Drying

The removal of a liquid from a material by the application of heat & is accomplished by the transfer of a liquid from a surface into an unsaturated vapor phase

There are many non thermal methods of drying

1- Expression of a solid to remove liquid (the squeezing of a wetted sponge)

2-The extraction of liquid from a solid by use of a solvent

3-The adsorption of water from a solvent by the use of desiccants

4- The absorption of moisture from gases by passage through sulfuric acid column.

5-Desication of a moisture from a solid by placing it in a sealed container with a moisture – removing material (silica gel).

Psychrometry

A critical factor in drying operations is the vapor-carrying capacity of the air, nitrogen, or other gas stream passing over the drying material.

This carrying capacity determines not only the rate of drying but also the extent of drying, i.e., the lowest moisture content to which a given material can be dried. The determination of the vapor concentration and carrying capacity of the gas is termed *psychrometry*. The air water vapor system is the system most commonly employed in pharmaceutical drying operations.

The concentration of water vapor in a gas is called the *humidity* of the gas.

Dried products are more stable than moist ones, as is the case in such (effervescent salt ,aspirin, hygroscopic powders, ascorbic acid ,& penicillin).

Humidity Measurement.

The most accurate means of measuring humidity is by the *gravimetric method.* In this procedure, a known amount of air is passed over a previously weighed moisture-absorbing chemical such as phosphorus pentoxide, and the resultant increase in weight of the chemical is measured.

Although accurate, the gravimetric method is cumbersome and slow. For rapid determination of humidity, temperature-measurement methods are most often used.

The simplest instrument for this purpose is the *sling psychrometer* (Fig. 3-2). It consists of two bulb thermometers set in a frame that is attached to a swivel handle. One thermometer, the *dry-bulb thermometer,* has a bare bulb; the bulb of the other thermometer, the *wet-bulb thermometer,* is covered by a wick saturated with water. The psychrometer is whirled through the air, and the two thermometer readings are taken at successive intervals until these temperatures no longer change.

https://automationforum.co/what-is-a-sling-psychrometer-limitations-application-working/

THEORY OF DRYING

Drying involves both heat & mass transfer operations.

Heat must be transferred to the material to be dried in order to supply the latent heat required for vaporization of the moisture.

The focus on the film of liquid at the surface of the material

The rate of evaporation is related to the rate of heat transfer by the equation

$dW/d\theta$ of water $= q/\lambda$ -----------(1) where

$dW/d\theta$ is the rate of evaporation

q is the overall rate of heat transfer

λ is the latent heat of vaporization of water

The rate of diffusion of moisture into the air stream is expressed by rate equations, the driving forces is a humidity differential, whereas for heat transfer is a temperature differential so the equation

- $dW\backslash d\theta$ =kA(Hs – Hg) where
- $dW\backslash d\theta$ is the rate of diffusion
- K is the coefficient of mass transfer
- A is the area of the evaporating surface
- Hs is the absolute humidity at the evaporating surface
- Hg is the absolute humidity in the passing air stream
- K is not a constant , but varies with velocity of the air stream passing over the evaporating surface , the relationship is in the form
- $K= cG^n$

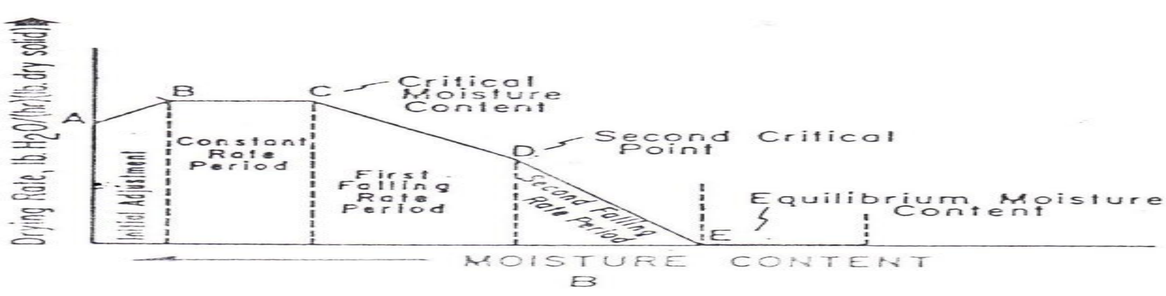
- Where c is a constant
- G is the rate of flow of air
- After an initial period of adjustment , the rate of evaporation is equal to the rate of diffusion of vapor & the rate of heat transfer so
- $dW/d\theta = q/\lambda = kA(Hs - Hg)$
- If the overall rate of heat transfer ,q , is expressed as the sum of the rates of heat transfer by convection, radiation, & conduction so
- $dW/d\theta = (q_c + q_r + q_k)/\lambda$

  $= kA(Hs - Hg)$

- Where all q are the rates of heat transfer by convection , radiation , conduction respectively.
- ***Drying of solids***
- 1-Loss on drying : LOD
- %LOD= (wt. of water in sample\total wt. of wet sample)X100
- 2-moisture content
- % MC =(wt of water in sample/wt of dry sample)X100

Behavior of solids during drying

- 1-first a wet solid placed in a drying oven, it begins to absorb heat & increases in temperature
- at the same time , the moisture begins evaporating & thus tends to cool the drying solid.
- 2- after a period of initial adjustment the rates of heating & cooling become equal & the temperature of the drying material stabilizes.
- This period of initial adjustment is shown as segment AB in Figures 3-3A and 3-3B.
- If the wet solid is initially at a higher temperature than the wet-bulb temperature, it cools down following segment A'B.



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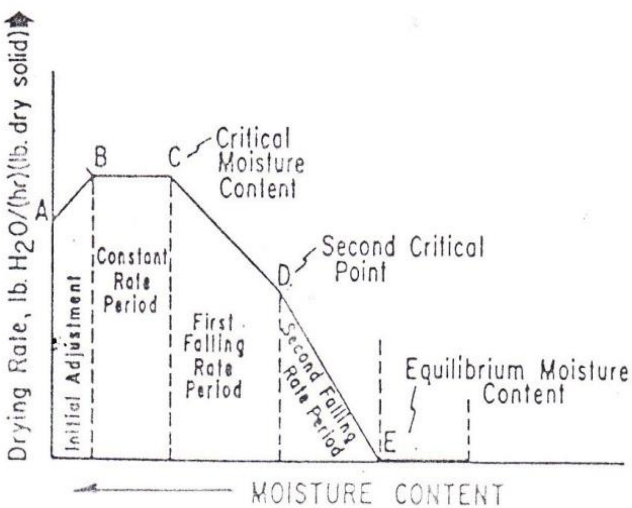
At point B, the temperature ~s stabilized and remains constant as long as there is a film of moisture remaining at the surface of the drying solid. Between points B and C, the moisture evaporating from the surface is replaced by water diffusing from the interior of the solid at a rate equal to the rate of evaporation. The rate of drying is constant, and the time BC is the *constant rate period.*



B

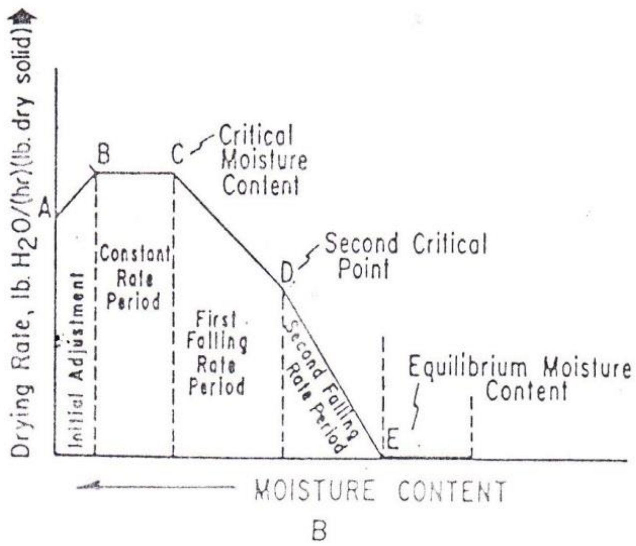
At point C, the surface water is no longer replaced at a rate fast enough to maintain a continuous film. Dry spots begin to appear, and the rate of drying begins to fall off. The moisture content at which this occurs is referred to as the *critical moisture content.* Between points C and D, the number and area of the dry spots continue to grow, and the rate of drying falls steadily.

The time CD is referred to as the *first falling rate period* or the period of *unsaturated surface drying*.

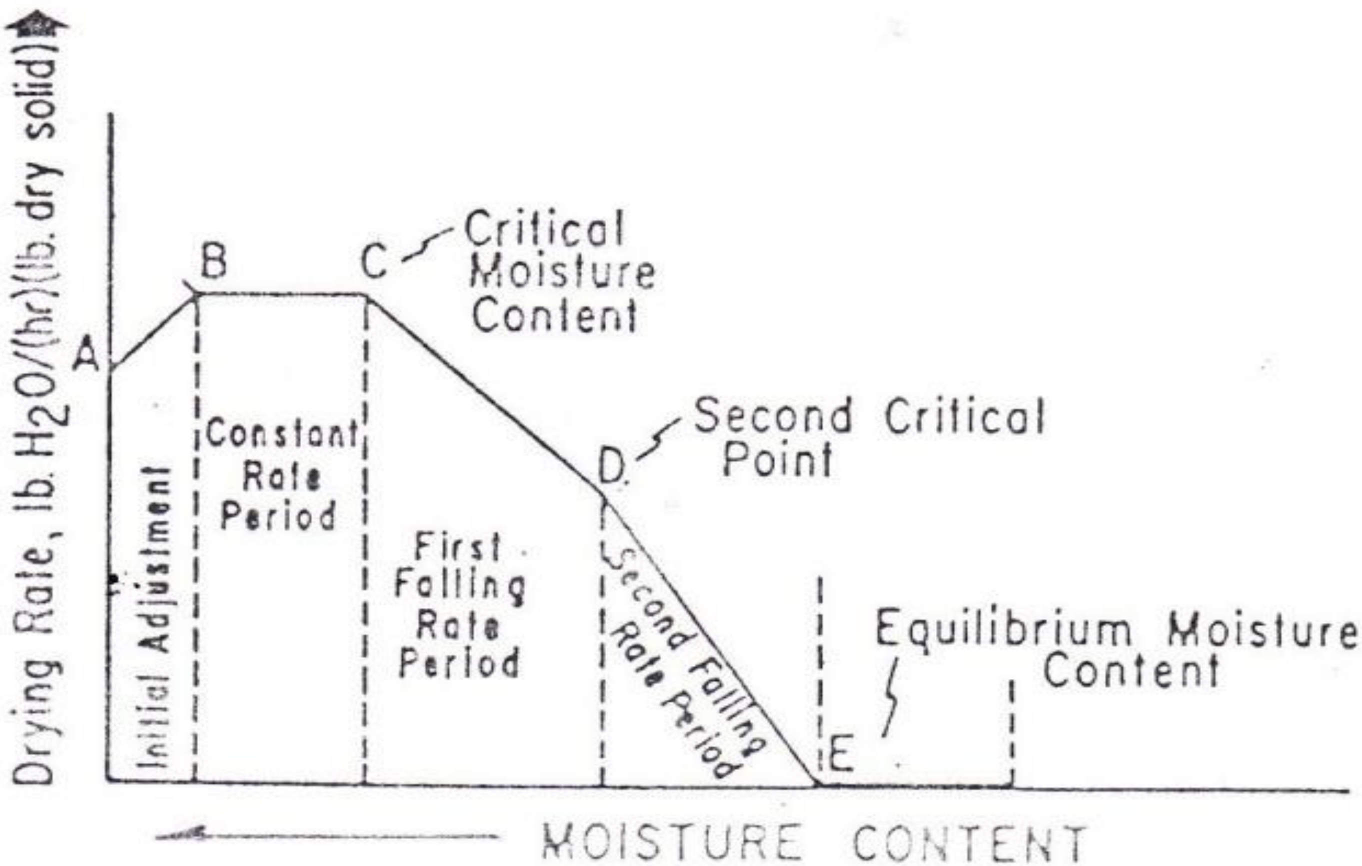
At point D, the film of surface water is completely evaporated, and the rate of drying depends on the rate of diffusion of moisture to the surface of the solid. Point D is referred to as the *second critical point.* Between points D and E the rate of drying falls even more rapidly than the first falling rate, and time DE is called the

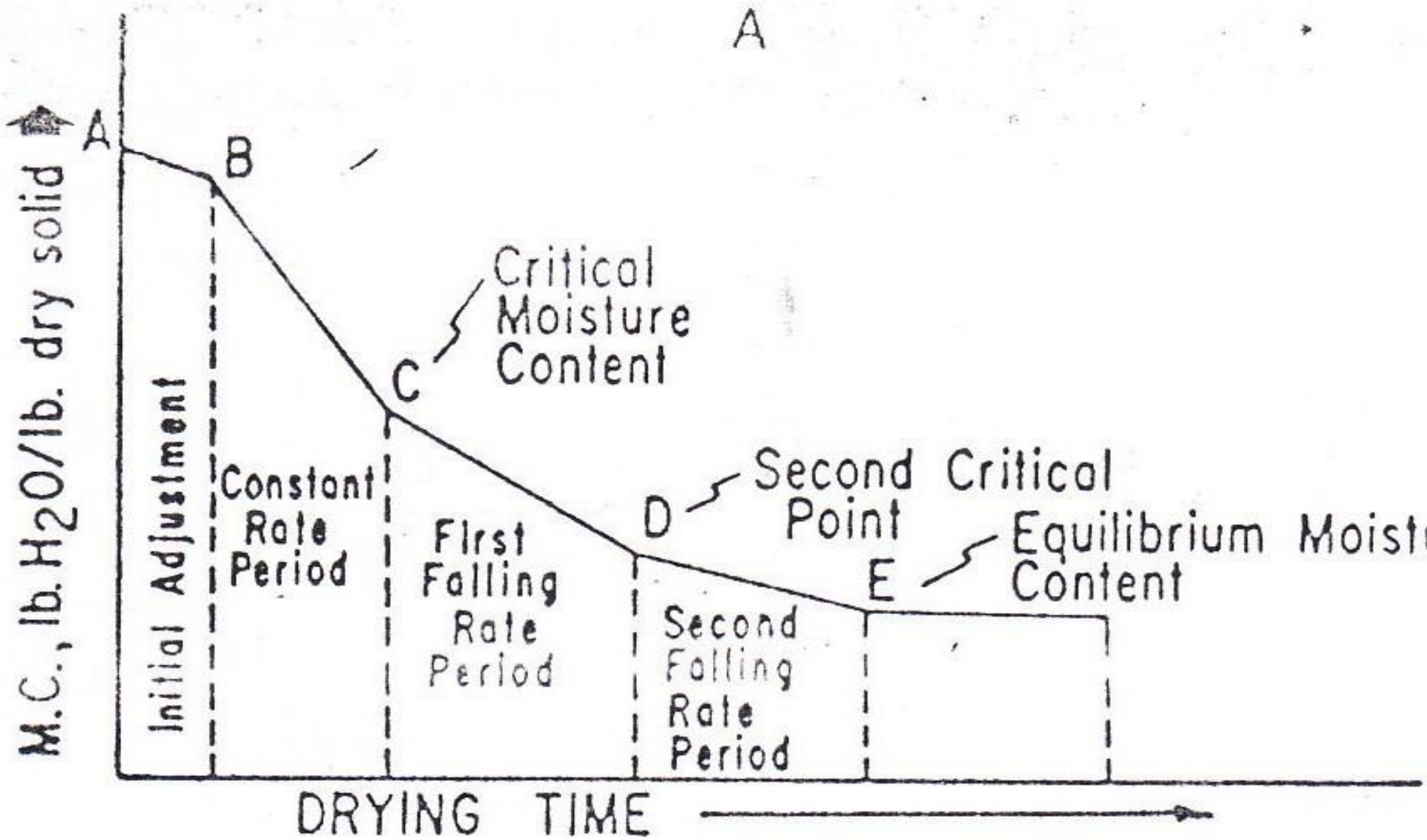
second falling rate period.

When the drying rate is equal to zero, starting at point E, the equilibrium moisture period begins, and the solid is in equilibrium with its surroundings, i.e., its temperature and moisture content remain constant. Continued drying after this point is a waste of time and energy.



Method of determining rate of drying: The difference in moisture content between any two measurements divided by the time period between measurements represents the rate of drying for this time period. This value is plotted against the midpoint of the time period for a drying rate versus time curve, or against the midpoint of the moisture content values for a drying rate versus moisture content curve.


Drying Rate, lb. H_2O/(hr)(lb. dry solid)
A
B
C
Critical
Moisture
Content
Second Critical
Point
D
E
Equilibrium Moisture
Content
Initial Adjustment
Constant
Rate
Period
First
Falling
Rate
Period
Second Falling
Rate Period
MOISTURE CONTENT
B



A
A
B
C
D
E
Critical
Moisture
Content
Second Critical
Point
Equilibrium Moisture
Content
Initial Adjustment
Constant
Rate
Period
First
Falling
Rate
Period
Second
Falling
Rate
Period
M.C., lb. H_2O/lb. dry solid
DRYING TIME

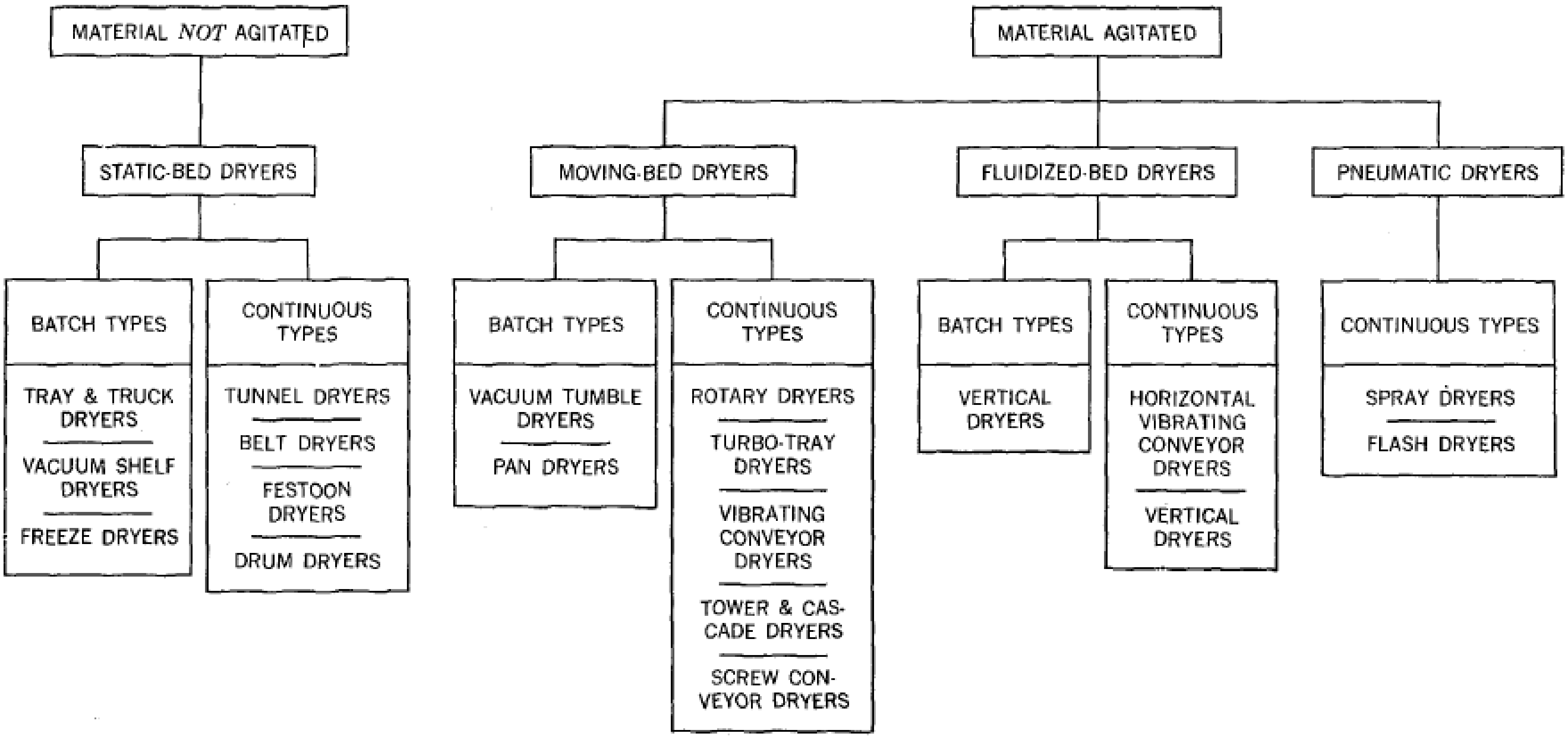


FIG. 3-5. *Classification of dryers, based on methods of solids handling.*

Classification of dryers

- 2 useful classifications are based on either the method of heat transfer or the method of solids handling.
- Classification according to the type of heat transfer is important in demonstrating gross differences in dryer design, operation, & energy requirements.
- Classification by the method of solids handling is more suitable when special attention must be given to the nature of the material to be dried.

- The classification according to their method of solids handling, the major criterion is the presence or absence of agitation of the material to be dried.
- A drier that produces excessive agitation is contraindicated when the dried material is friable & subject to attrition.
- If the dried product is intended to pulverized then the drying time can be reduced & the process made more efficient.

Classification based on the method of solids handling are divided into the following types

- 1-static bed dryers
- 2-moving bed dryers
- 3-fluidized bed dryers
- 4-pneumatic dryers

Static bed dryers

- In which there is no relative movement among the solid particles being dried, although there may be bulk motion of the entire drying mass.
- Only a fraction of the total number of particles is directly exposed to heat sources. The exposed surface can be increased by decreasing the thickness of the bed & allowing drying air to flow through it.

Moving bed dryers

- In which the drying particles are partially separated so that they flow over each other
- Motion may be induced by either
- 1-gravity
- 2- mechanical agitation.
- The resultant separation of the particles & continuous exposure of new surfaces allow more rapid heat & mass transfer than the can occur in static beds.

Fluidized bed dryers

- In which the solid particles are partially suspended in an upward moving gas stream.
- The particles are lifted & then fall back in a random manner so that the resultant mixture of solid & gas acts like a boiling liquid.
- The gas solid contact is excellent & result in better heat & mass transfer than in static & moving beds.

Pneumatic dryers

- In which the drying particles are entrained & conveyed in a high velocity gas stream.
- Pneumatic systems further improve on fluidized beds, because there is no channeling or short circulation of the gas flow path through a bed of particles.
- Each particles is surrounded by an envelope of drying gas.
- The resultant heat & mass transfer are extremely rapid so drying times are short.

Static bed systems
Tray & Truck dryers

- Tray dryers are sometimes called shelf, cabinet, or compartment dryers.
- This dryer consists of a cabinet in which the material to be dried is spread on tiers of trays.
- The no. of trays varies with the size of the dryer.
- Dryer of laboratory size may contain as few as 3 trays where as larger dryers hold as many as 20 trays.

Truck dryer

- Truck dryer in which the trays are loaded (racks equipped with wheels), which can be rolled into & out of the drying cabinet.
- In plant operations, the truck dryer is preferred over the tray dryer because it offers greater convenience in loading & unloading.
- The trucks usually contain 1 or 2 tiers of trays, with about 18 or more trays per tier.

Tray dryer

https://www.google.com/search?q=tray+dryer&hl=en&tbm=isch&sxsrf=ALeKk01gnIzwV6C6a1kzpHAdG-vmI6R5rA%3A1620462017696&source=hp&biw=1093&bih=526&ei=wUmWYIC1J9LSkgXgiICgAQ&oq=tray+dryer&gs_lcp=CgNpbWcQAzICCAAyAggAMgIIADICCAAyAggAMgIIADICCAAyAggAMgIIADICCAA6BwgjEOoCECc6BAgjECc6BQgAELEDUOwXWOM4YNg_aAFwAHgAgAGQAYgBpgqSAQQwLjEwmAEAoAEBqgELZ3dzLXdpei1pbWewAQo&sclient=img&ved=0ahUKEwjAmby307nwAhVSqaQKHWAEABQQ4dUDCAc&uact=5#imgrc=hXrkMDyaN25rvM

Tray dryers may be classified as direct or indirect.

- Direct type: in which heating is accomplished by the forced circulation of large volumes of heated air.
- Indirect tray dryers utilize heated shelves or radiant heat sources inside drying chamber to evaporate the moisture.
- The trays used have solid, perforated or wire mesh bottoms.
- To achieve uniform drying, there must be a constant temp. & uniform airflow over the material being dried.

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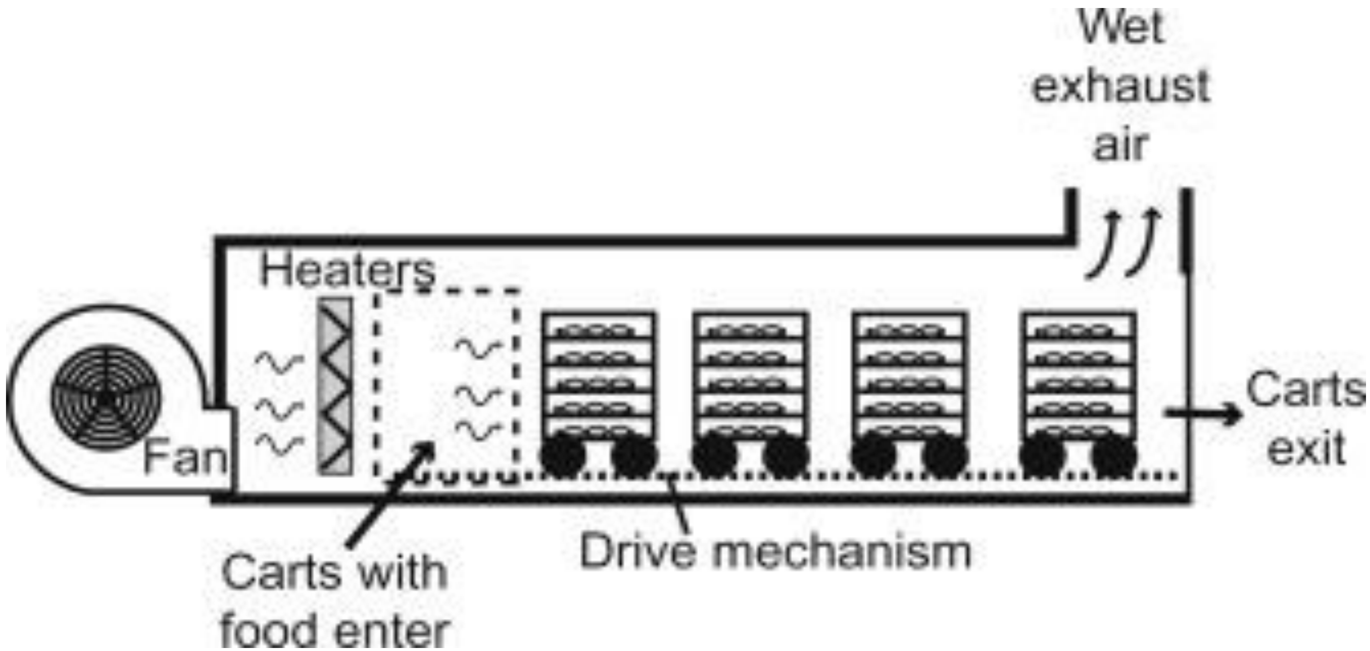
Tunnel dryers

- Which are adaptations of the truck dryer for continuous drying. The trucks are moved through the drying tunnel by a moving chain.
- These trucks are loaded on one side of the dryer, allowed to reside in the heating chamber for a time sufficiently long to effect the desired drying & then discharge at the exit.
- The operation may be described as semicontinuous, because each truck requires individual loading & unloading before & after the drying cycle.



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Conveyor dryers

- Are an improvement over tunnel dryers because they are truly continuous .
- The individual trucks of the tunnel are replaced with an endless belt or screen that carries the wet material through the drying tunnel.
- Conveyor dryers provide for uninterrupted loading & unloading & are thus more suitable for handling large volumes of materials.

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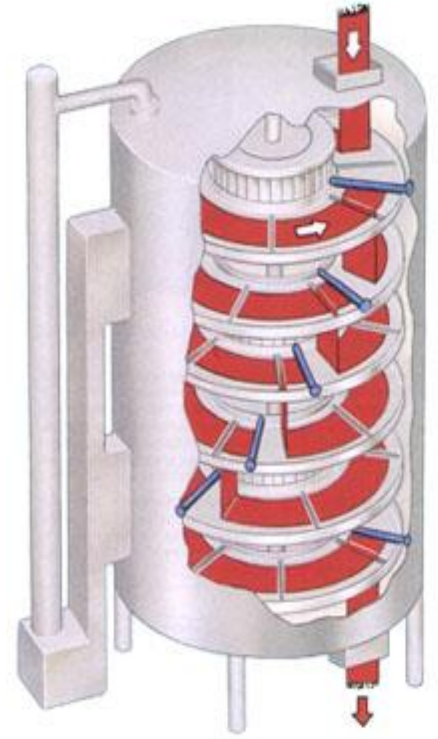
Moving bed systems /Turbo tray dryers

- Is a continuous shelf. It consist of a series of rotating annular trays arranged in a vertical stack, all of which rotate slowly at 0.1 to 1 rpm.
- Heated air is circulated over the trays by fans mounted in the center of the stack.
- Wet mass fed through the roof of the dryer is leveled by a stationary wiper. After about seven-eights of a revolution the material being dried is pushed through redial slots onto tray below where it is again spread & leveled.



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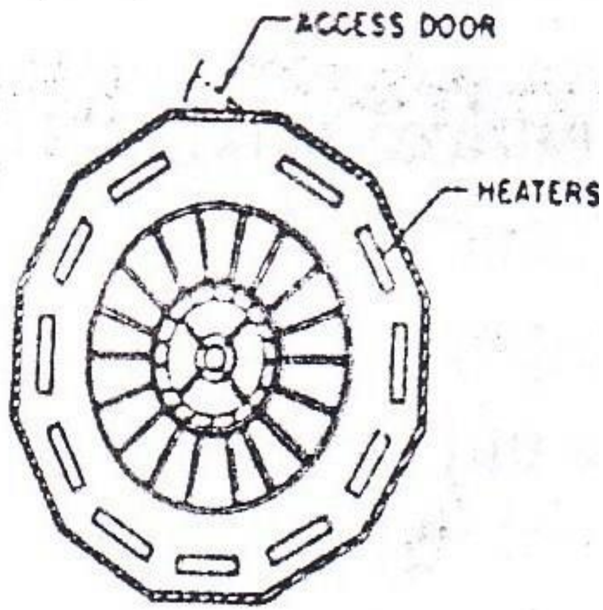
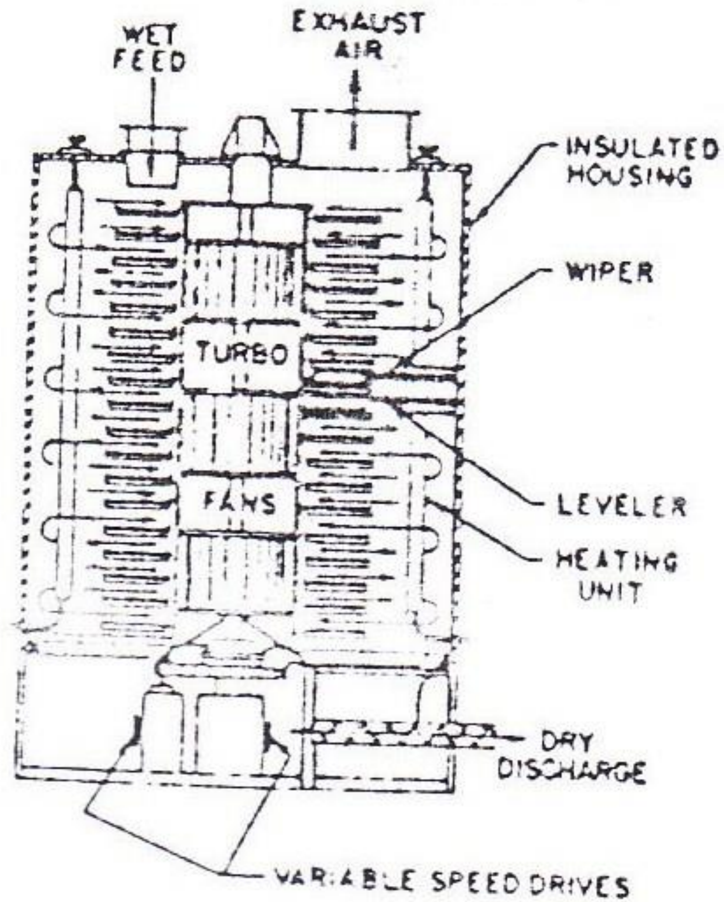
Because the turbo tray dryer continuously exposes new surfaces to the air drying rates are faster than for tunnel dryers.





Pan dryers

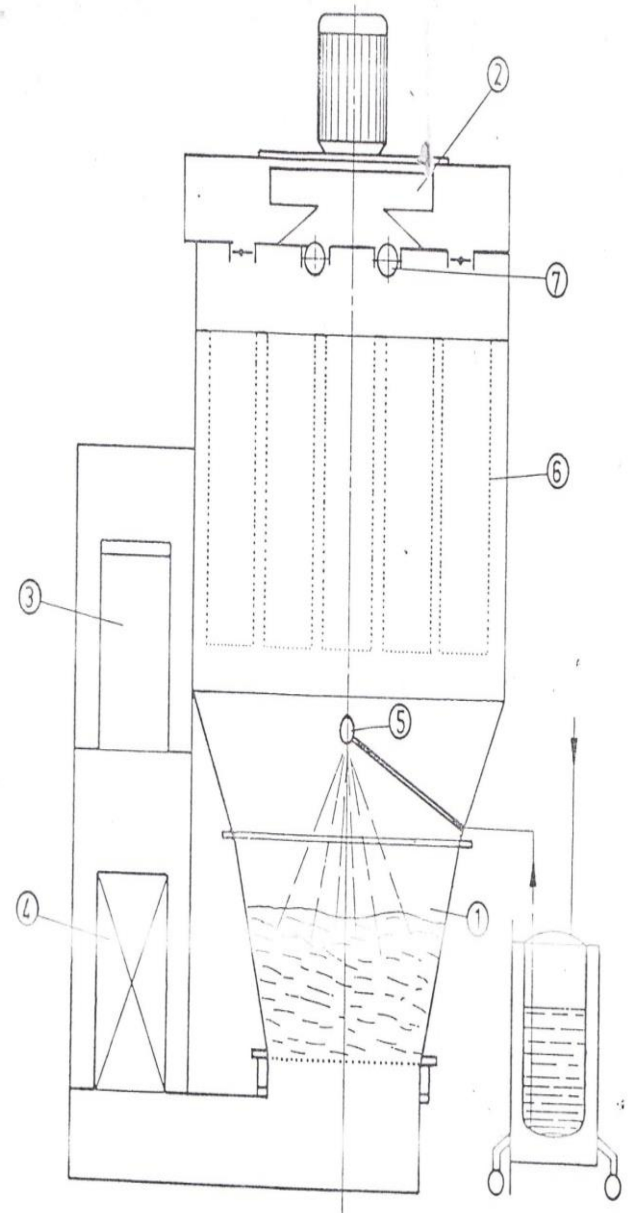
- They are moving bed dryers of the indirect type that may operate under atmospheric pressure or vacuum & are generally used to dry small patches of paste or slurries. The dryer consists of a shallow, circular jacketed pan.
- Heat is supplied by steam or hot water.
- There is a set of rotating plows in the pan that evolve slowly, scraping the moisture – laden mass from the walls & exposing new surfaces to contact with the heated sides & bottom.

https://www.3v-tech.com/en/process-equipment/13/dryers/39/pan-dryer-multidry-ev

- Atmospheric pan drying allows moisture to escape where as in vacuum dryers in which the pan is completely enclosed .
- The dried material is discharged through a door on the bottom of the pan.

Fluidized – bed systems

- They are of 2 types 1-vertical & 2-horizontal.
- 1- the vertical types consist of a fan mounted in the upper part of the apparatuse.
- The air is heated to the required temperature in an air heater & flows upward through the wet material which is contained in a drying chamber fitted with a wire mesh support at the bottom.
- The air flow rate is adjusted by means of a damper, & a bag collector filter is provided at the top of the drying chamber.



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- This unit is used as a granulator. The dry ingredients are placed in the chamber & fluidized while the granulating liquid is sprayed into the bed causing the particles to agglomerate into granules.
- At the end of the granulating cycle, the granules are dried by heating the fluidized air.

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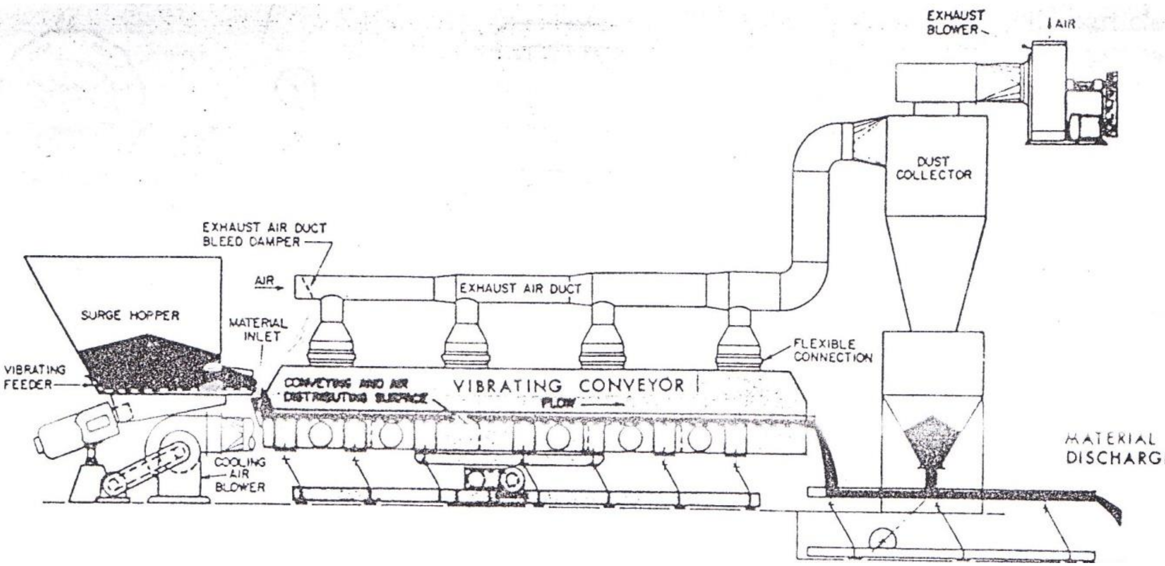
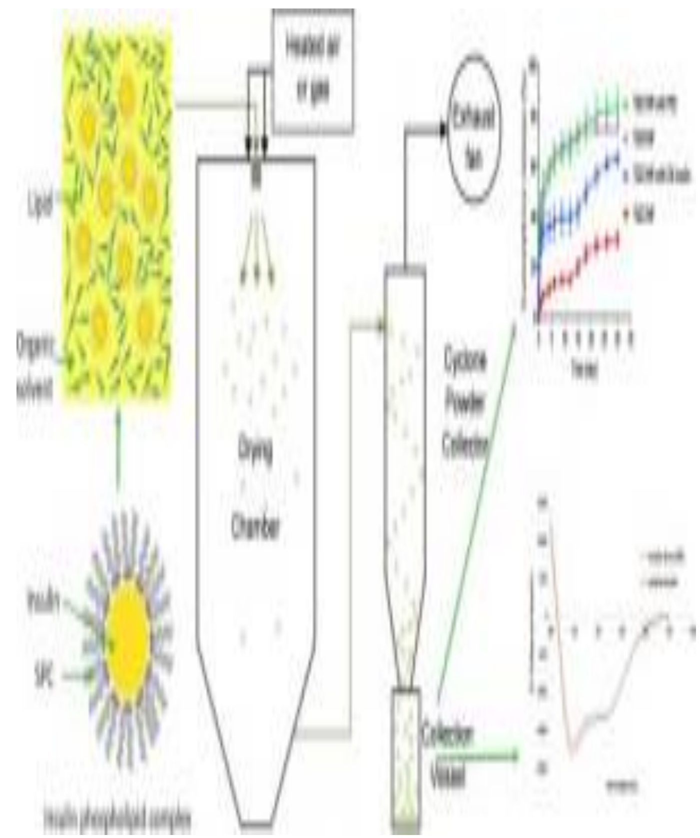

EXHAUST BLOWER
AIR
DUST COLLECTOR
EXHAUST AIR DUCT BLEED DAMPER
AIR
EXHAUST AIR DUCT
SURGE HOPPER
MATERIAL INLET
FLEXIBLE CONNECTION
VIBRATING FEEDER
CONVEYING AND AIR DISTRIBUTING SURFACE
VIBRATING CONVEYOR
FLOW
MATERIAL DISCHARGE
COOLING AIR BLOWER

Pneumatic systems
spray dryer

- spray dryers differ from most other dryers in that they can handle only fluid materials such as solutions, slurries, & thin pastes.
- The fluid is dispersed as fine droplets into a moving stream of hot gas where they evaporate rapidly before reaching the wall of the drying chamber.
- The product dries into a fine powder which is carried by the gas current & gravity flow into a collection system.



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