DRYING

Drying: Drying is defined as the removal of moisture or liquid from an item to a level of <5%. It is a natural & oldest process of food preservation. Generally drying means sun drying.

Or

Drying may be defined as the simultaneously heat & mass transfer process.

Drying is a heat and mass transfer process: The mechanism of water removal by drying involves two simultaneous processes, namely, transfer of heat for the evaporation of water to the food and transport of the water vapors formed away from the food. Drying is, therefore, an operation based on *simultaneous heat and mass transfer*.

Dehydration: The terms dehydration and drying are used interchangeably to describe the unit operation in which all the water normally present in a foodstuff is removed by evaporation or sublimation, as a result of the application of heat under controlled conditions. The basic difference between drying and dehydration is, drying is natural process and dehydration is an artificial process.

Moisture content of various foods before and after Drying:

Food	Moisture before drying %	Moisture after drying %
Milk		
Whole	87	5.0
Nonfat	90	5.0
Egg		
Whole	74	2.9
White	88	7.3
Yolk	51	1.1
Beef, lean, roasted	60	1.5
Chicken, broiled	61	1.6
Beans, snap, cooked	92	11.5
Corn, sweet, cooked	76	3.2
Potatoes, boiled	80	4.0
Apple juice	86	6.2
Figs, raw	78	3.6
Parsley, raw	84	5.3

Dehydration Vs Sun drying:

Dehydration	**Sun Drying**
Dehydration implies control over climatic conditions within a chamber, or microenvironment control.	Sun drying is at the mercy of the elements.
Dried foods from a dehydration unit can have better quality than sun dried counterparts.	Dried foods from a sun drying unit can have less quality than dehydration counterparts.
Less land required	More land required
Sanitary conditions are controllable within a dehydration plant.	In open fields contamination from dust, insects, birds and rodents are major problems.
The color of dehydrated fruit is inferior to sun-dried fruit.	The color of sun-dried fruit is superior to dehydrated fruit.
In cooking quality dehydrated foods are usually superior to sun-dried counterparts.	In cooking quality sun-dried foods are usually inferior to dehydrated counterparts.
Cost is high	Cost is low

Importance of Drying: The main technological objectives of food dehydration are:

● Preservation as a result of depression of water activity

● Reduction in weight and volume

● Transformation of a food to a form more convenient to store, package, transport and use, e.g. transformation of liquids such as milk or coffee extract, to a dry powder that can be reconstituted to the original form by addition of water (instant products)

● Imparting to a food product a particular desirable feature such as a different flavor, crispiness, chewiness etc., i.e. creating a new food (e.g. transformation of grapes to raisins).

Depending on the mode of transfer, industrial drying processes can be grouped in two categories:

Convective drying: hot and dry gas (usually air) is used both to supply the heat necessary for evaporation and to remove the water vapor from the surface of the food. Both heat and mass exchanges between the gas and the particle are essentially convective transfers, although conduction and radiation may also be involved to some extent. This widespread mode of drying is also known as air drying.

Conductive (boiling) drying: the moist food is brought into contact with a hot surface (or, in a particular application, with superheated steam). The water in the food is 'boiled-off'. In essence, boiling drying is tantamount to 'evaporation to dryness'. Vacuum drying, drum drying and drying in superheated steam are cases of this mode of drying.

Some Terminology:

Water activity, a_w: The ratio of partial vapour pressure present in food to partial vapour pressure of pure water at the same temperature

$$a_w = p / p_0$$

Here,

p = water vapor pressure over sample;

p_0 = water vapor pressure over pure water

Equilibrium relative humidity (ERH): Equilibrium relative humidity is the humidity at a given temperature at which food will neither lose moisture to atmosphere nor pick moisture from the atmosphere.

Equilibrium moisture content (EMC): when the vapor pressure of water held by a cereal grain is equal to the water vapor pressure of the surrounding air, the moisture content of the material is called equilibrium moisture content.

Wet basis: Moisture content of a grain on a wet basis is expressed as the ratio of the weight of water present to the total weight of the grain.

Moisture content on wet basis is given by

$$M_w = \frac{W_w}{W_w + W_d} \quad \text{...(1)}$$

Where, M_w = Moisture content on wet basis, ratio

W_w = Weight of moisture,

W_d = Weight of bone dry material

Dry basis: Moisture content of a grain on dry basis is expressed as the ratio of the weight of water present to the weight of the bone dry material.

Moisture content on dry basis is given by

$$M_d = \frac{W_w}{W_d} \quad \text{..(2)}$$

Where, M_d = Moisture content on dry basis, ratio

W_w = Weight of moisture,

W_d = Weight of bone dry material

Comparison between Wet and Dry Basis

Wet Basis	Dry basis
Use: Moisture content on a wet basis is used for commercial designation and also universally by farmers, agriculturist and merchants.	**Use:** For this reason dry basis moisture contents are used in many engineering calculations and mainly used by researchers in research works.
Nature: This method of expression tends to give incorrect impression when applied to drying since both moisture content and the basis on which it is computed change as drying proceeds.	**Nature:** The basis on which it is computed does not change as drying changes.
Calculated value of Moisture content on wet basis is smaller then moisture content on dry basis.	Calculated value of Moisture content on dry basis is greater then moisture content on wet basis.

Adsorption and Desorption Isotherm

Adsorption isotherm is a plot of equilibrium moisture content versus relative humidity at a given temperature for a material which has been subjected to a wetting environment.

Desorption isotherm is a similar plot for a material which has been subjected to a drying environment. The difference between the desorption and the adsorption isotherms at a given temperature for a material is termed as the hysteresis effect.

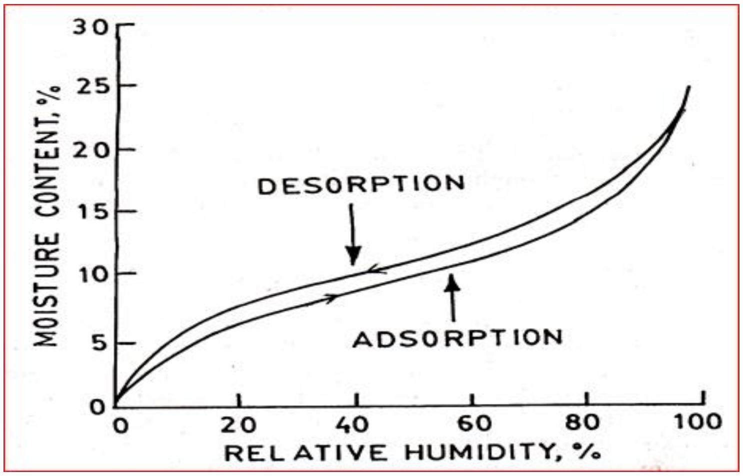


Figure: Water adsorption isotherm, Desorption isotherm and Hysteresis of moisture sorption of wheat at 35^{o}C

Drying rate curves: The removal mass of water of per unit time at per unit mass of dry matter is called drying rate.

From the above figure we observe that the initial moisture removal (A to B) occurs as the product & the water within the product experience a slight increase in temperature. The section (B to C) of the curve is known as constant rate drying period is associated with the removal of unbound water within the product. In most situation, the constant rate drying period will continued until the moisture content will reduce to the critical moisture content. Below point C is known as the critical moisture content & defined as the moisture content at which drying rate starts falling. Moreover, the points C represents the starts of the falling rate periods, which can be divided into two stages. In the first falling rate period (C to D), the food surface is no longer capable of supplying sufficient free moisture to saturate the air above E. And the drying rate of the product decrease until the product surface of the food is completely dry. Further more the section (D to E) of the curve is known as second falling rate period. In which the product surface is completely dry and water interface moves into the solid. The amount of water remove during falling rate period is very small while the time requires may be long. Since the drying rate is slow and drying continues until the moisture content falls down to the equilibrium value for the prevailing air humidity and then drying stops.

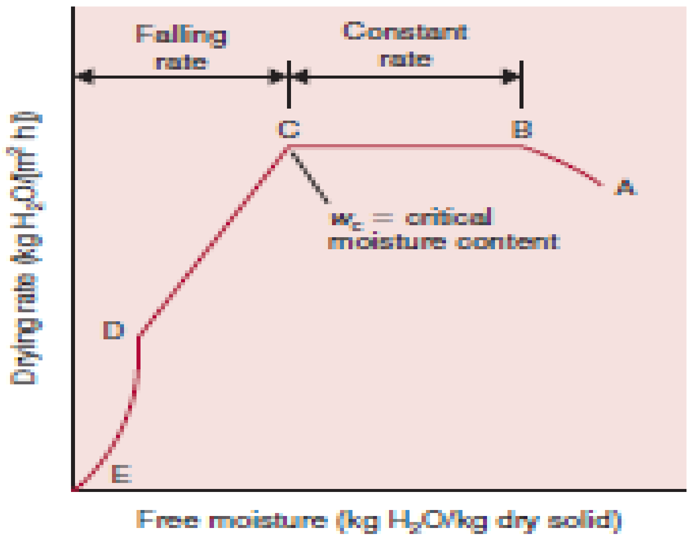


Fig: Drying Rate Curve

Case hardening: If the temperature of the air is high and the relative humidity of the air is low, there is danger that moisture will be removed from the surface of foods being dried more rapidly than water can diffuse from the moist interior of the food particle, and a hardening or casing will be formed. This impervious layer or boundary will retard the free diffusion of moisture. This condition is referred as case hardening. It is prevented by controlling the relative humidity of the circulating air and the temperature of the air.

Factors controlling the rate of drying:

- **Surface area**: Subdivision of food provides more surface area for contact with heating medium as well as the moisture escape. The smaller particles the shorter distance the heat must travel to center of food and the moisture must travel to reach surface.
- **Drying temperature**: This varies with the food and the method of drying. The greater the temperature difference between heating medium and the food, greater is the rate of heat transfer. When hot air is used, it also aids the removal of moisture away from the food and the higher the temperature of the air, the more moisture it will hold before becoming saturated.
- **Relative humidity of air:** When a food material is kept in contact with air at a constant temperature and humidity it will attain a definite moisture content.
- **Velocity of air:** Higher velocity of air is more effective in drying.
- **Drying time**: The drying time depends on the type of food and its moisture content and temperature of drying.

Methods of drying:

- Sun drying
- Fluidized Bed Drying
- Tunnel drying

- Roller drying
- Tray or Cabinet Drying
- Spray drying
- Freeze drying

Sun drying: This method is one of the most traditional methods of drying. It is slow and only practical in hot, dry climates. However, it is still used today e.g. sun dried chillies, raisins or tomatoes.

The food, such as fish, is also vulnerable to contamination through pollution and vermin, e.g. rodents and flies**.**

Fig: Sun drying process

Fluidized Bed Drying: Warm air is blown upwards directly underneath the food, causing it to flow and remain separated. This procedure is suitable for small items such as peas and coffee.

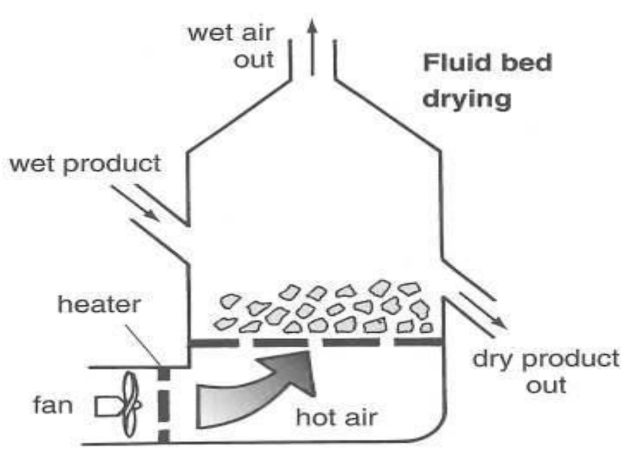


Fig: Fluidized bed drying

Tunnel drying: Hot air is blown over the product, such as vegetables. The concurrent system dries the food rapidly with little shrinkage, but leaves a relatively high moisture content. The counter-current system is slower, but produces a product with a low moisture level.
A disadvantage of this process is that the product tends to shrink and is less easy to rehydrate.

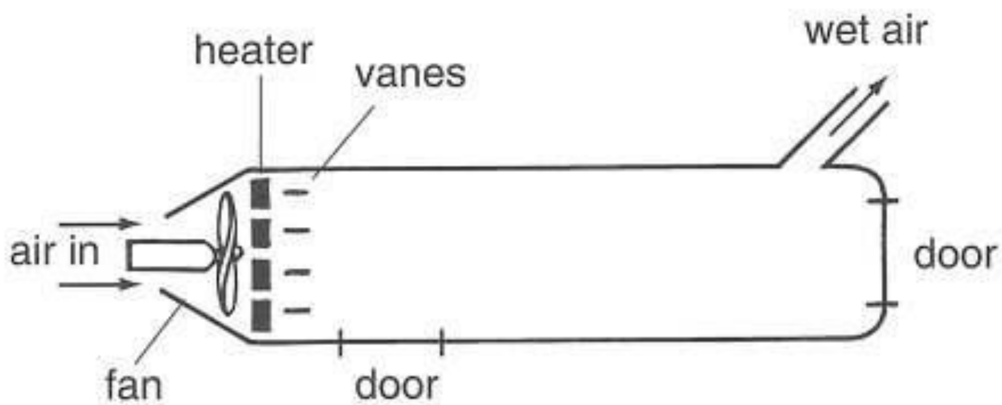


Fig: tunnel drying

Roller drying: The food product, in a liquid or paste form, is uniformly spread over heated rollers or drums which rotate slowly. The heat causes the moisture to evaporate leaving a dried product behind. A scraper then removes this for use. This method is suitable for instant mashed potato and baby foods.

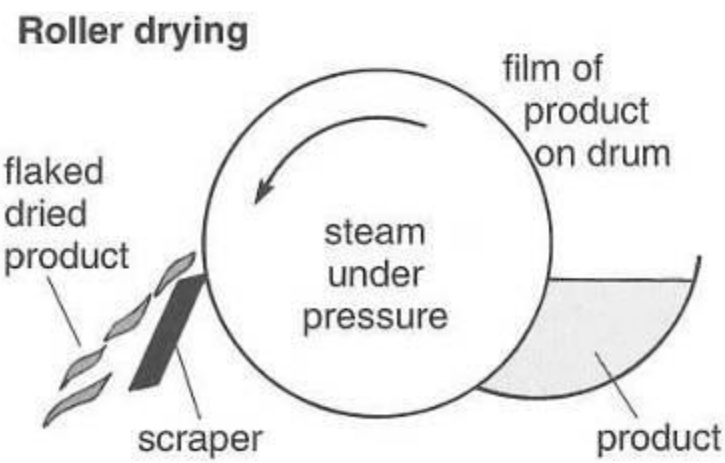


Fig: Roller drying

Tray or Cabinet Drying: These types of drying systems use trays or similar product holders to expose the product to heated air in an enclosed space. The trays holding the product inside a cabinet or similar enclosure are exposed to heated air so that dehydration will proceed. Air movement over the product surface is at relatively high velocities to ensure that heat and mass transfer will proceed in an efficient manner.

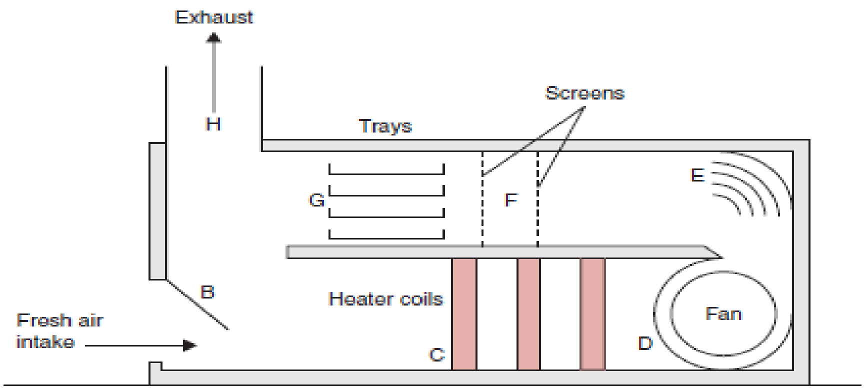


Fig: Tray or Cabinet drying

Spray drying: In a spray dryer, foods are transformed from slurry into a dry powder. A fine dispersion of pre-concentrated food is first 'atomized' to form droplets (10-200 min diameter) and sprayed into a current of heated air at 150-300°C in a large drying chamber. The feed rate is controlled to produce an outlet air temperature of 90-100°C, which corresponds to a wet-bulb temperature (and product temperature) of 40-50°C. The spray-drying operation is easily divided into three distinct processes; atomization, drying through the contact between the droplets and the heated air, and collection of the product by separating it from the drying air. A typical spray dryer configuration is shown in figure. The dryer configuration and the properties of the feed material determine the operating conditions necessary to provide a high-quality finished product

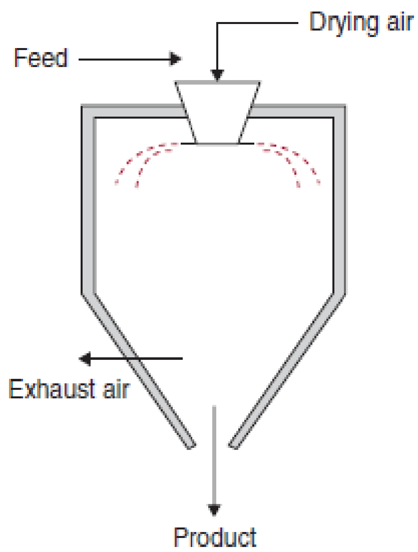


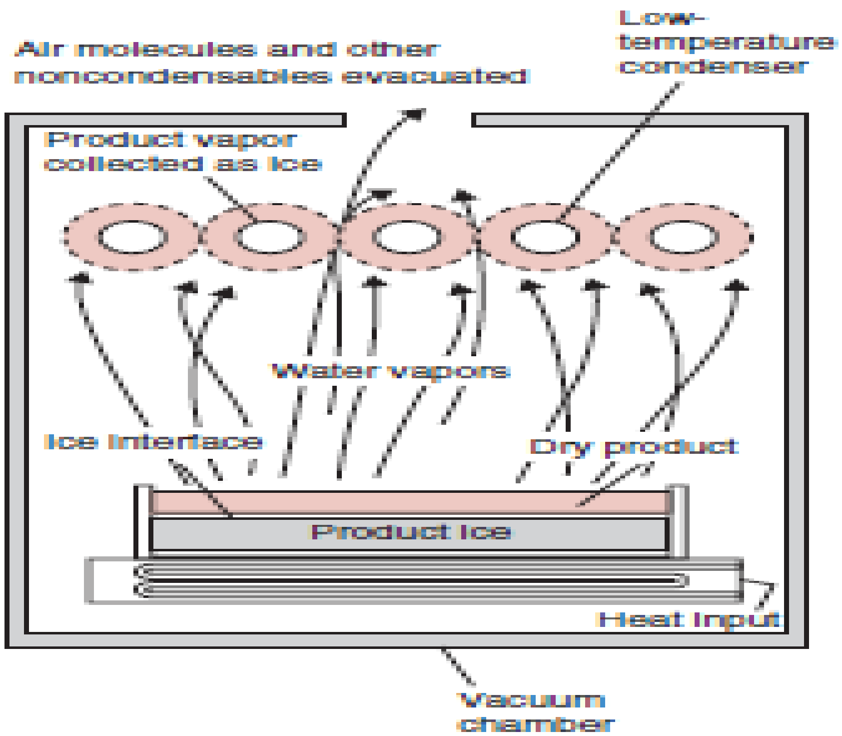
Fig: Spray drying

Freeze drying: Freeze drying process is subdivided into three main steps: the prefreezing, the sublimation drying and the secondary drying.

1. Prefereezing Step: The freezing of clean water normally takes place at a constant temperature of 273 K, ice crystals forming and growing from the liquid water gradually as heat is removed. In freeze drying clean water is not considered food.

2. Sublimation Drying: In the sublimation-drying step the two main transport processes are heat transfer and water vapour transfer. In the normal vacuum freeze drier heat is transferred to the product surface and on through the product layers to the sublimation front. The driving force of this heat transfer is the temperature difference from the heater surface to the sublimation front.

3. Secondary Drying: The secondary drying step is very similar to the latter steps of any drying process, when water is no longer mobile in the product in the liquid form and a temperature rise is necessary to release the hygroscopically bound water. Foods normally in the secondary drying can tolerate the sufficient rise in temperature over the sublimation temperature to achieve this.



Drying equipment:

- Hot air drier.
- Kiln drier
- Cabinet, tray or compartment drier.
- Tunnel drier.
- Conveyor drier.
- Fluidized bed drier.
- Rotary drier.
- Spray drier.
- Pneumatic drier.

Types of dryer used for various foods, food by-products, and wastes:

Product	Type of Dryer
Vegetables, confectionery, fruits, pectin	Compartment and tunnel tray
Grass, grain, vegetables, fruit, nuts, breakfast cereals	Conveyor band
Grass, grain, apple pomace, lactose, poultry manure, peat, starch (vacuum)	Rotary
Coffee, milk, tea, fruit purees	Spray
Starch, fruit pulp, distillery waste products, crops	Pneumatic
Coffee, meat extracts, malted and other confectioneries	Freeze dryers and vacuum dryers

Influence of dehydration on nutritive value of food: In drying, a food loses its moisture content, which results in increasing the concentration of nutrients in the remaining mass. Proteins, fats and carbohydrates are present in larger amounts per unit weight in dried foods than in their fresh counterpart. With dried foods, there is a loss in vitamin content. The water soluble vitamins are diminished during blanching and enzyme inactivation. Ascorbic acid and carotene are subject to damage by oxidative processes. Riboflavin is light sensitive. Thiamin is heat sensitive and destroyed by sulfuring. Sun drying causes large losses in carotene content. Vitamin C is lost in great proportions in sun dried fruits. Freeze drying of fruits retains greater portions of vitamin C and other nutrients. The retention of vitamins in dehydrated foods is generally superior in all counts than sun dried foods.

Influence of Drying on protein: The biological value of dried protein is dependent on the method of drying. Prolonged exposures to high temperatures can render the protein may increase the digestibility of protein over native material.

Influence of Drying on fats: Rancidity is an important problem in dried foods.The oxidation of fats in foods is greater at higher temperatures than at low temperatures of dehydration.

Influence of Drying on Carbohydrates: The principal deterioration in fruits is in carbohydrates. Discoloration may be due to enzymatic browning or to caramelization types of reaction.

Influence of Drying on microorganisms: One obvious method of control microorganisms is in the restriction of moisture for growth. Molds can grow on food substrates with as little as 12% moisture, and some are known to grow in foods with less than 5% moisture. Bacteria and yeasts require higher moisture levels, usually over 30%. Grain are dried to about 12% moisture, Fruits are dried to 16 to 25% moisture. These will mold if given high humidity conditions and exposed to air. This problem is solved by using sodium chloride during drying.

Influence of drying on enzyme activity: Enzymes require moisture to be active. Enzyme activity is reduced with decreasing moisture. Enzyme activity is nil at moisture level below 1 %. Two enzyme are used as indicators generally of residual enzyme activity. These are catalase and peroxidase. Catalase is less resistant to heat treatments than is peroxidase.

Influence of Drying on pigments of foods: The color of foods dependent upon the circumstances under which food is viewed, and the ability of the food to reflect, scatter, absorb or transmit visible light.

Dehydrated Foods: Fruits, vegetables, animal products, fish, milk, eggs are dehydrated by various methods.

Packaging of dehydrated foods: Eggs, meat, milk, and vegetables are ordinary packaged in tin containers. Occasionally fiberboard ar flexible film material may be employed. Tin offers protection against insects, moisture loss or gain, and permits packaging with an inert gas. For long time storage of dehydrated foods, functional containers which are hermetically sealed and resistant to penetration by insects are required.

Relationship between MC_{db} and MC_{wb}:

We know that,

$$MC_{db} = \frac{\text{mass of water}}{\text{mass of dry solids}}$$

$$= \frac{\frac{\text{mass of water}}{\text{mass of moist sample}}}{\frac{\text{mass of dry solids}}{\text{mass of moist sample}}}$$

$$= \frac{\frac{\text{mass of water}}{\text{mass of moist sample}}}{\frac{\text{mass of moist sample} - \text{mass of water}}{\text{mass of moist sample}}}$$

$$= \frac{\frac{\text{mass of water}}{\text{mass of moist sample}}}{1 - \frac{\text{mass of water}}{\text{mass of moist sample}}}$$

$$= \frac{\text{MC}_{wb}}{1 - \text{MC}_{wb}}$$

The above relationship is useful to calculate MC_{db} when MC_{wb} is known. Similarly, if MC_{db} is known, then MC_{wb} may be calculated from the following equation.

$$MC_{wb} = \frac{\text{mass of water}}{\text{mass of moist sample}}$$

$$= \frac{\text{mass of water}}{\text{mass of water} + \text{mass of dry solids}}$$

$$= \frac{\frac{\text{mass of water}}{\text{mass of dry solids}}}{\frac{\text{mass of water} + \text{mass of dry solids}}{\text{mass of dry solids}}}$$

$$= \frac{\frac{\text{mass of water}}{\text{mass of dry solids}}}{\frac{\text{mass of water}}{\text{mass of dry solids}} + 1}$$

$$= \frac{\text{MC}_{db}}{\text{MC}_{db} + 1}$$

Problem 1: Convert a moisture content of 85% wet basis to moisture content dry basis.

Solution

a. MC_{wb} = 85%

b. In fractional notation, MC_{wb} = 0.85

c. From equation,

$$MC_{db} = \frac{MC_{wb}}{1 - MC_{wb}}$$

$$= \frac{0.85}{1 - 0.85}$$

$$= 5.67$$

or

$$MC_{db} = 567\%$$