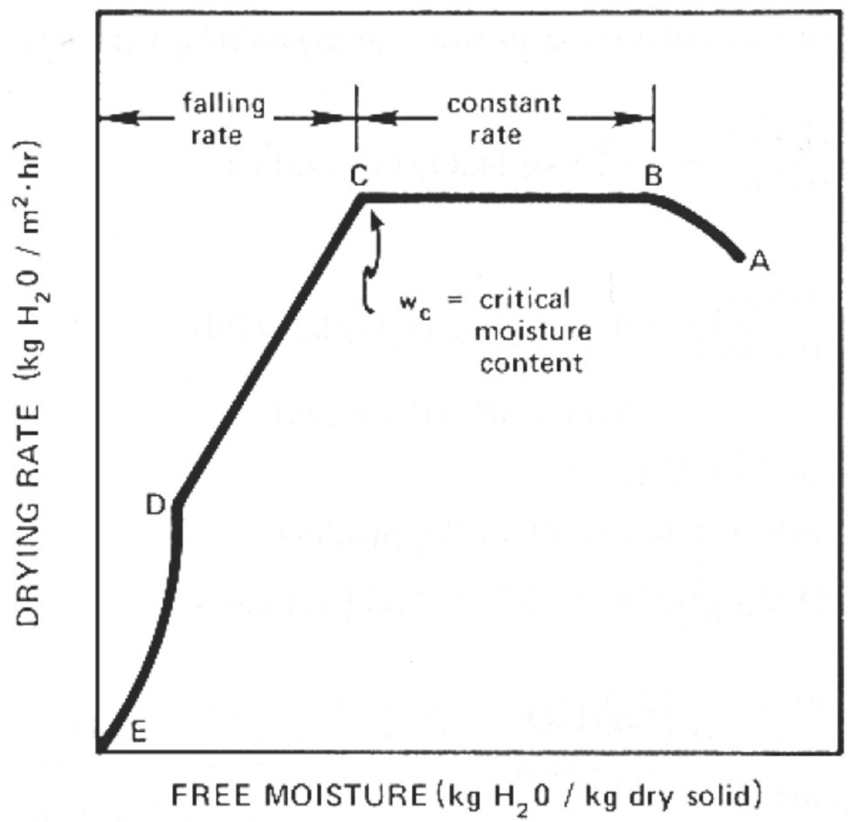
Drying rate 1

Drying process of a material can be described as a series of steps in which drying rate plays a key role. Following figure shows typical drying rate curve for a constant drying conditions.



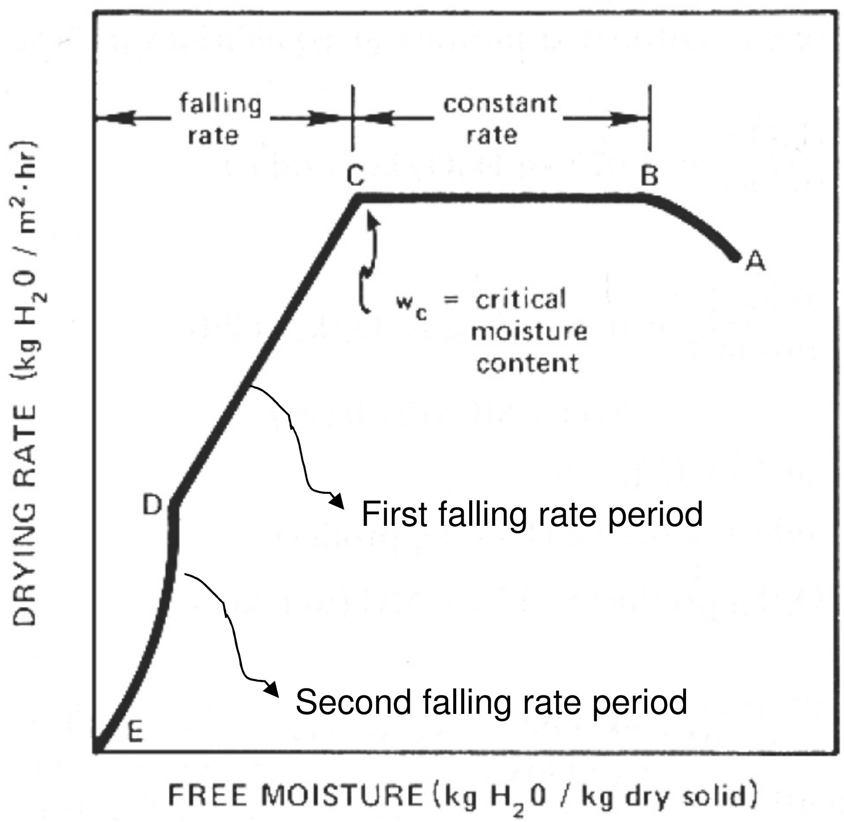
Point B represents equilibrium temperature conditions of the product surface.

Section B to C of the curve, known as the constant rate periods, represents removal of unbound water from the product.

The water acts as if the solid is not present. The surface of the product is very wet and water. **And the water activity is equal to one.**

The constant rate period continues as long as the amount of water evaporates is equal to the amount of water supplied to the surface of the material.

Drying rate 2



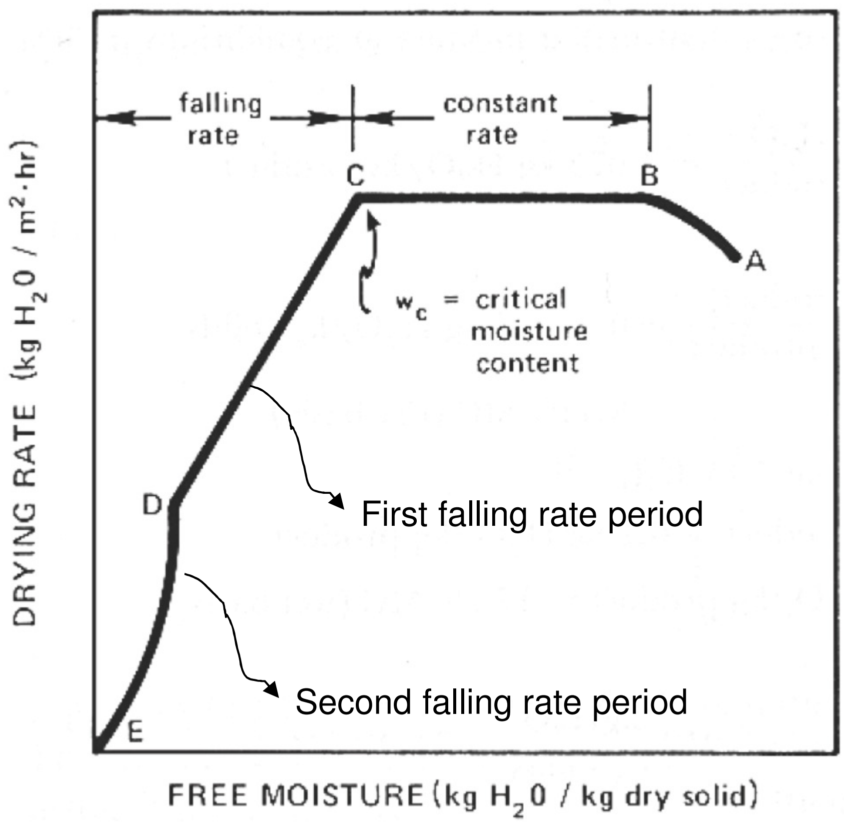
The falling rate period is reached when the drying rate starts to decrease, and the surface water activity falls to less than one.

The rate of drying is governed by the internal flow of liquid or vapor. This point is represented by C in the figure.

At this point there is not enough water on the surface to maintain a water activity value of one.

The falling rate period can be divided into two steps. A first falling drying rate occurs when wetted spots in the surface continually diminish until the surface is dried (Point D).

Drying rate 3

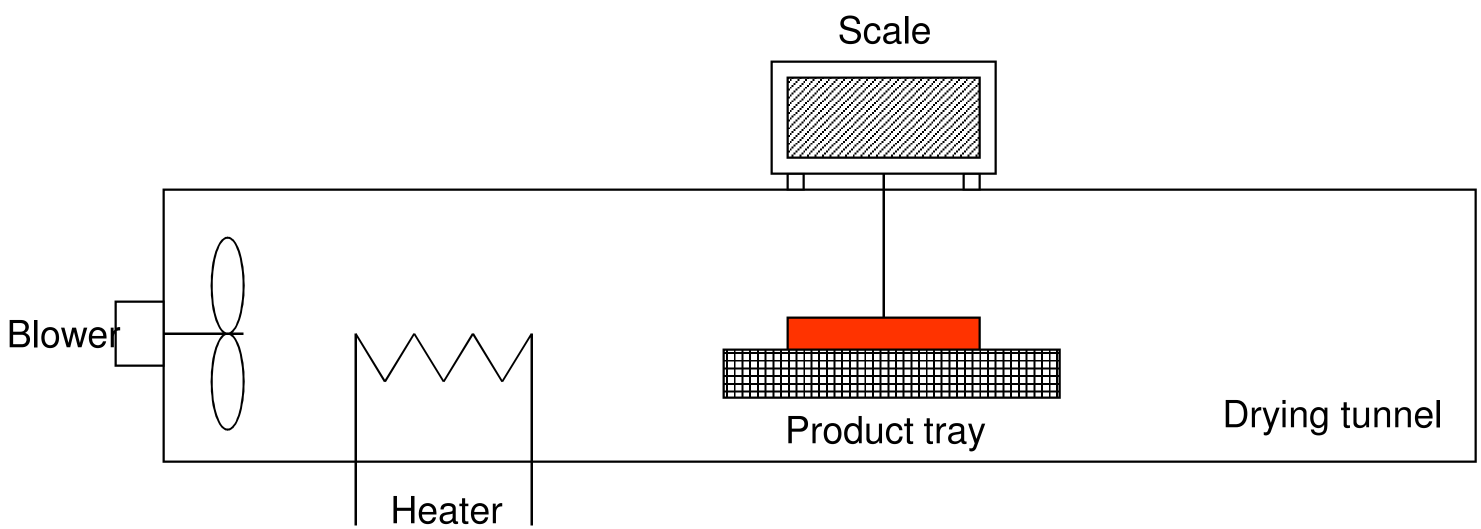


Second falling rate period begins at point D when the surface is completely dry. The plane of evaporation recedes from the surface. Heat required for moisture removal is transferred through the solid to the vaporization of moisture in the solid and the vapor moves through the solid into air stream.

The amount water removed in this period can be relatively small compared to the constant rate and first falling rate period.

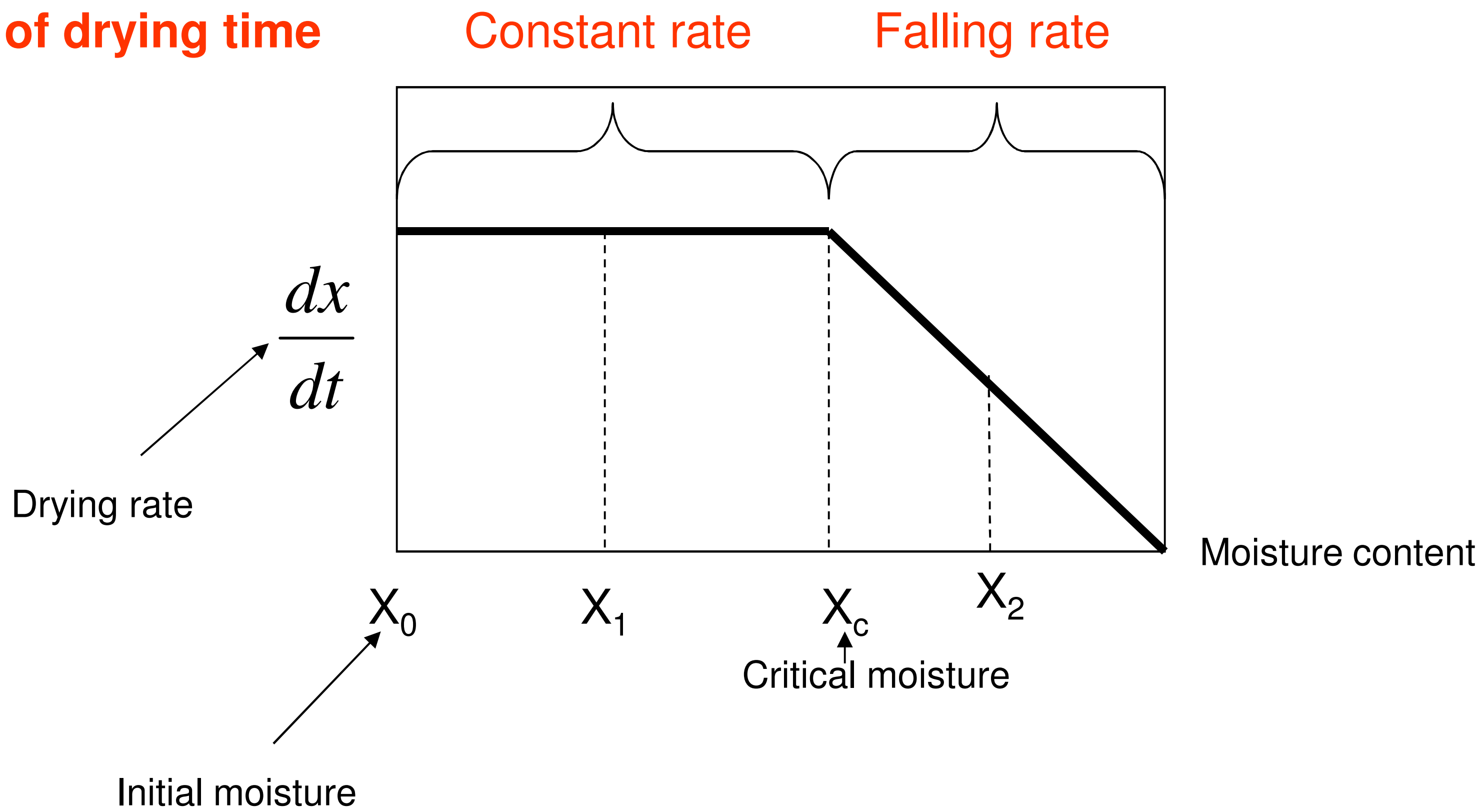
However this period may take much longer than constant rate period because the drying is slow.

Drying rate experiments can be simply done by measuring the weight change during drying. The material to be dried is placed on the tray. The tray is suspended from a balance and exposed to air flow in drying tunnel.



Water removed/time can be easily determined

Calculation of drying time



For the constant rate time $$t_c = \frac{x_o - x_c}{R_c}$$

For the falling rate time $$t = \frac{x_o - x_c}{R_c} + \frac{x_c}{R_c} \ln \frac{x_c}{x_2}$$

Freeze Drying

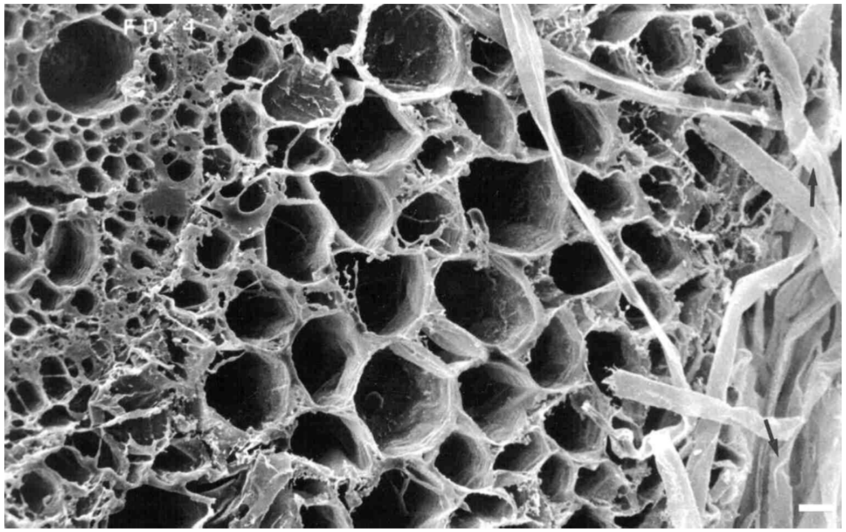
Certain food stuff which can not be heated even to moderate temperatures in ordinary drying, may be freeze dried.

The substance to be dried is usually frozen by very cold air. In freeze drying the water is as a vapor by sublimation from the frozen material in a vacuum chamber.

After the moisture sublimes to a vapor, it is removed by mechanical vacuum pumps or steam jet ejector

Freeze Drying

As a rule, freeze drying produces the highest quality food product obtainable by any drying method. During freeze drying the porous structure of the material do not collapse.



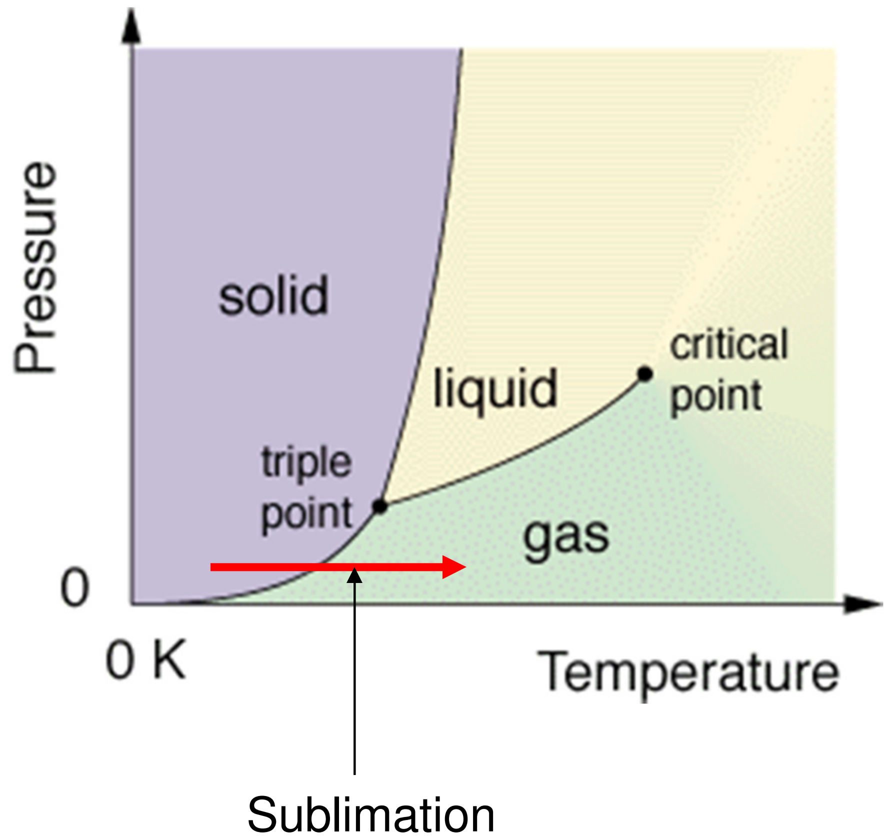
When water is added later, the rehydrated product retains much of its original structural form.

Freeze drying of food materials also has the advantage of little loss of flavor and aroma.

The low temperature involved minimize the degradative reactions which normally occur in ordinary drying processes.

However freeze drying is an expensive form of dehydration for foods because of slow drying rate.

Sublimation of an element or substance is a conversion between the solid and the gas phases with no intermediate liquid stage. Sublimation is a phase transition that occurs at temperatures and pressures below the triple point (see phase diagram).



Freeze Drying

Since the vapor pressure of ice is very small, freeze drying requires very low pressure or high vacuum.

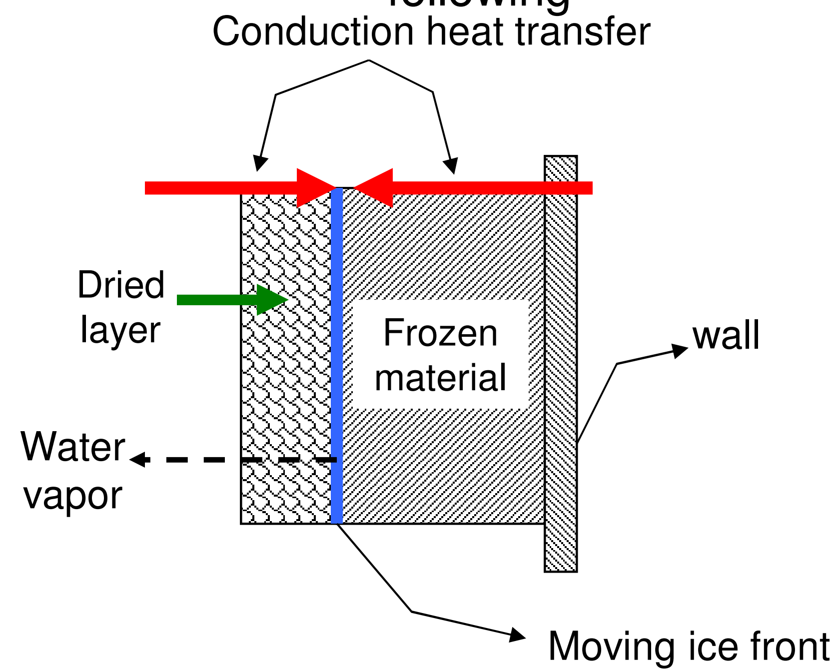
If water in a pure state, freeze drying at or near 0C at 4.58 mmHg could be performed.

However water is usually in solution form or a combined state, the material must be cooled below 0C to keep water in the solid phase.

Most freeze drying processes are done at -10C or lower and at pressures of about 2mmHg or less.

Freeze Drying

During a steady state freeze drying process the heat flux can be defined as following



$$q = h(T_e - T_s) = \frac{k}{\Delta L}(T_s - T_f)$$

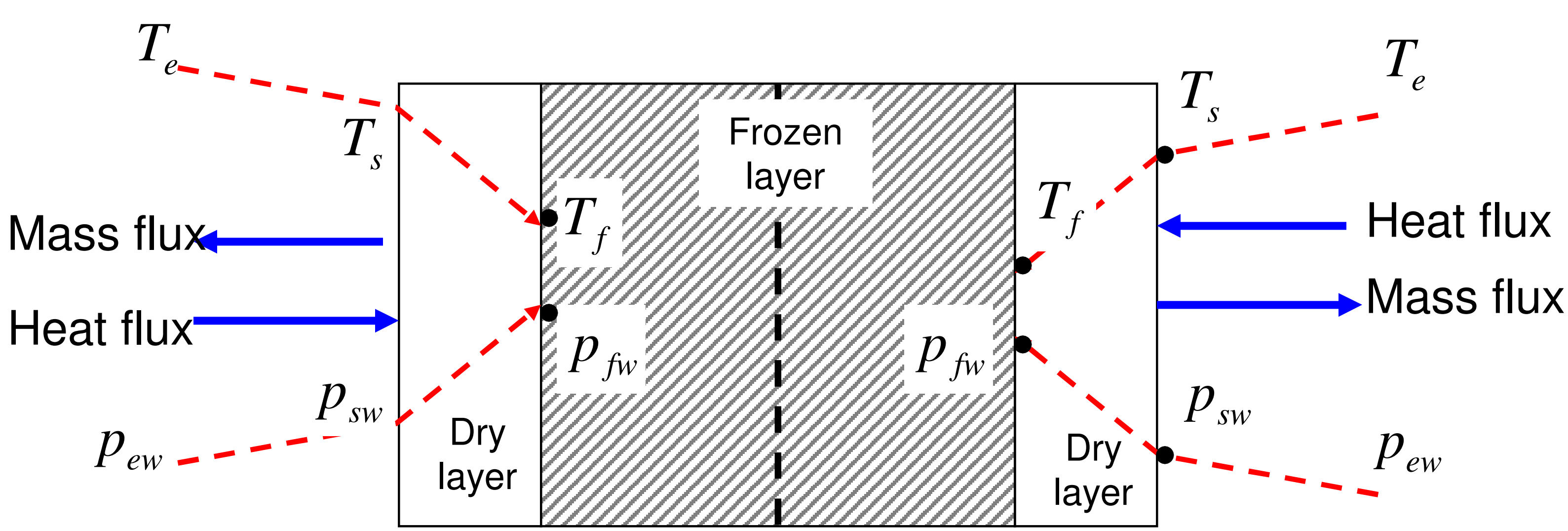
q = heat flux (j/s)
Te = external temperature
Ts = surface temperature of dry material (C)
Tf = temperature of sublimation on ice front(C).
k = thermal conductivity
ΔL = thickness of dry layer

Freeze Drying

During a steady state freeze drying process the mass flux can be defined as following

$$N_a = \frac{D'}{RT\Delta L}(p_{fw} - p_{sw}) = k_g(p_{sw} - p_{ew})$$

Na = mass flux in kg.mol/s.m^2
kg = external mass transfer coefficient kg.mol/s.m^2.atm
psw = partial vapor pressure on the surface of dried later in atm
pew = external partial vapor pressure in atm
pfw = partial vapor pressure at ice front
D'=diffusivity in dry layer m^2/s



Freeze Drying

$$q = h(T_e - T_s) = \frac{k}{\Delta L}(T_s - T_f)$$

rearrange

$$q = \frac{1}{1/h + \Delta L/k}(T_e - T_f)$$

$$N_a = \frac{D'}{RT\Delta L}(p_{fw} - p_{sw}) = k_g(p_{sw} - p_{ew})$$

rearrange

$$N_a = \frac{1}{1/k_g + RT\Delta L/D'}(p_{fw} - p_{ew})$$

Freeze Drying time calculation

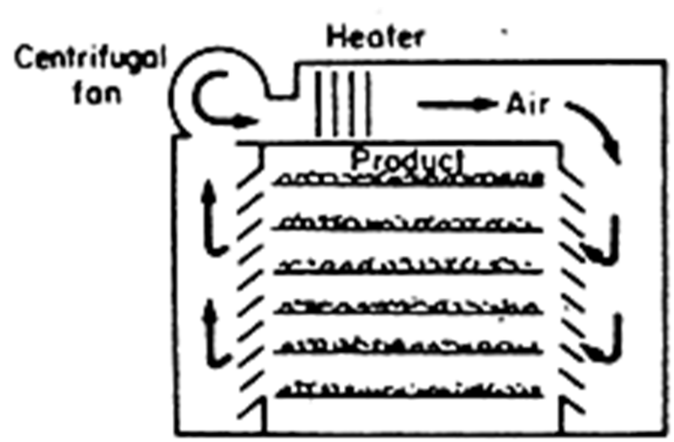
Time required for freeze drying process can be calculated according to the following equation

$$t_s = \rho \frac{(X_o - X_f)}{2K_p(1 + X_o)} \frac{a^2}{(p_{fw} - p_{sw})}$$

- ρ: Density of the frozen portion
- X_o: Initial moisture content (kg water/kg dry material)
- X_f: Final moisture content (kg water/kg dry material)
- a: Half thickness of the food material in m
- K_p: Permeability of the dry layer in kg.m / s µmHg
- p_{fw}: Partial pressure of water at the ice front (Sublimation pressure) in µmHg
- p_{sw}: Partial pressure of water at the dried surface in µmHg

Dryer types
Tray dryer

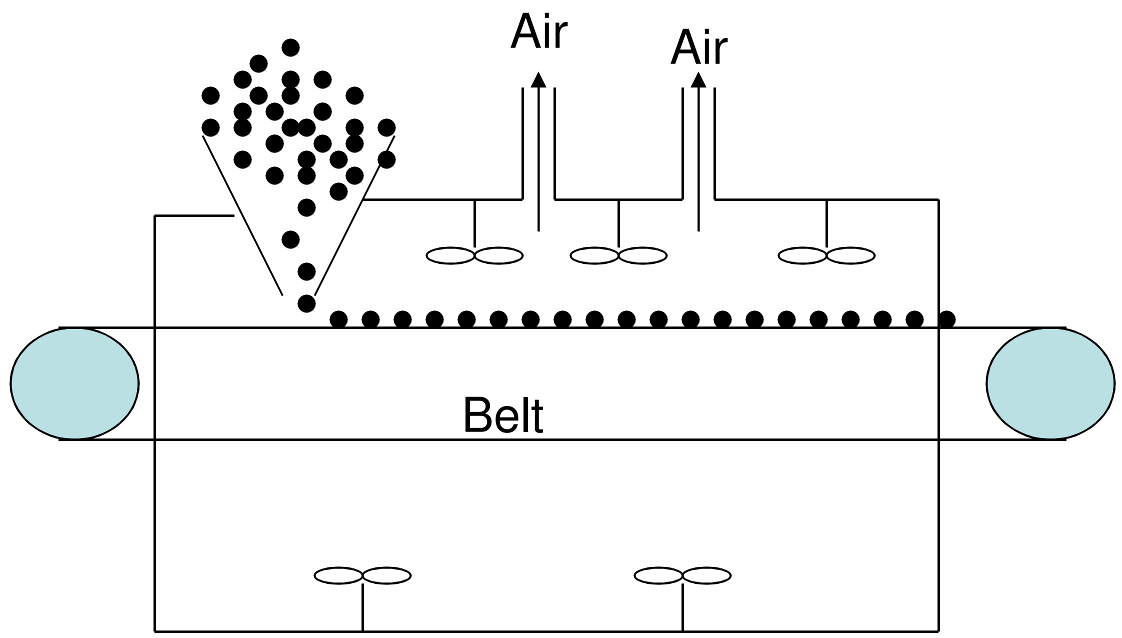
In tray dryers, the food is spread out, generally quite thinly, on trays in which the drying takes place. Heating may be by an air current sweeping across the trays, by conduction from heated trays or heated shelves on which the trays lie, or by radiation from heated surfaces. Most tray dryers are heated by air, which also removes the moist vapours.



TRAY DRYER

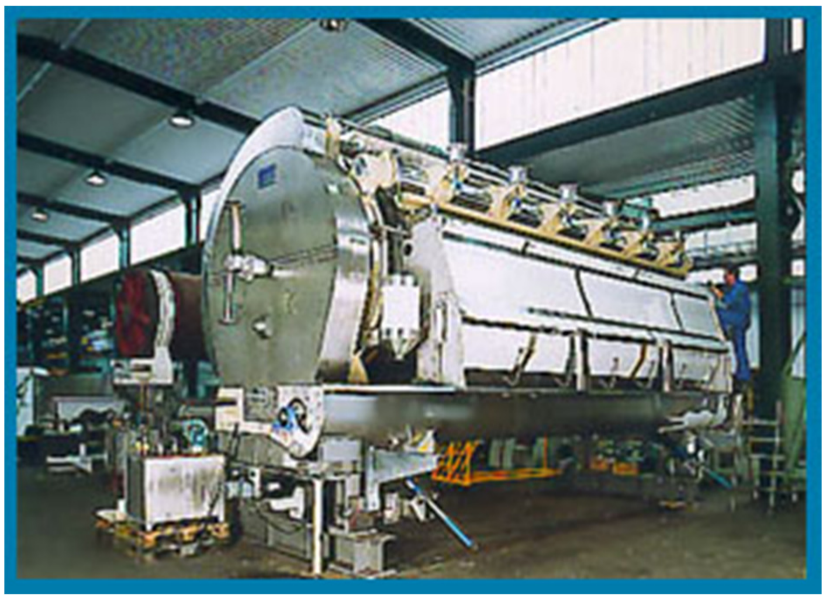
Tunnel Dryers

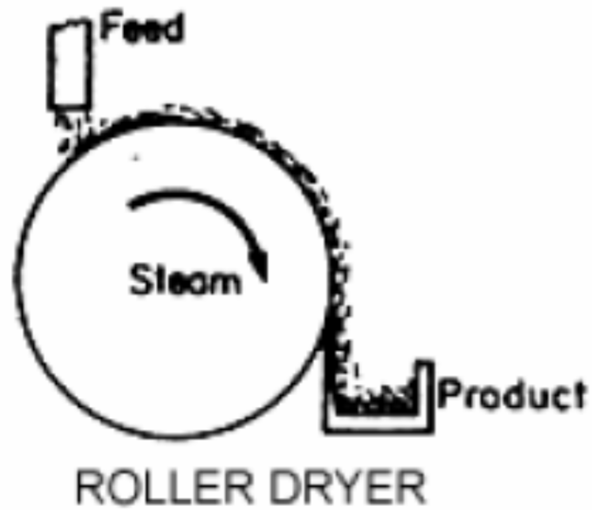
These may be regarded as developments of the tray dryer, in which the trays on trolleys move through a tunnel where the heat is applied and the vapors removed. In most cases, air is used in tunnel drying and the material can move through the dryer either parallel or counter current to the air flow. Sometimes the dryers are compartmented, and cross-flow may also be used.



Roller or Drum Dryers

In these the food is spread over the surface of a heated drum. The drum rotates, with the food being applied to the drum at one part of the cycle. The food remains on the drum surface for the greater part of the rotation, during which time the drying takes place, and is then scraped off. Drum drying may be regarded as conduction drying.



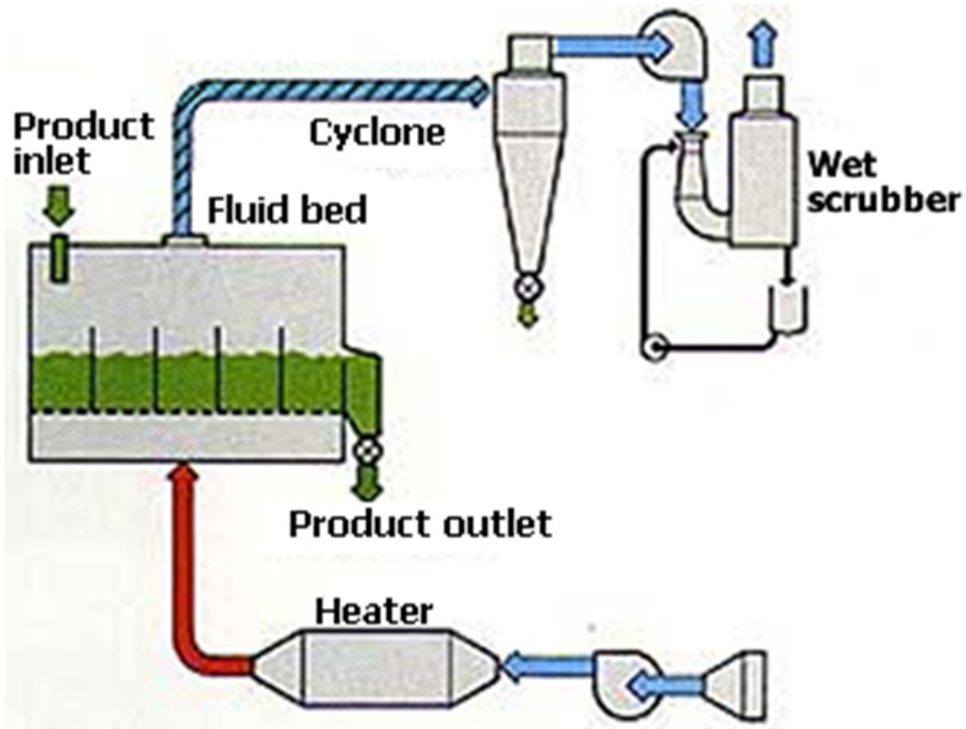


Fluidized Bed Dryers

In a fluidized bed dryer, the food material is maintained suspended against gravity in an upward-flowing air stream. There may also be a horizontal air flow helping to convey the food through the dryer. Heat is transferred from the air to the food material, mostly by convection.

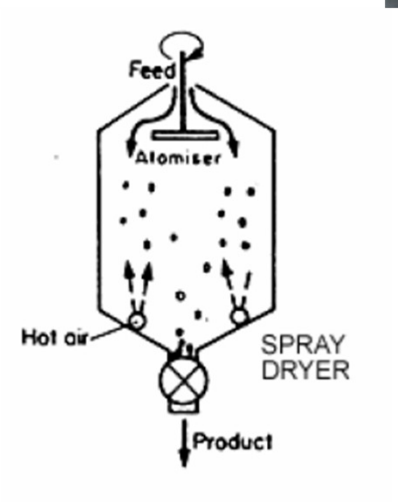
Fluid bed drying offers important advantages over other methods of drying particulate materials.

Particle fluidization gives easy material transport, high rates of heat exchange at high thermal efficiency while preventing overheating of individual particles.



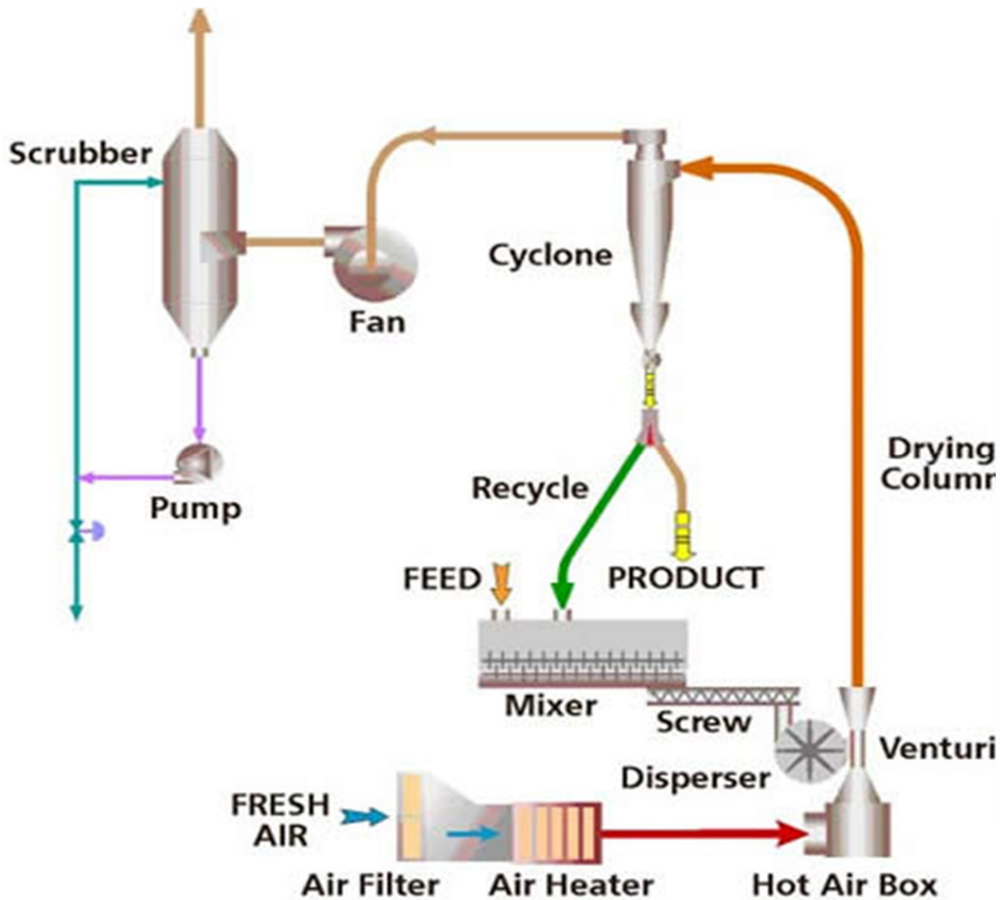
Spray Dryers

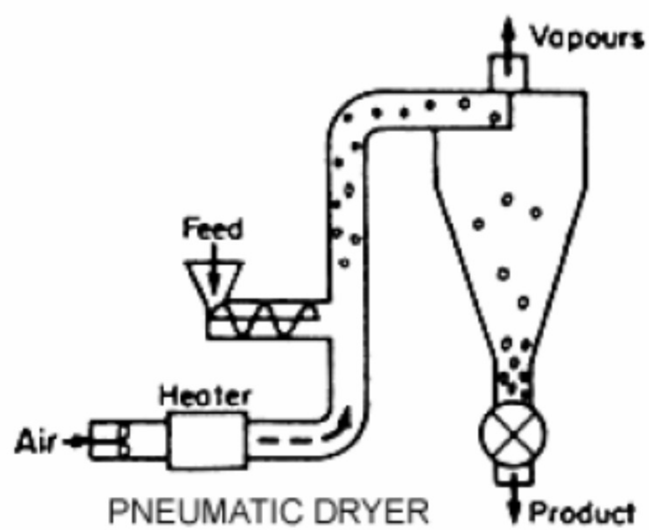
In a spray dryer, liquid or fine solid material in a slurry is sprayed in the form of a fine droplet dispersion into a current of heated air. Air and solids may move in parallel or counterflow. Drying occurs very rapidly, so that this process is very useful for materials that are damaged by exposure to heat for any appreciable length of time. The dryer body is large so that the particles can settle, as they dry, without touching the walls on which they might otherwise stick. Commercial dryers can be very large of the order of 10 m diameter and 20 m high.



Pneumatic Dryers

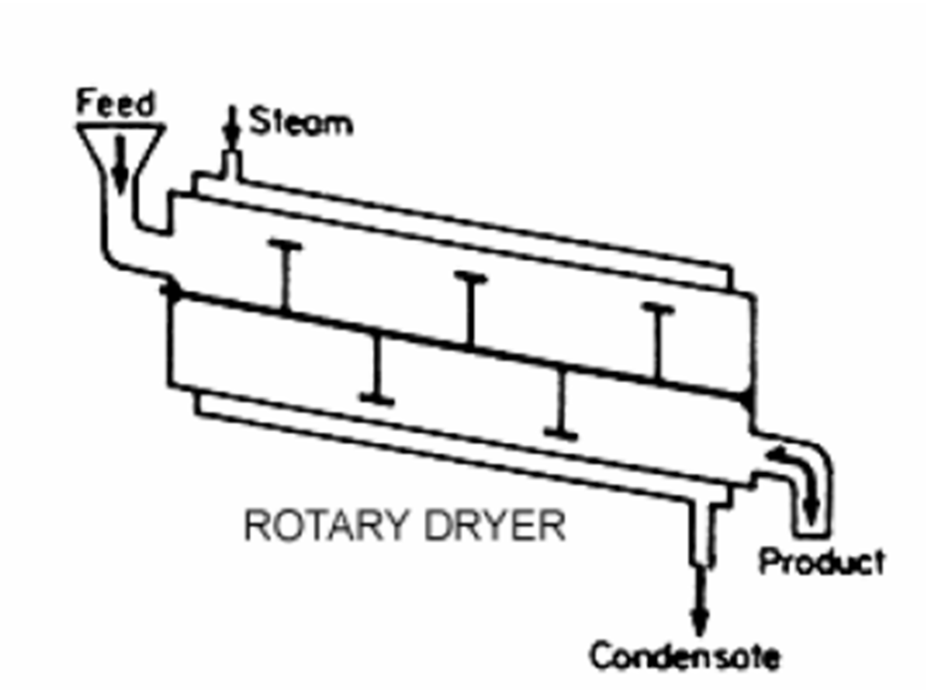
In a pneumatic dryer, the solid food particles are conveyed rapidly in an air stream, the velocity and turbulence of the stream maintaining the particles in suspension. Heated air accomplishes the drying and often some form of classifying device is included in the equipment. In the classifier, the dried material is separated, the dry material passes out as product and the moist remainder is recirculated for further drying.





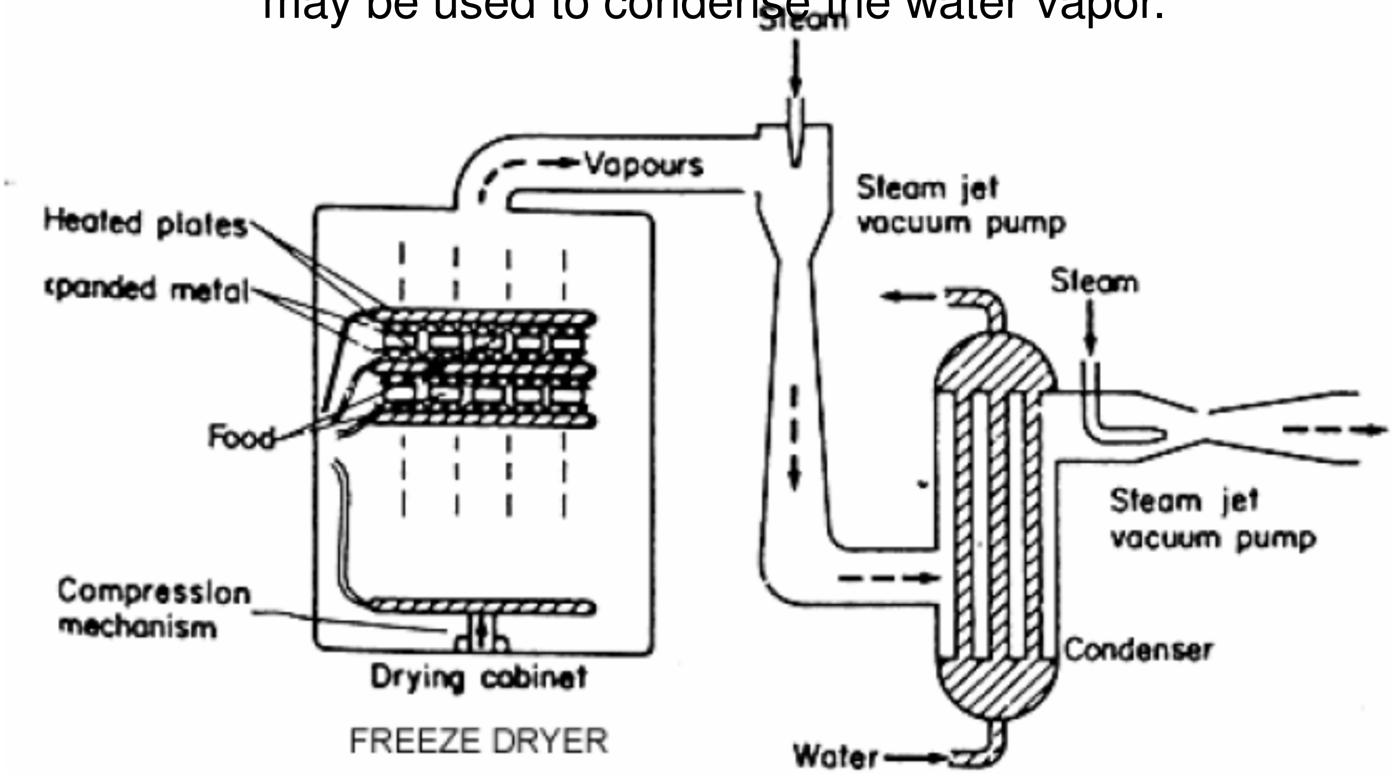
Rotary Dryers

The foodstuff is contained in a horizontal inclined cylinder through which it travels, being heated either by air flow through the cylinder, or by conduction of heat from the cylinder walls. In some cases, the cylinder rotates and in others the cylinder is stationary and a paddle or screw rotates within the cylinder conveying the material through.



Freeze Dryers

The material is held on shelves or belts in a chamber that is under high vacuum. In most cases, the food is frozen before being loaded into the dryer. Heat is transferred to the food by conduction or radiation and the vapor is removed by vacuum pump and then condensed. In one process, given the name accelerated freeze drying, heat transfer is by conduction; sheets of expanded metal are inserted between the foodstuffs and heated plates to improve heat transfer to the uneven surfaces, and moisture removal. The pieces of food are shaped so as to present the largest possible flat surface to the expanded metal and the plates to obtain good heat transfer. A refrigerated condenser may be used to condense the water vapor.



FREEZE DRYER