect heating. In a direct heating the combustion products are mixed with the drying air or flue gases come in contact with the paddy. Indirect heating, on the other hand, involves a heat exchanger for heating up the drying air. Indirect heating decreases the total fuel efficiency of the dryer.

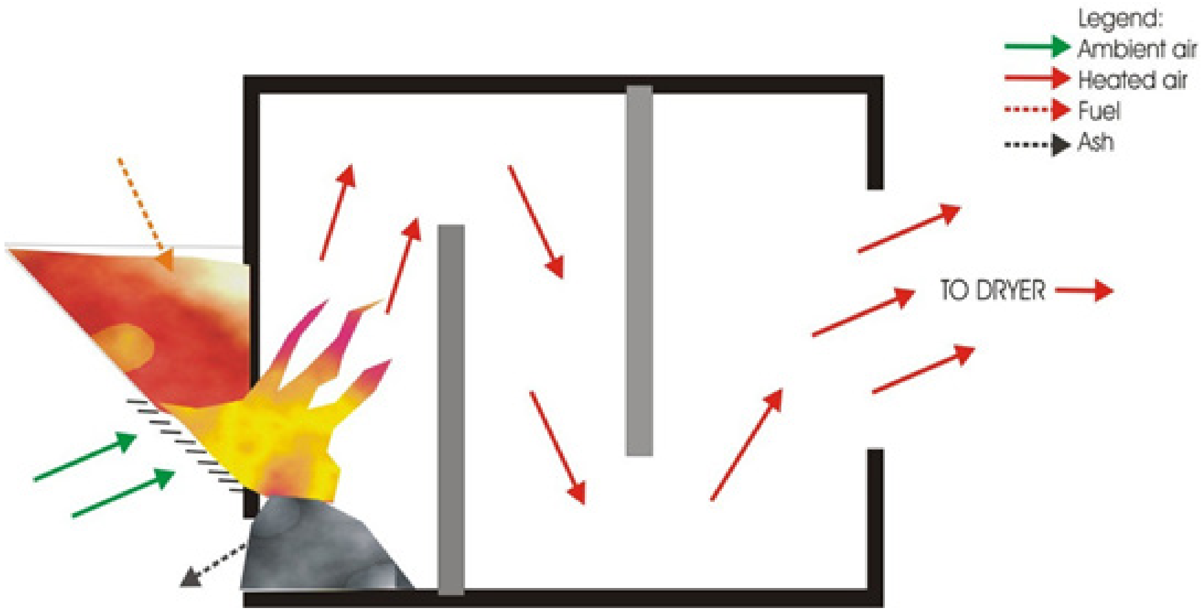


Figure 7. *Schematic diagram of PHilMech direct biomass furnace (Grate type)*

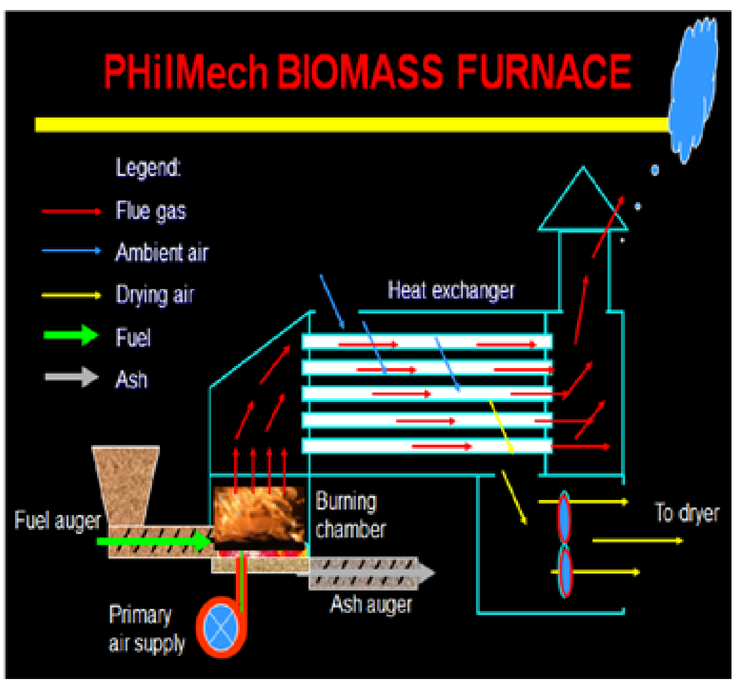


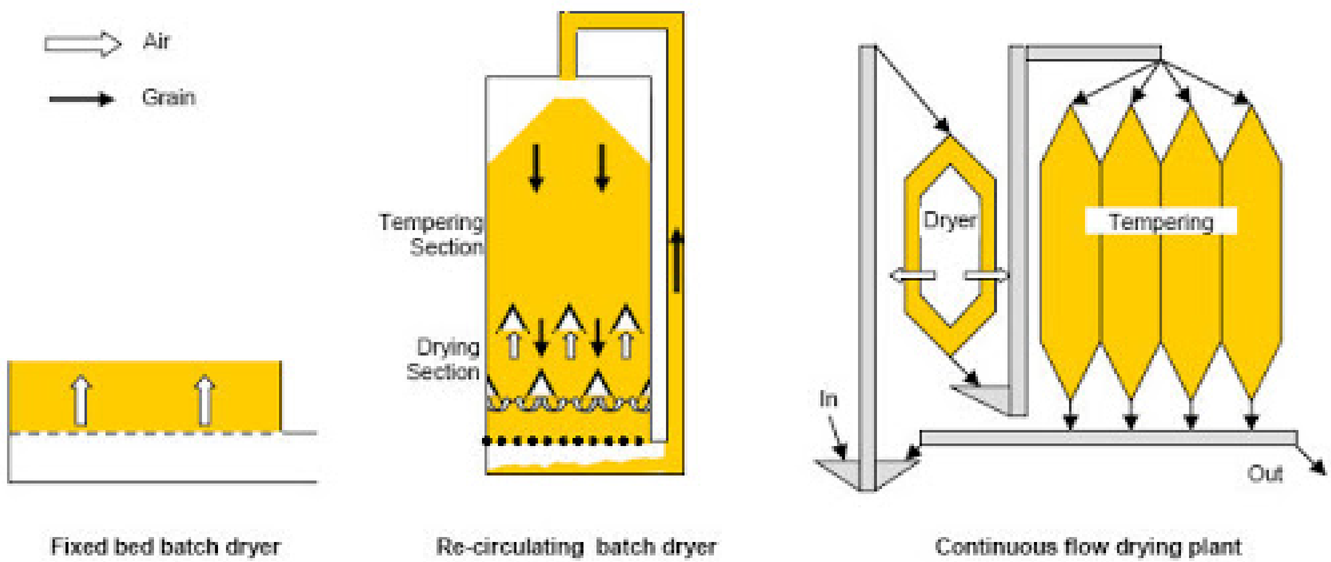
Figure 8. *Schematic diagram of PHilMech indirect biomass*

6. Why is mechanical drying recommended?

In general, mechanically dried grain will produce better quality rice compared to sun drying. Mechanical drying will lead to more uniform drying of grain and higher milling yield and head rice recovery. For production of premium quality rice or seed, mechanical drying with heated air dryers is highly recommended. Grain re-circulation allows for uniform dried grains and automatic drying air temperature control will maximize the drying rate and at the same time reduce over-heating or over-drying.

7. What are the Different Types of Heated Air Dryer?

The most common way of characterizing heated air drying systems is through the description of the way how the grain is being held in or flows through the system. Figure 5 shows the difference between fixed bed batch dryers, re-circulation batch dryers and continuous flow dryers.



Source: IRRI, (2002)

Figure 9. *Dryer classification according to crop holding / crop flow?*

8. What are the different types of heated air dryer?

The most common types of grain dryers in Asia are the fixed bed dryer and the re-circulating batch dryer. They are both batch-fed dryers meaning that a certain quantity of grain is loaded and dried before the dryer is unloaded and a new batch can be dried.

- Fixed-Bed Batch Dryer
  Fixed bed dryers usually have rectangular bins with plenum chamber underneath, otherwise known as the flat-bed dryer. It has been developed for farm or village-level use. Their capacity ranges from 1 to 6 tons/day with drying time of 6 to 12 hours.

- **Re-circulating Batch Dryers**

  In many Asian countries re-circulating batch dryers are increasingly being used by the private sector for producing better quality grain and for handling large amounts in the peak season safely. This type of dryer avoids the problems of moisture gradients experienced with bin dryers by re-circulating the grain during drying.

9. How does the recirculating batch dryer works?

The dryer generally has a drying section and a tempering section, and grain circulates through these sections in order to alternate drying and tempering. At the same time the grains are mixed which results in minimal moisture variation in the dried grains. In general, burners are separated from the fan and the fan draws air through the dryer and the burner that is mounted on the opposite side of the dryer. Re-circulation of grain is done by a belt or auger for unloading and bucket elevator for vertical transport of the grain.

Source: IRRI, (2002)

Figure 10. *A row of re-circulating batch dryer in the Philippines*

10. What are the main advantages of the re-circulating dryer?

- Its size and shape occupies only very limited floor space and it can easily be placed inside a grain store or warehouse.
- The continuous mixing of the grain during the drying operation results in a very low moisture.

- During the circulation process the grain is tempered when it passes through sections of the dryer where it is not exposed to the hot drying air.

- Automatic controls with automatic shutoff. However, the loading, unloading and circulation of grain create dust which needs to be collected.

11. What are the types of re-circulating batch dryers?

Depending on airflow relative to grain flow, there are two different types of re-circulating dryers as shown in Figure 15.

- Cross flow: simpler construction, better with wet grain.

- Mixed flow: better grain quality from better mixing

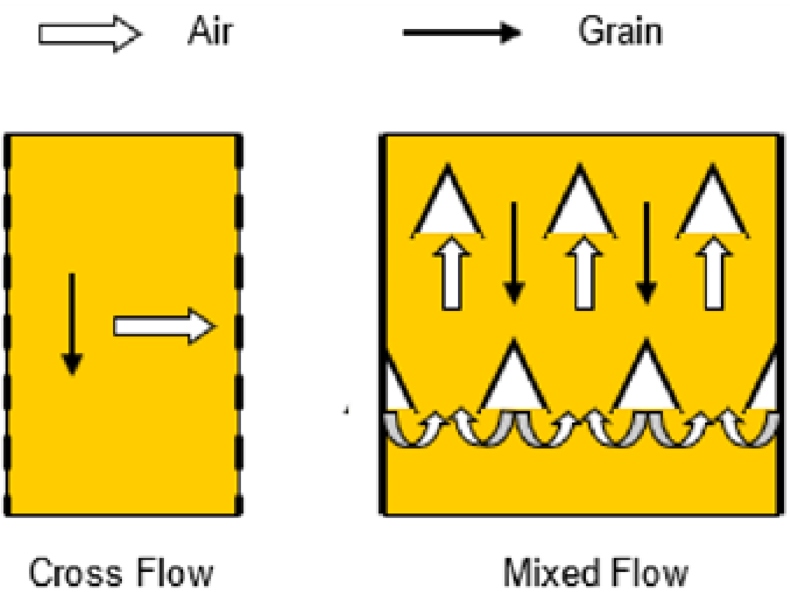


Figure 11. *Cross and mixed flow type of re-circulating dryers*

12. What are the differences between cross flow and mixed flow dryers?

In cross flow dryers the grains are not mixed while they are passing the drying section and being exposed to the hot drying air. This means that a moisture gradient develops in the drying section of the dryer. In the recirculation and tempering process this gradient is reduced because the wet and dry grains are mixed while they are being conveyed and subsequently moisture transfer happens from the wetter to the dryer grains. While this process is not optimal it still produces much better quality than a fixed bed dryer because the moisture gradients are much smaller.

In a mixed flow dryer, the grain is permanently being mixed while it passes the drying section and thus a moisture gradient cannot develop. Mixed flow drying sections, however, have limitations when the crop is very wet and has a lot of foreign materials. Because there are more components inside the drying section clogging can happen more easily than in cross-flow drying sections.

13. What is a continuous-flow dryer?

Continuous-flow dryers can be considered as an extension of re-circulating batch dryers. However, rather than the grain re-circulating from bottom to top, as in the latter, the grain is removed from the bottom, in some systems, cooled, and then conveyed to tempering or storage bins. In their simplest form, continuous-flow dryers have a garner (or holding) bin on top of the drying chamber. In some continuous-flow dryers, holding bin is located below the drying compartment in which ambient air is blown through the grain.

14. What are the three categories of continuous-flow dryers based on the way in which grain is exposed to the drying air?

- Cross flow, in which the grain moves downward in a column between two perforated metal sheets while the air is forced through the grain horizontally. Dryers of this type are relatively simple and inexpensive, but, unless mixing systems are incorporated, moisture gradients are set up across the bed.

- Counter-flow, which employs a round bin with an unloading system at the base and an upward air flow. These dryers are relatively efficient since the air exhausts through the wettest grain. Bed depths of up to 3-4 m can be used.

- Concurrent flow, which is the reverse of counter flow drying in that the air moves down through the bed. High air temperatures can be used since the air first encounters wet, and sometimes cold, grain. Drying is rapid in the upper layers but slower at the bottom with some tempering action. Bed depths of at least a meter are used.

The most commonly used continuous-flow dryer is the cross flow columnar dryer, which can be classified as non-mixing and mixing types.

In one version of a non-mixing dryer drying takes place between two parallel screens, 150250 mm apart on either side of the plenum chamber. The air escapes from the dryer through louvers on either side of the dryer. The flow rate of grain through the dryer is controlled by a regulator gate at the base of the drying column. Since the grain flows plug-like through the drying, section the layer of grain closer to the plenum chamber is dried by hotter and dryer air than is the grain on the outside. However, mixing is effected to a fair degree when the grain is discharged and conveyed to tempering and storage bins.

Air temperatures of 45-55°C and airflows of 2-4 m3/s per ton of grain are used. Flow problems can be encountered with very wet and dirty grain as the grain may clog. Teter (1987) notes that if very wet paddy is to be dried then the grain should be cleaned and pre-dried to at least 22 percent moisture before a non-mixing dryer can be used.

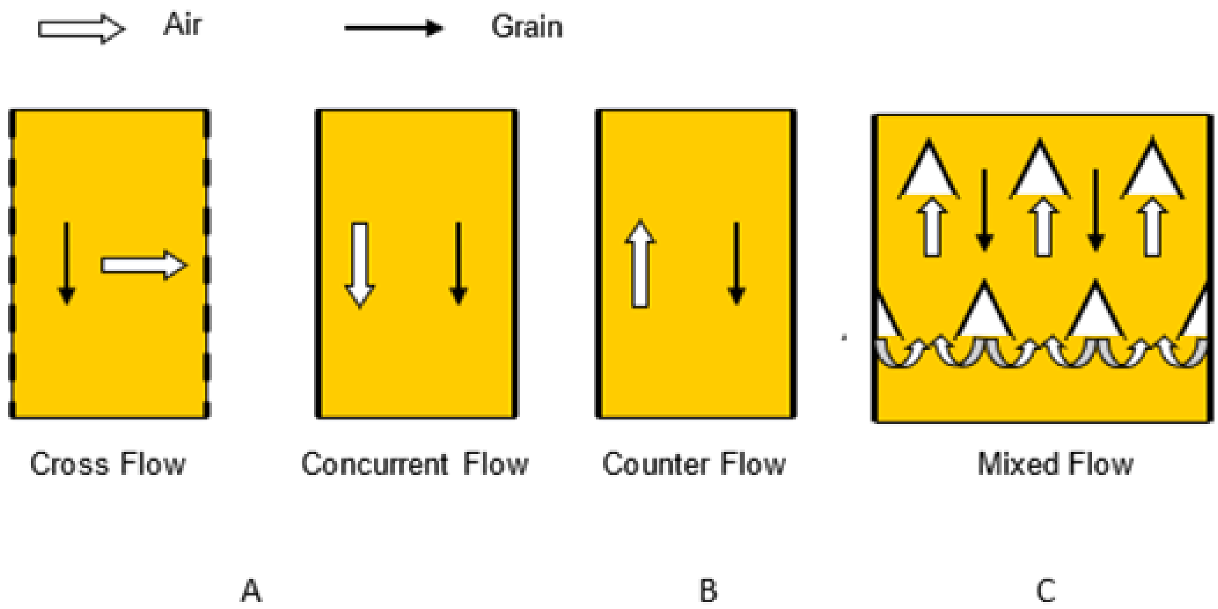


Figure 12. *Cross flow columnar dryers*

Another design of the mixing type is the Louisiana State University (LSU) dryer, as shown in Figure 13 In this version, the drying section consists of a vertical compartment across of which rows of air channels are installed. One end of each channel is open and the other is closed. Alternative rows are open to the plenum chamber and intervening rows to the exhaust section. Alternate rows are also offset such that the channel tops divide the moving stream of grain as it descends providing considerable mixing.

15. How is continuous-flow dryer differ to batch-in and recirculating dryers

Compared to batch-in bin and re-circulating dryers, continuous-flow dryers offer the largest drying capacity. When large volumes of wet grain are to be dried in a single site, these are the types of dryers to be considered first. They are most commonly used in a multi-pass drying operation. Investment costs are high but because of the large flow rate, operating costs per ton can be lower than the larger batch-in-bin dryers and re-circulating dryers.

16. What is a multi-pass drying system?

In a multi-pass drying system, continuous-flow dryers are used in association with tempering bins. During each pass through the dryer, the grain is dried for 15 to 30 minutes with a reduction in moisture content of 1 to 3 percent. Drying at this rate sets up moisture gradients within the individual grains. After each pass, the grain is held in a tempering bin where the moisture within the kernel equalizes as moisture diffuses from the interior of each kernel to the surface. The combination of rapid drying and tempering is repeated until the desired moisture content is attained. Using this procedure, the actual residence time of the grain within the continuous-flow dryer is of the order of 2 to 3 hours to effect a 10 percent reduction in moisture. Selection of the number of passes is a compromise between the dryer efficiency (i.e. fewer passes) and grain quality (i.e. longer drying time).

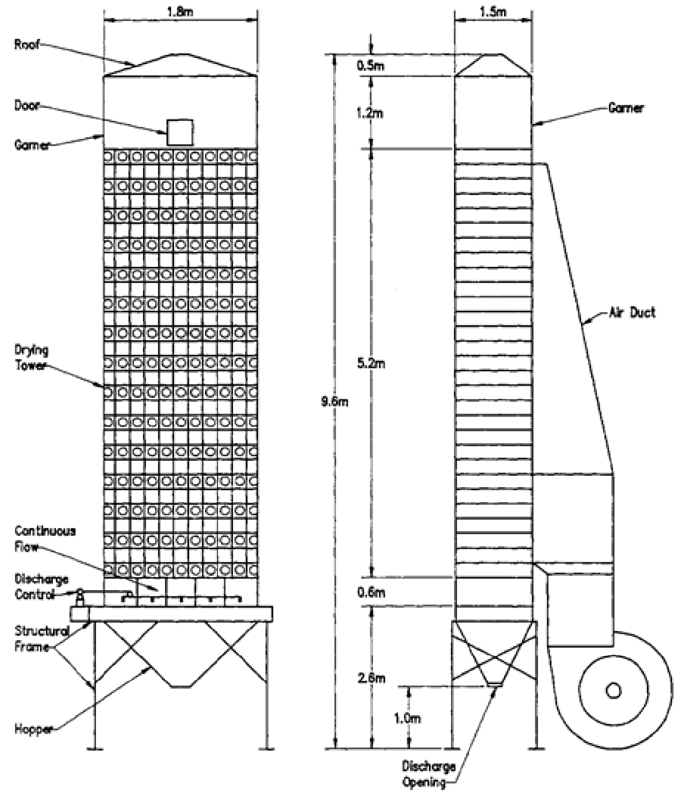


Figure 13. *Schematic diagram of Louisiana State University (LSU) Dryer*

Figure 14. *A multi-pass continuous flow dryer*

Tempering periods are usually 4 to 24 hours in duration. The tempering bins may be aerated with ambient air to cool the grain with some slight moisture removal.

It is vital that the operation of drying with tempering is carefully planned and managed to ensure maximum throughput and efficiency. This usually means that the plant is operated 24 hours a day with two or more batches of grain being dried at a time. Well trained management and staff are essential.

16. What is a fluidized bed drying system?

A fluidized bed is formed when a quantity of a solid particulate substance (usually present in a holding vessel) is placed under appropriate conditions to cause a solid/fluid mixture to behave as a fluid. This is usually achieved by the introduction of pressurized fluid through the particulate medium. This results in the medium then having many properties and characteristics of normal fluids, such as the ability to free-flow under gravity, or to be pumped using fluid type technologies.

The resulting phenomenon is called fluidization. Fluidized beds are used for several purposes, such as fluidized bed reactors (types of chemical reactors), fluid catalytic cracking, fluidized bed combustion, heat or mass transfer or interface modification, such as applying a coating onto solid items. This technique is also becoming more common in aquaculture for the production of shellfish in integrated multi-trophic aquaculture systems

17. What are the properties of a fluidized-bed dryer?

A fluidized bed consists of fluid-solid mixture that exhibits fluid-like properties. As such, the upper surface of the bed is relatively horizontal, which is analogous to hydrostatic behavior. The bed can be considered to be a heterogeneous mixture of fluid and solid that can be represented by a single bulk density.

In fluidized beds, the contact of the solid particles with the fluidization medium (a gas or a liquid) is greatly enhanced when compared to packed beds. This behavior in fluidized combustion beds enables good thermal transport inside the system and good heat transfer between the bed and its container. Similar to the good heat transfer, which enables thermal uniformity analogous to that of a well-mixed gas, the bed can have a significant heat-capacity whilst maintaining a homogeneous temperature field.

18. What are the uses of fluidized bed dryer?

Fluidized beds are used as a technical process which has the ability to promote high levels of contact between gases and solids. In a fluidized bed a characteristic set of basic properties can be utilized, indispensable to modern process and chemical engineering, these properties include:

- Extremely high surface area contacts between fluid and solid per unit bed volume
- High relative velocities between the fluid and the dispersed solid phase.

- High levels of intermixing of the particulate phase.

- Frequent particle-particle and particle-wall collisions.

  Fluidized beds are also used for efficient bulk drying of materials. Fluidized bed technology in dryers increases efficiency by allowing for the entire surface of the drying material to be suspended and therefore exposed to the air. This process can also be combined with heating or cooling, if necessary, according to the specifications of the application.

  Bed types can be coarsely classified by their flow behavior, including:

- **Stationary or bubbling fluidized bed** is the classical approach where the gas at low velocities is used and fluidization of the solids is relatively stationary, with some fine particles being entrained.

- **Circulating fluidized beds (CFB)**, where g ases are at a higher velocity sufficient to suspend the particle bed, due to a larger kinetic energy of the fluid. As such the surface of the bed is less smooth and larger particles can be entrained from the bed than for stationary beds. Entrained particles are recirculated via an external loop back into the reactor bed. Depending on the process, the particles may be classified by a cyclone separator and separated from or returned to the bed, based upon particle cut size.

- **Vibratory fluidized beds** are similar to stationary beds, but add a mechanical vibration to further excite the particles for increased entrainment.

- **Transport or flash reactor (FR).** At velocities higher than CFB, particles approach the velocity of the gas. Slip velocity between gas and solid is significantly reduced at the cost of less homogeneous heat distribution.

- **Annular fluidized bed (AFB).** A large nozzle at the center of a bubble bed introduces gas as high velocity achieving the rapid mixing zone above the surrounding bed comparable to that found in the external loop of a CFB.

OPERATION AND MAINTENANCE OF DIFFERENT DRYING SYSTEM

Batch-type Flatbed Dryer

1. What are the major parts and function of a flatbed dryer?

A flatbed dryer consists of four main components and often has some additional accesso ries. The main components are: (1) the drying bin for holding the grain; (2) the fan for moving the air through the dryer and the grain: (3) The air distribution system: (4) The heating system raised the teperature of the drying air.

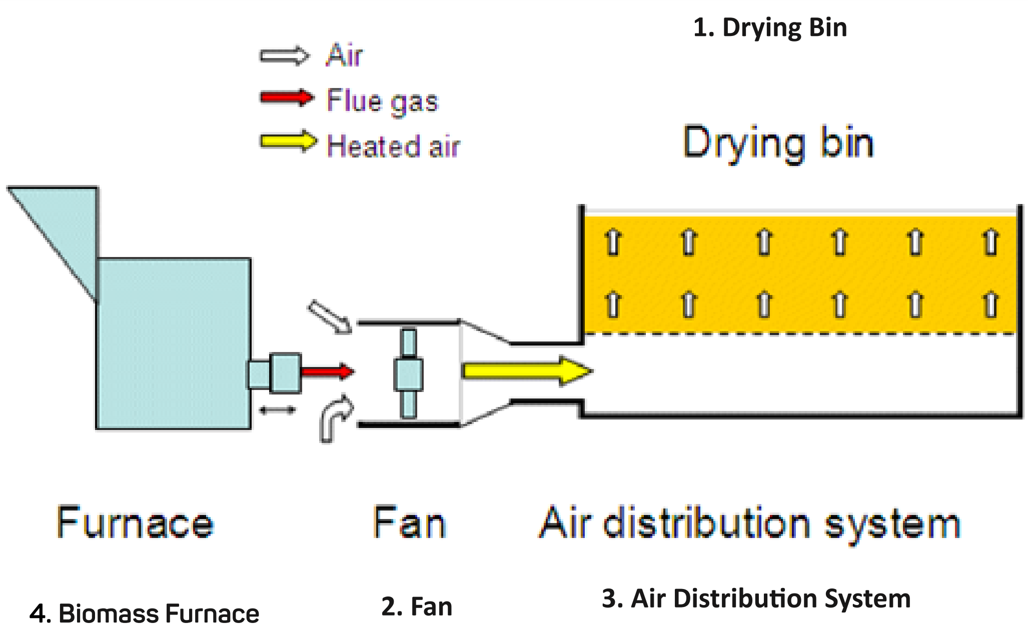


Figure 15. *Schematic diagram of a flatbed dryer*

- Biomass Furnace

o A biomass furnace is the most common heat source in heating the drying air for a flatbed dryer in the Philippines. Bio-mass furnace comes in a variety of designs and forms but they can be classified into direct-fired and indirect-fired.

o Direct-fired furnaces are cheaper because it does not utilize any heat exchanger. Its main problem is the control of smoke and fly ash from coming into the dryer which affects the quality of the grain. Smoke and fly ash cause darkening of the grain surface and is a fire-hazard. Figure 15 shows a grate-type direct-fired furnace. Baffles are employed to minimize entry of ash into the dryer but they are usually ineffective. Figure 16 shows a cyclonic type direct-fired furnace. Fuel is fed tangentially and burned as it spirals downward inside the burning chamber. Flue gas and some fly ash may flow into the dryer.

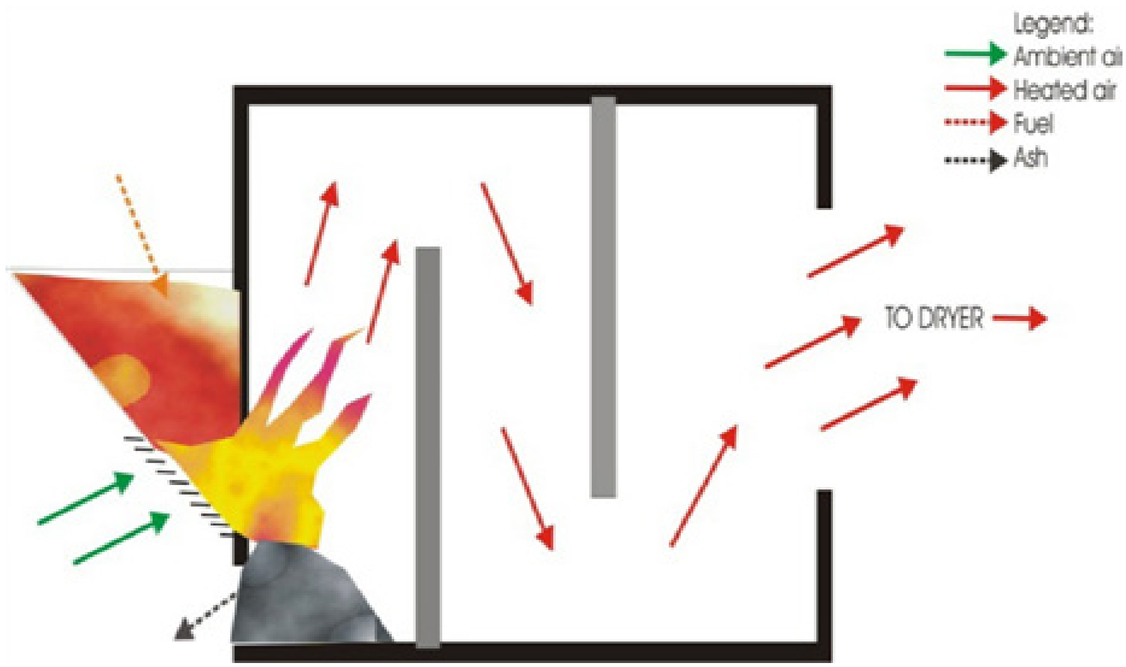


Figure 16. *Schematic diagram of direct-fired grate-type furnace*

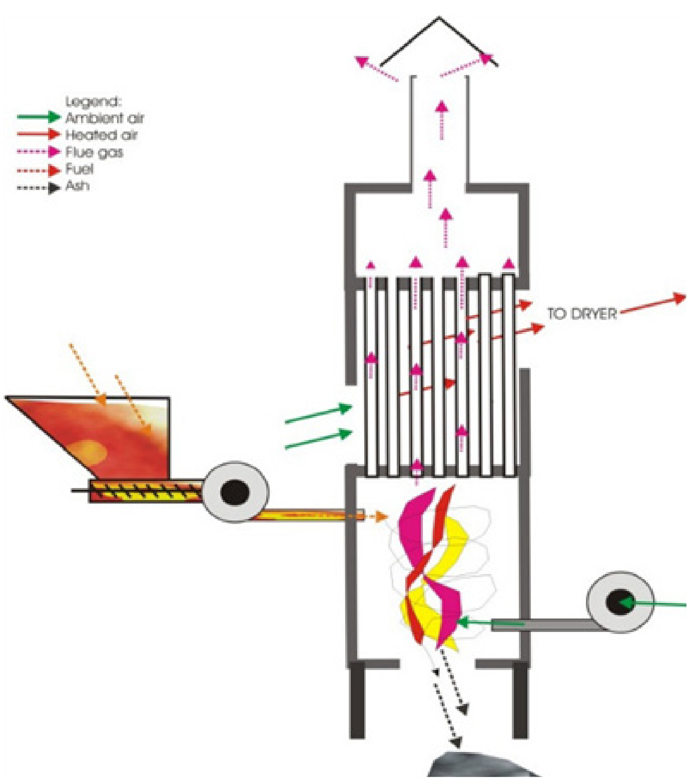


Figure 17. *Schematic diagram of a direct-fired cyclonic furnace*

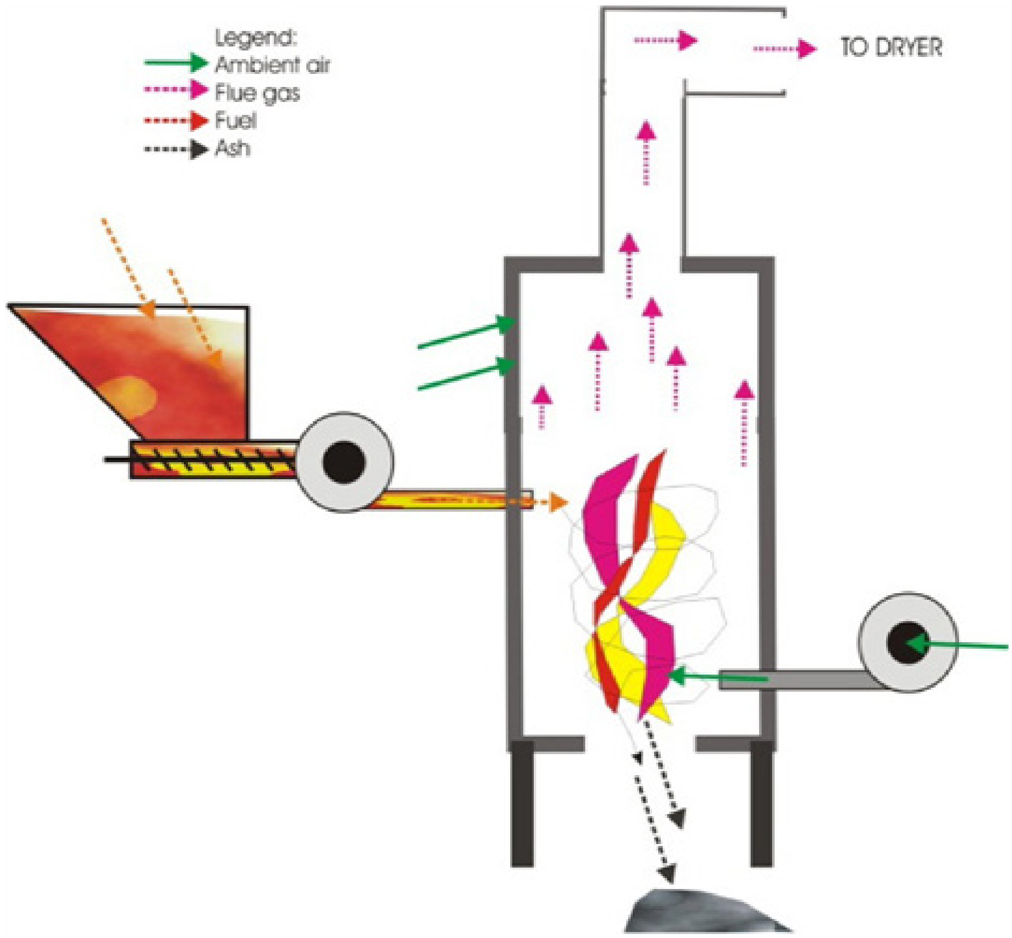


Figure 18, *The same cyclonic surface with heat exchanger*

Indirect -fired furnaces utilize heat exchangers to prevent smoke and fly ash from coming into the dryer. Heat exchangers, usually made of durable materials that resist high temperatures such as fire tubes, makes indirect-fired furnaces two to three times more expensive than direct-fired furnaces but they supply clean and smokeless air to the dryer.

There are also two main types of indirect-fired furnaces, the dry-type and wet-type.
In drytypes, hot flue gas flows into one end of the fire tubes and exits at the other end while cold air is heated as it flows around the heated surface of fire tubes. Figure 18 shows the same cyclonic furnace with a heat exchanger to provide clean hot air.

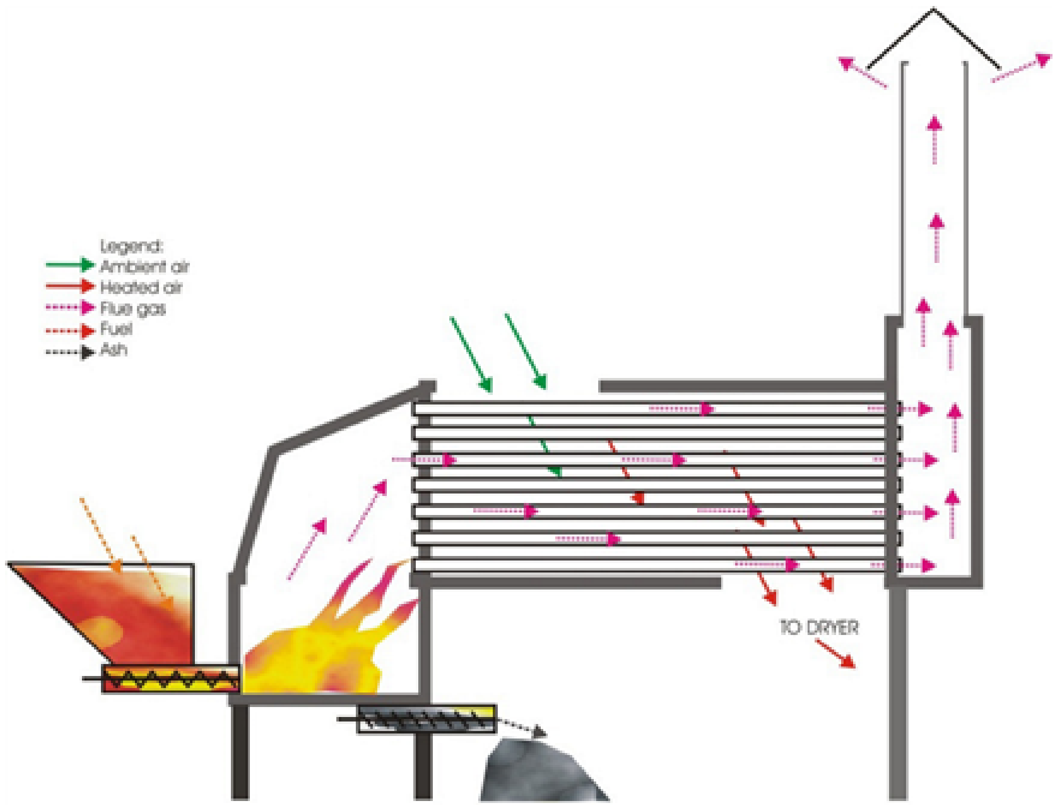


Figure 19-a. *Schematic diagram of an auger-fed indirect-fired biomass furnace*

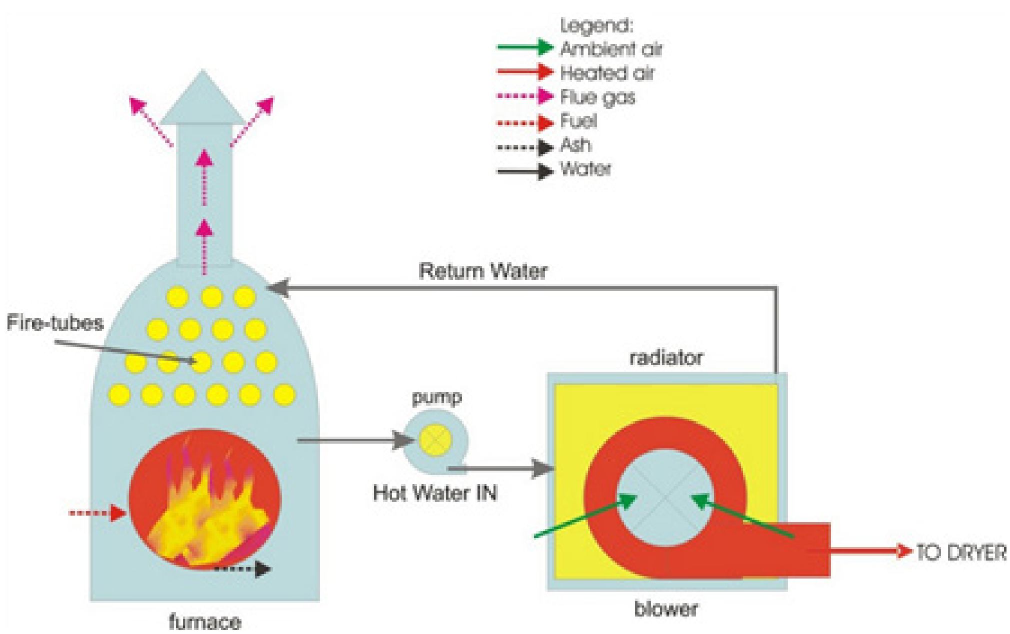


Figure 19-b. *Schemic diagram of an auger-fed indirect fired biomass furnace*

- **Fan**

  An axial flow fan is commonly used in moving the drying air through the drying chamber to remove the moisture that was extracted from the grains. The fan used in a flatbed dryer is usually powered by a 12 hp diesel engine or by an electric motor.

- **Air Distribution System**

  Air duct system is commonly used in fixed-batch type dryers for distributing air in the grain bulk. Flatbed dryers have plenum chamber into which a fan delivers the drying air before it enters the grain bulk. It also has a perforated false floor for even distribution of air.

- **Drying Bin**

  A flatbed dryer drying bin are usually has a rectangular bin with plenum chamber underneath. The walls of the drying bin could be made of wood, brick or metal. The floor of the drying chamber is preferably made from fine wire mesh or perforated screens, suitably supported. To facilitate an even airflow through the bed the length of the drying chamber should be 2 to 3 times the width. The height of the plenum chamber is of the order of 0.3 m. Unloading ports can be fitted at intervals in the walls of the drying chamber.

2. What are the pre-operating procedures (for flatbed dryers)?

- clean the drying bin, drying chamber and its surrounding;
- clean and remove the accumulated ash in the furnace assembly;
- check belts, pulley, bearings and bolts before operating the dryer.
- tighten loose screws/bolts;
- check the belt tension and its alignment. Make adjustments if needed. Never make the larger pulley larger than the driven pulley;
- check the air duct connection. Make sure the canvass is not damage, has no air leaks and it is properly attached to the blower and to the bin;
- make sure that the plenum is properly sealed;
- check engine. Make sure the engine is in good running condition. Check its water, oil and diesel levels; and
- prepare sufficient amount of rice hull for the whole drying operation. Rice hull must be dry and free of foreign materials that can clog the rice hull hopper.
- make sure that fire extinguishing materials and equipment (such as fire extinguisher or water) are in place.

3. What are the operating procedures for flatbed dryer?

- Load the grains manually

  - o During loading, minimize stepping on the grains to avoid compression. Compressed grains could cause unequal air distribution, thus, uneven drying

  - o Never overload the drying bin to avoid spillage

  - o Always level the grains to have proportionate air distribution

- Measure the initial moisture content (MCi) of the grains using a moisture meter. Get MC readings from different sampling points (3 on top, 2 in the middle and 3 at the bottom)

- Start the furnace

  - o If the grain is dripping wet or the moisture content is 26 percent or above, run the blower at least 1 to 2 hours to air the grains. After the aeration, start firing the furnace.
  - o Load the rice hull to the hopper
  - o Open the hopper to feed rice hull at the combustion chamber
  - o Ignite the loaded rice hull. Do not use highly flammable substance (such as gasoline and alcohol) to start up fire in the furnace. This may cause spontaneous combustion.

- When the rice hull starts to burn, start the engine at low RPM (at idle level) to run the blower. Allow additional rice hull to flow.

  - o If the fire is already stable, adjust engine to make it run at 1,600 rpm or 24.4 mm (1 inch) of water static pressure. (The floating method is an alternative way to measure the airflow. A paper placed above the grains will float at least an inch from the grains). Maintain the recommended static pressure setting regardless if it is for seeds or for milling purposes.

  - o Check the drying temperature using a dial type thermometer. Monitor if the required temperature of the grain is reached.

  - o Regularly remove the carbonized rice hull from the furnace. Put out the removed rice hull from the furnace with water.

- Set temperature as recommended

  - o Palay

    For seeds: drying air temperature should never exceed 43°C. This is done regardless of the initial MC.
    For food: drying temperature can be set at 50 to 60°C all throughout the drying period

o Corn

Drying temperature can be set at 43°C up to 60°C (109.3°F-140°F) all throughout the drying period

- Maintain the correct airflow, 10,500 CFM at 30 mm H20 static pressure (for full capacity of the grain bin)
- Use the floatation method whenever necessary to determine the appropriate air flow rate.
- Mix the grains every three hours when the moisture gradient is more than 2 percent.

  o When mixing, turn-off the engine and stop feeding rice hull to the furnace o Use a shovel (preferably with rubber at the edge) in mixing but avoid scraping the perforated flooring.

  o Mix the grains from one end of the drying bin to the other and then from top to bottom. Make sure that the grains on the top will be in the bottom, and the grains at the bottom will be in the top of the drying bin. Grains should be leveled after mixing. o Repeat the steps whenever necessary until the MC of grains reaches 14 percent. (always level the grain surface)

- When the grain reaches 14 percent MC, stop feeding rice hull to the furnace.
- Let the blower run for 30 minutes more to cool down the grains before sacking. This aeration is done depending on the prevailing atmospheric and weather conditions during drying. Also, aeration will help prevent the furnace from cracking.
- Discharge the grains manually at unloading ports. With 2 to 4 persons, unloading usually takes 1 hour.

4. What are the post-operating procedures for flatbed dryer?

- When drying is over, rice hull inside the hopper and all remaining rice hull inside the furnace shall be removed and put out with water.
- Never pour water inside the furnace's combustion chamber.
- Dispose properly the carbonized rice hull. Make sure the carbonized rice hull properly extinguished.
- Sweep and clean the drying bin and the drying area/surrounding

5. What are the safety precautions?

- The workers of the dryer should be physically fit. Persons with fever and other sickness, or under the influence of liquor should never operate the dryer
- Wear comfortable clothes while drying. Avoid loose clothes; otherwise keep away from moving parts

- Remove all inflammable materials near the furnace area
- Always check for loose bolts and nuts, set screw on all moving parts
- Use dust mask while operating the dryer to prevent inhaling the dust and smoke
- During operation, avoid storing rice hull near the furnace
- Check rice hull for any foreign contaminants such as stones, bots, etc. to avoid clogging at the hopper

6. How to maintain the flatbed dryer?

- Lubricate bearings regularly
- Clean and remove ash from the furnace after every drying operation
- Check and tighten loose bolts and nuts, set screws and belts before start of operation
- Check the oil level
- After the drying season, apply oil (food safe lubricants like coconut oil, cooking oil, etc.) on the perforated flooring
- Keep the engine in a safe place

Recirculating Batch Type Dryer

1. What are the major parts and functions of a re-circulating batch type dryer?

A re-circulating batch dryer consists of: (1) Drying and tempering bin for holding the grains; (2) Bucket elevators and conveyors for circulating, loading, and unloading grains; (3) Burner for heating the drying air; and (4) Electronic controller and on-line moisture meter for controlling the drying operation.

- Drying and tempering bin for holding the grains

A drying bin hold grains for drying. It comes in different shapes according to the requirements of the design of the dryers. A recirculating batch dryer also has a garner or a holding bin on which ambient air is blown to the grain for tempering.

- Bucket elevators and conveyors for circulating, loading and unloading grains
Conveyors and elevators are used to transport grains to load before drying, circulate during drying and unload grains dried grains. Elevators should be properly sized so that they match the capacity of the dryer. Conveyors and elevators improve the drying efficiency and minimize labor costs.

Indirect-fired biomass furnace is also commonly used for a recirculating batch type dryer. It utilizes heat exchangers to prevent smoke and fly ash from entering the drying chamber. Heat exchangers, usually made of durable materials that can withstand high temperatures such as fire tubes, makes indirect-fired furnaces two to three times more expensive than direct-fired furnace but it can supply clean and smokeless air to the dryer.

There are two types of indirect fired furnace the dry-type and the wet-type. In a dry-type, hot flue gas flows into one end of the fire tubes and exits at the other end while cold air is heated as it flows around the heated surface of fire tubes. Dry-types have a temperature automatic controller that automatically turns ON and OFF the feed auger to maintain a set drying air temperature.

Wet-types employ liquid heating medium, usually water, to absorb and transport heat from the furnace to the dryer. It is more expensive than dry types because it uses two heat exchangers.

Axial-flow and centrifugal fan can be used for a recirculating batch type dryer. Axial fans provide high airflow rate at lower pressure which can suffice the high air volume requirement of a Recirculating Batch Dryer to remove water quickly in a lesser drying time.

- Electronic controller and on-line moisture meter for controlling the drying operation
  A recirculating batch type dryer usually coupled with an electronic controller which automatically turns ON and OFF the drying mechanism to maintain set temperature and desired moisture content.

- Ancillary equipment may include chute, primary air blower, secondary air blower, grain spreader, moisture sensor, dust collection equipment, pre-cleaner, and fuel gage.

- Most dryers of this kind are designed with safety device to operate safely without causing grain degradation. these dryers have a heated air temperature sensor, an automatic conveyor stop sensor, which checks if grains are circulating correctly, an air pressure switch, which checks if drying air is flowing correctly, a thermostat to prevent overheating; a grain level detector to detect if grains are fully loaded in the dryer, and a flame detector to detect a burner flame, etc.

2. What are the pre-operating procedures?

- Check and adjust all parts of the recirculating dryer before drying operation

  o There should be no missing parts of the recirculating dryer. Sometimes missing parts are usually the grease fitting, bearings, pulleys, set screws, nuts and bolts and wiring.

  o There should be no defective components of the dryer. Defective parts maybe a result of rusting, cracking, cramping and tearing. If defective parts occur, ensure repair before drying operation

  o Bearing fitting are properly greased o Check if rotating shafts are aligned o Check if transmission drive is aligned

- o Check the working area. Debris such as lodge grain straw, plastic twine, hardened dust, sprouted grains, stones and pebbles should be removed before drying operation

- Pre-cleaning of grain before drying maybe required depending on the presence of impurities.

- Check power source and ensure that the control panel is functioning.

- Check the ancillary equipment such as the air blower and the moisture sensor.

- When using a biomass heating system, ensure sufficient amount of rice hull or other bio mass fuel, for the whole drying operations. Rice hull or other biomass fuel should be dry and free of foreign materials that can clog the biomass fuel feeding mechanism of the heating system.

3. What are the operating procedures?

- Load the grain to the grain loading hopper. Ensure the bucket elevators and conveyor system is functioning

- Firing of the biomass furnace. Load sufficient rice hull or other biomass fuel at the rice hull hopper assembly.

- Start the drying operation

  - o Get the grains initial moisture content (MCi)

  - o Switch ON the control panel

  - o Load the grains to the damping pit that will convey the grains to the drying chamber. The recirculating batch dryer, generally has tempering and drying sections, for the grains to circulate alternately.

  - o Preventing over drying of part of the grain bulk by using low drying temperatures in a recirculating batch system to prevent thermal stress and cracking of the grain. Set air temperature of 60^{0}C to 80^{0}C with air flow rates of 0.9 to 1.6 m3/ s per tonne of grain (Wimberly 1983). For seed purposes, air temperatures should never exceed 43^{0}C, regardless of the moisture content, to avoid overheating of the grain which kills the germ.

  - o Drying rate with heated air is about 0.6 to 1.0 %/hr, with the standard rate in most dryers being about 0.8 %/hr (Rice postharvest technology 1995). Control of the drying rate can be effected by adjusting the auger speed to regulate the flow of grain through the dryer.

  - o Determining when the product is dry by getting the grain moisture content using a moisture meter or measuring the time required to dry the grain. Recirculating batch dryers are usually equipped with automatic moisture sensor.

- o When the moisture content of the grains reaches 14 percent, cooling and tempering the grain is recommended to maintain grain quality. Tempering bins maybe aerated with ambient air to cool the grain.

- o Unloading of dried grains through its conveyors system. o When drying is through, switch OFF the control panel.

4. **What are the post-operating procedures?**

- When drying is over, remove the excess rice hull or use all remaining rice hull inside the bio mass heating system.
- Put out the burning rice hull with water.
- Dispose properly the carbonized rice hull. Make sure the carbonized rice hull properly extinguished.
- Switch off or disengage all electrical power source.

5. **What are the safety precautions?**

- Trained operator is required in operating the dryer.
- Operators should wear comfortable and suitable clothes while drying. Avoid loose clothes; otherwise keep away from moving parts.
- Always check for loose bolts and nuts, set screw on all moving parts.
- Check rice hull for any foreign contaminants such as stones, bots, etc. to avoid clogging at the auger feeding mechanism of the furnace
- The 'no smoking' regulations should be strictly enforced and appropriate notices should be displayed displayed.

6. **How to maintain the dryer?**

- Prioritizing levels of maintenance along with good record keeping can assist in achieving a true maintenance regime.
- Conduct inspection of the grain dryer every after drying operation.

  o Is the component or equipment of the dryer clean?
  o Is the equipment or component functional?
  o Is the equipment or component in good working order?
  o Is the equipment or component safe?

- Keep inspection reports every after drying operation. Lubrication records should be noted on the inspection report as well.

- When using a kerosene or fuel heating system, make the fuel train a separate inspection re port. Some component failures of the fuel train can be disastrous. (e.g. a fuel valve forced open with a pipe wrench can still be functional, but certainly not safe).
- Create a detailed checklist showing and identifying component areas. This checklist will serve as an extension of the pre-season inspection and any repairs. As repairs are done in season, note them on this form. If a dryer sheet repaired is done, show location of repair and extent of repair.

7. What are the problems encountered with mechanical dryers, their potential causes and possible solutions?

- Knowing the primary go-to service providers is important. Without quick and easy access to this information and knowledge of their hours of support and locations, It will be more difficult maintaining the priority discipline and make quick and often ill-advised repairs with escalating risk. The operator should maintain an updated list of his secondary support personnel as well.

- What to do in case of fire:

  o When the operator first detect or suspect a fire, the entire drying operation should be shut down, including grain flow into and out of the dryer. The emergency controls may have previously completed this step.

  o Shut off the electrical and fuel supply to the dryer.

  o Do not try to cool a fire by running the dryer's fan(s). This will only add oxygen to the fire and intensify the fire.

  o Never run grain from the dryer into the elevator or other storage if a fire is known or suspected.

  o Locate the area of the fire. o If the fire is in the interior of the dryer, but not in the grain column, extinguish it with a fire extinguisher or water hose as quickly as possible. Poor housekeeping inside the dryer likely caused this type of fire. After extinguishing the fire, check for damage to the dryer, and then thoroughly clean the dryer before attempting to restart it.

  o If the fire is within the grain column, emergency discharge slide gates at the bottom of each column should be opened to permit fast dumping of the burning grain from the affected grain columns. It is not necessary to dump the entire dryer, only those columns where burning grain are detected. After the fire is extinguished, check the dryer for damage.

  o A fire extinguisher should always be located at or near the dryer. If a fire seems to be spreading out of control or if there is any question at all about the location of the fire or even if a fire exists, call the fire department.

Note: Dryer fires often occur after the dryer is shut down for the night. Always inspect the interior of a dryer after it has been shut down for possible hot spots or smoldering.

7. What are the potential causes and possible solutions to the problems encounteredin using a mechanical dryer?

Problem	Potential Causes	Possible Solutions
Long drying time	Ineffective fan	Test fan, replace fan
	Reduced airflow from turbulences or high resistance of air distribution system	Clean perforated sheets, bigger plenum chamber and air ducts.
	Low temperatures	Increase temperature within acceptable limits
Uneven drying	Too high drying air temperatures	Reduce air temperature, Mix after initial drying
		Improve temperature control
High fuel consumption	Ineffective fan or air-distribution system	Improve air distribution system, use fan with higher efficiency
	Air-flow rates too high	Reduce air flow rate to normal levels (smaller fan)
Low germination rate	Too high drying air temperatures	Reduce air temperature
	Low germination potential of paddy	Dry 1 Kg of the same crop in the shade, make germination test and compare with machine dried sample
High number of broken grains	Moisture gradient, re-wetting after drying	Reduce delays in drying, don't do field drying, dry immediately after harvesting
	Feeding of grain with different MC, re-wetting of dryer grain fractions	Mix grain during drying in batch dryers

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