DRYING in food processing – aims and methods

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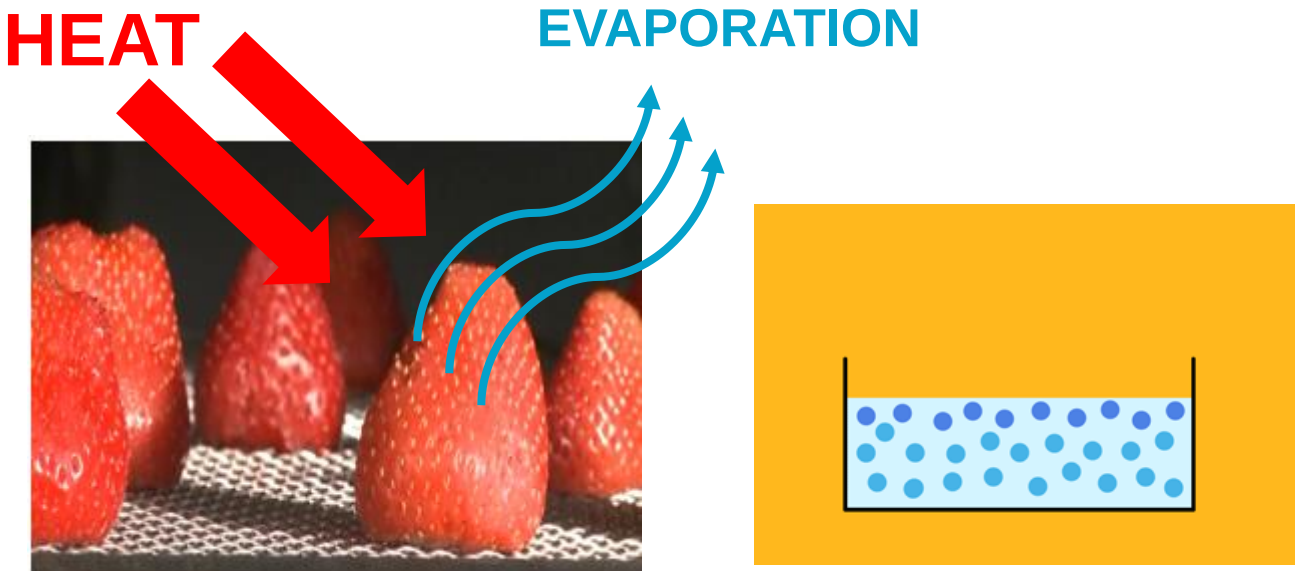
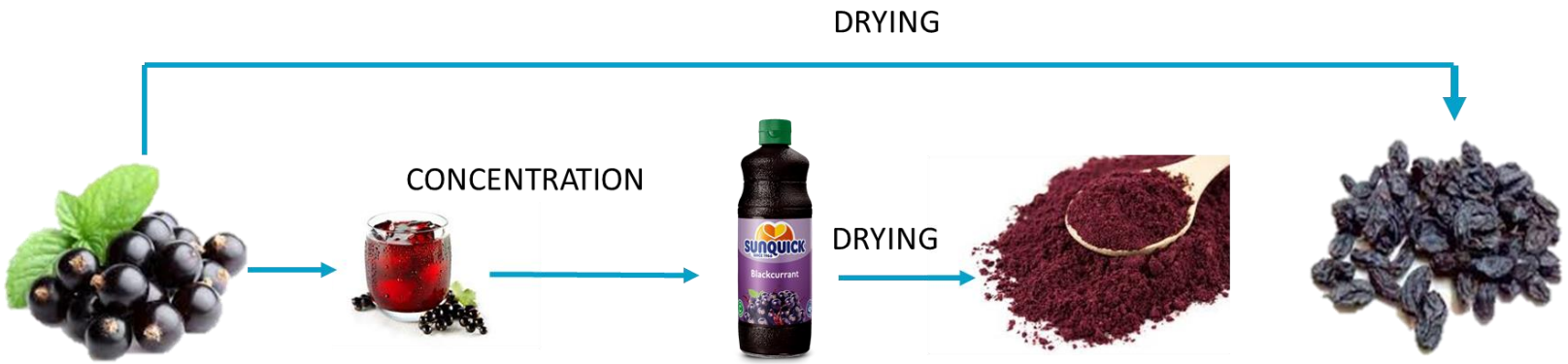
DEFINITION

DRYING is the removal of water by <u>evaporation below boiling point</u> from solid or liquid food, with the purpose of obtaining a solid product sufficiently low in water content





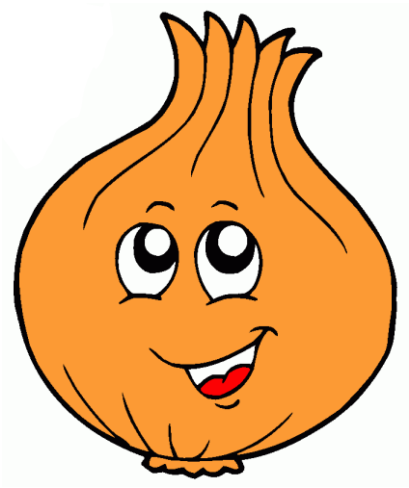
Aims of drying in food industry

- PRESERVATION

- REDUCTION OF THE COSTS or difficulty of packaging, handling, storage and transport

- PROVIDING/CREATING NEW PROPERTIES

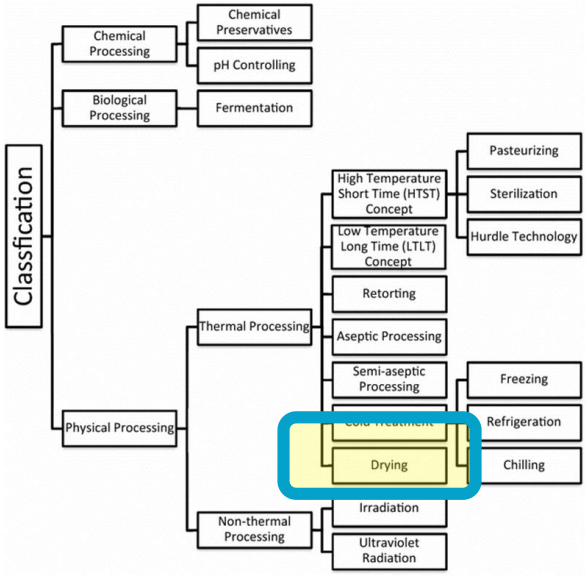
New properties - dried onion



Drying as a preservation method

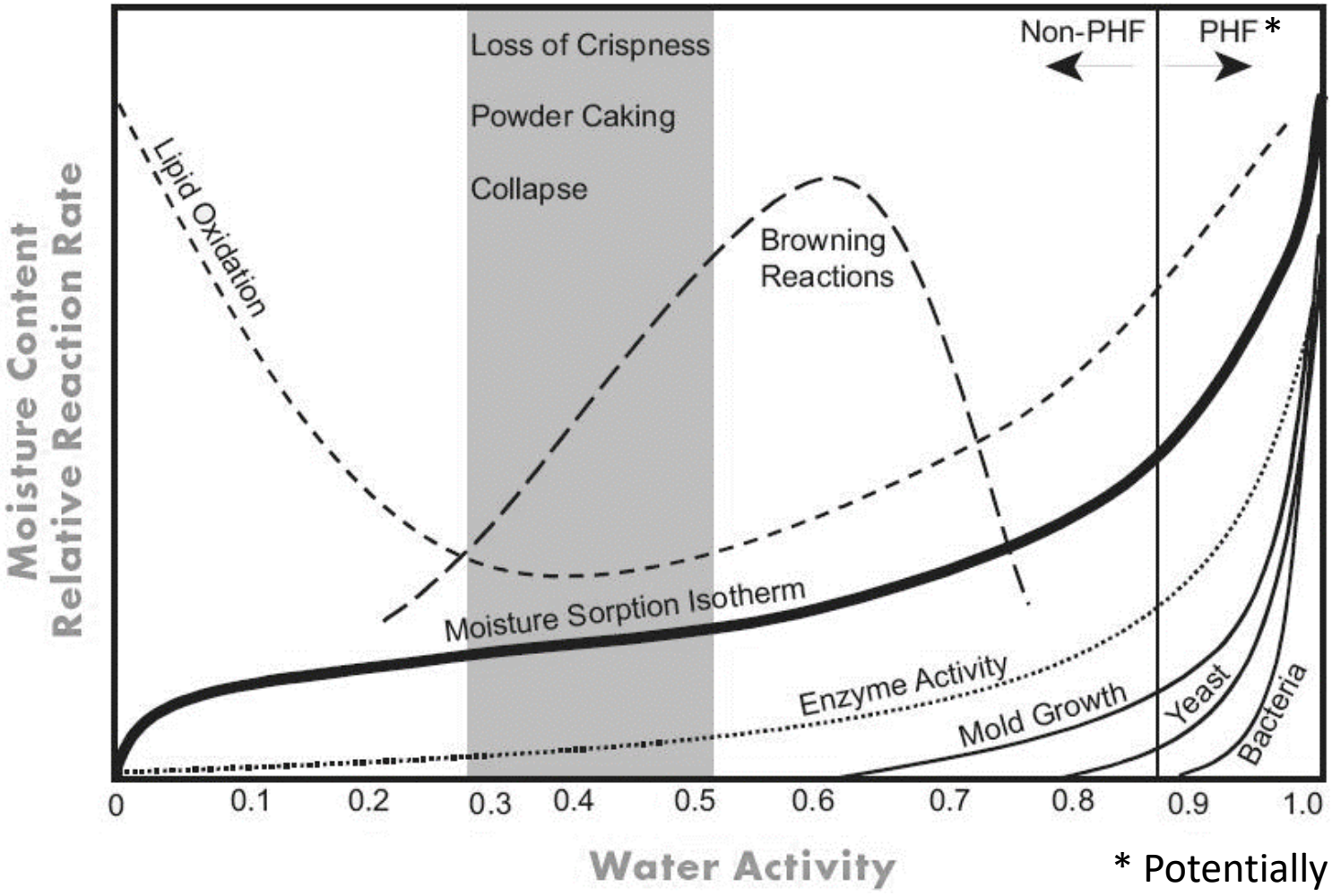
Food spoilage – irreversible changes where food becomes inedible, or its quality is dangerous

Food harm can be prevented or reduced by implementing food preservation techniques



Why drying preserves food?

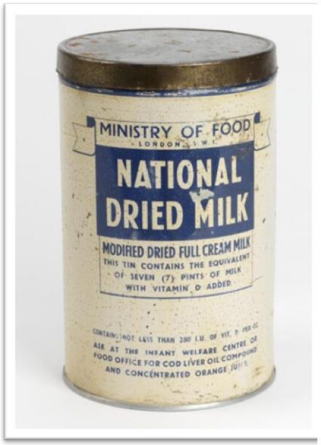
FOOD STABILITY DIAGRAM

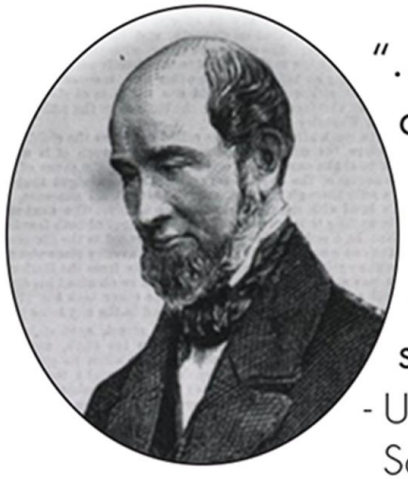


Pathogenic bacteria cannot grow below 0.85-0.86

* Potentially Hazardous Food

The history and place of drying In food industry



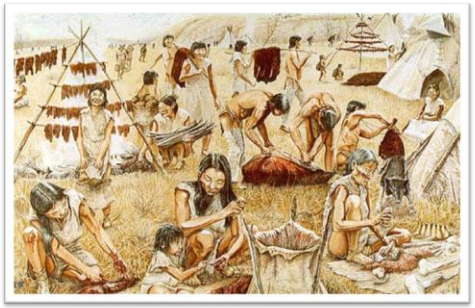


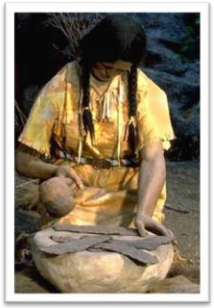
"...the prevention of the destructive chemical change" by "bringing a fluid...into a state of minute division..."

- US Patent No. 125,406
Samuel R. Percy, 1872

Source: History of Medicine, US National Library of Medicine

Traditional dried products

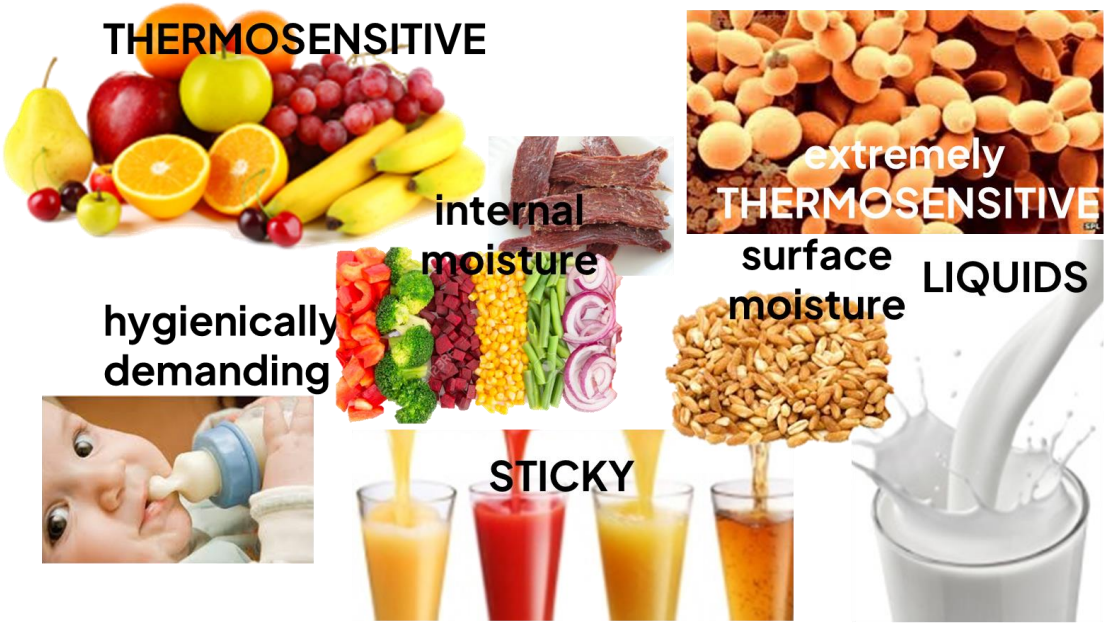




Current applications

Applications

Large diversity of raw materials



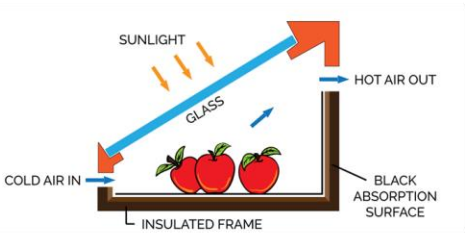
Large diversity of equipment:

over 100 variants of dryers

Drying – energy intensive process

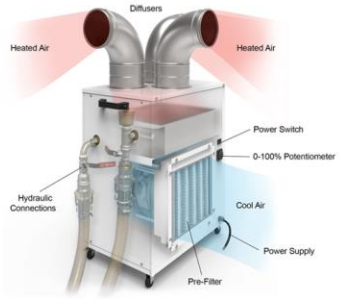
Different sources of energy are used

Solar energy

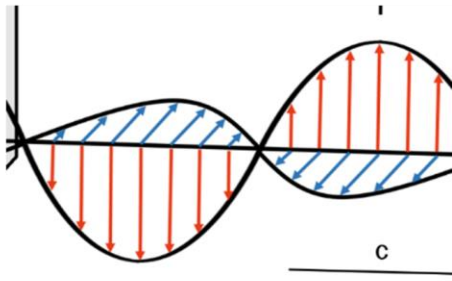


Steam

Electric current



Electromagnetic waves



1. High latent heat of water evaporation

2. Low thermal efficiency

Energy consumption in drying

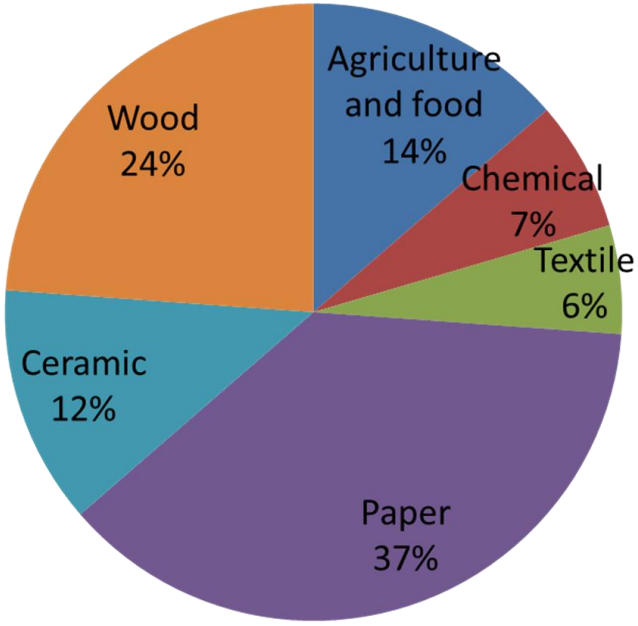
Table 12.1 Comparative costs of water removal

	Separation costs per unit volume of water removed (arbitrary units)
Spray drying	17–50
Drum drying	10–25
Centrifugation	0.1–10
UF/RO	0.2–7
Evaporation	0.2–5

After Timmins in Goldblith et al., 1975. Freeze drying and advanced food technology, London: Academic

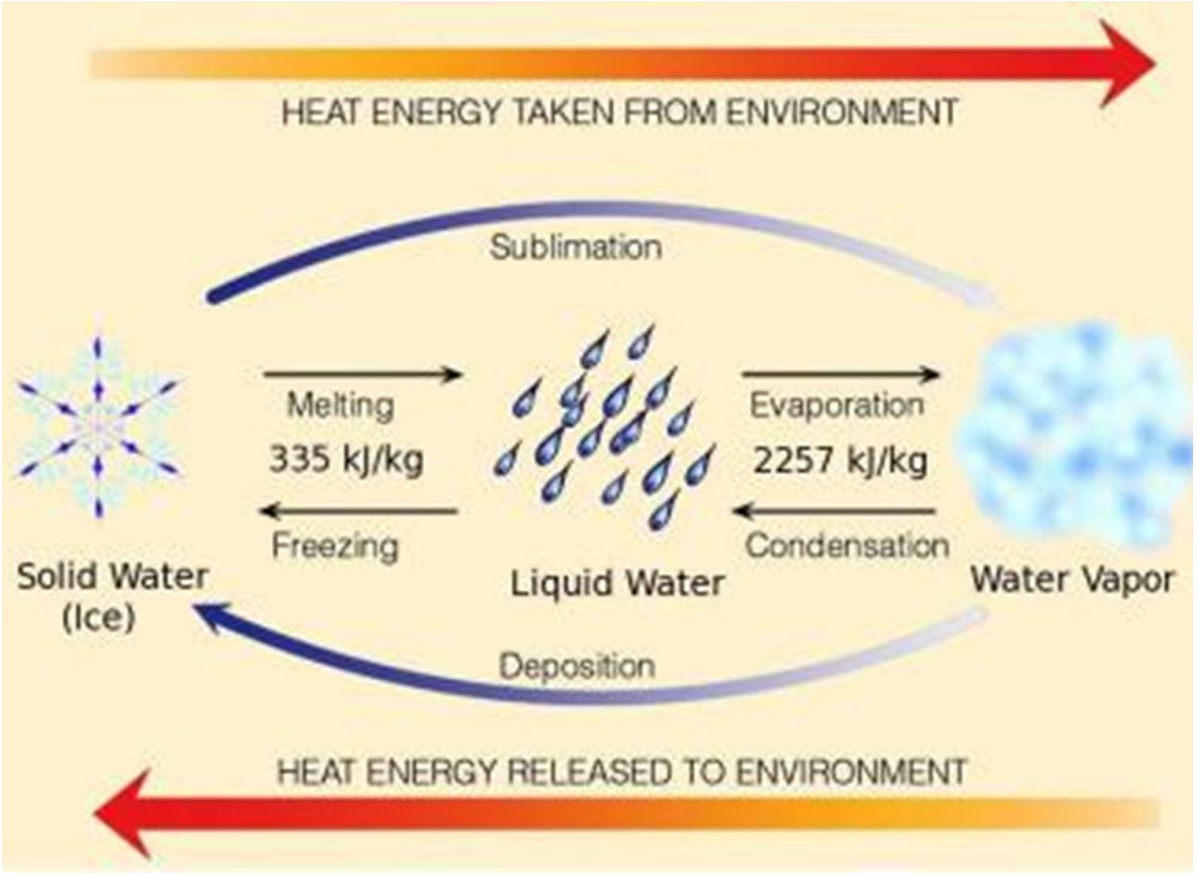
100% energy consumption in industry

99% without heat recovery



Energy consumption in drying

High latent heat of water evaporation

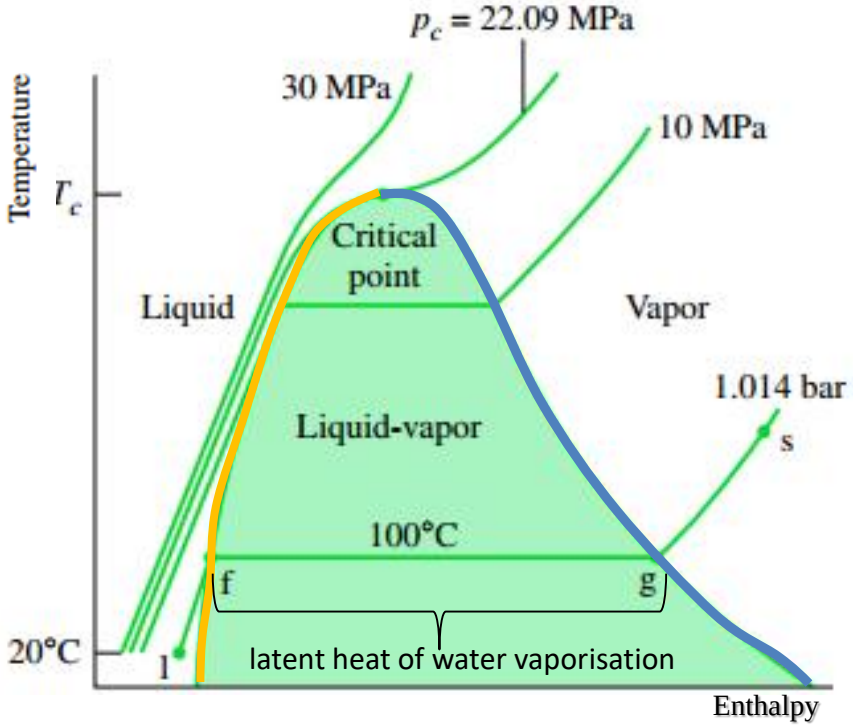


	Latent heat of evaporation [kJ/kg]
Acetic acid	*402*
Acetone	*518*
Ethanol	*846*
Ammonia	*1369*
Carbon dioxide	*574*
Glycerine	*974*
Helium	*21*
Hydrogen	*461*
Iodine	*164*
Oxygen	*214*
Propane	*428*
Propylene	*342*
Toluene	*351*
Turpentine	*293*
Water	*2256*

Energy consumption in drying

High latent heat of water evaporation

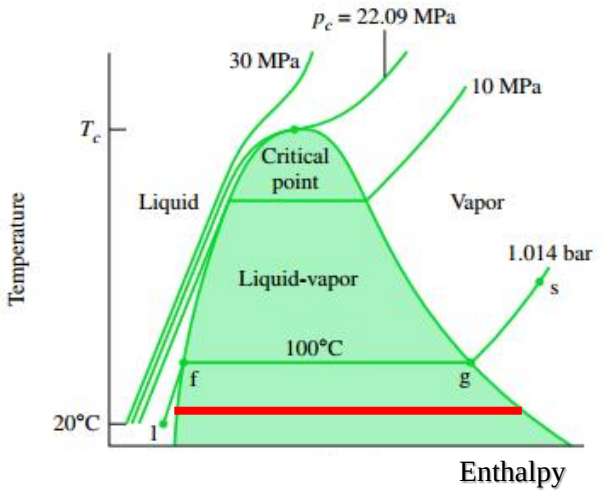
Latent heat of water vaporisation depends on pressure



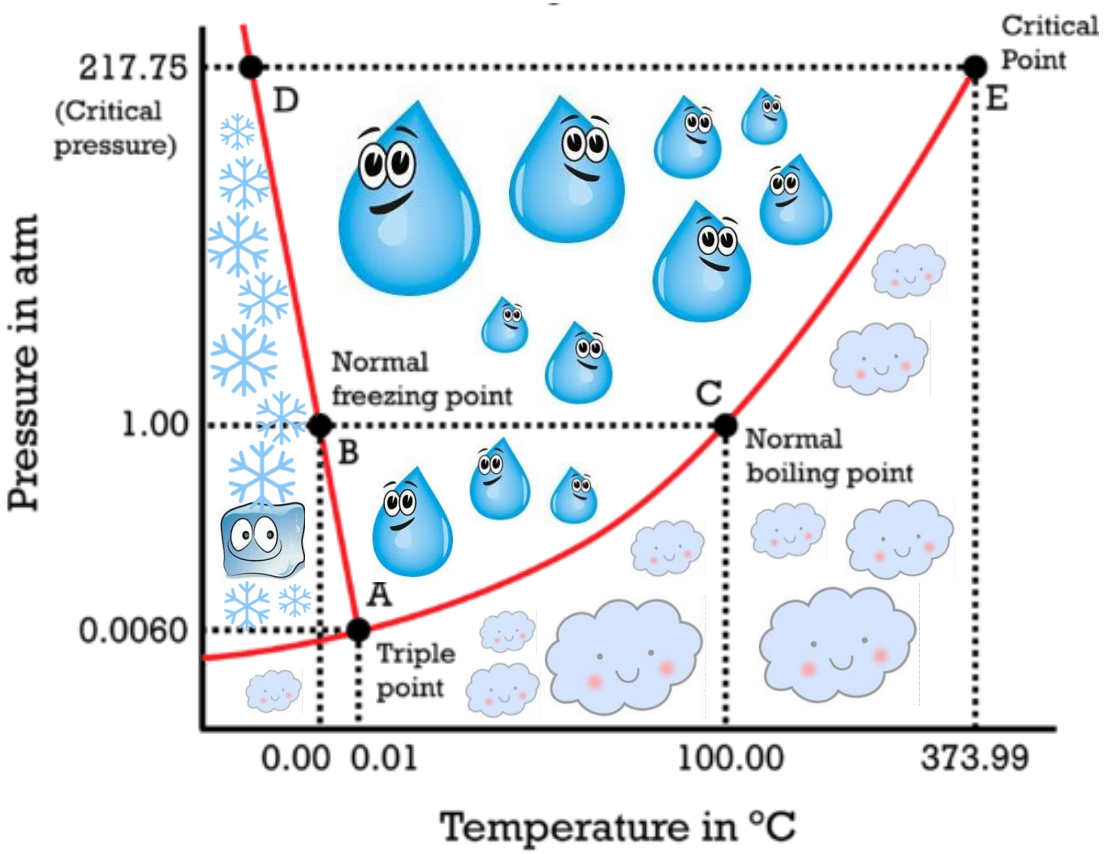
f - saturated liquid

g - saturated vapor

Energy consumption in drying



High latent heat of water evaporation



critical point - the temperature and pressure of both phases become equal and two phases can no longer be separated; the highest temperature at which the liquid state may exist

triple point - exact temperature and pressure conditions, specific for each material, at which all three phases coexist

A phase diagram of water showing the equilibrium curves between various physical states and their dependence on pressure and temperature

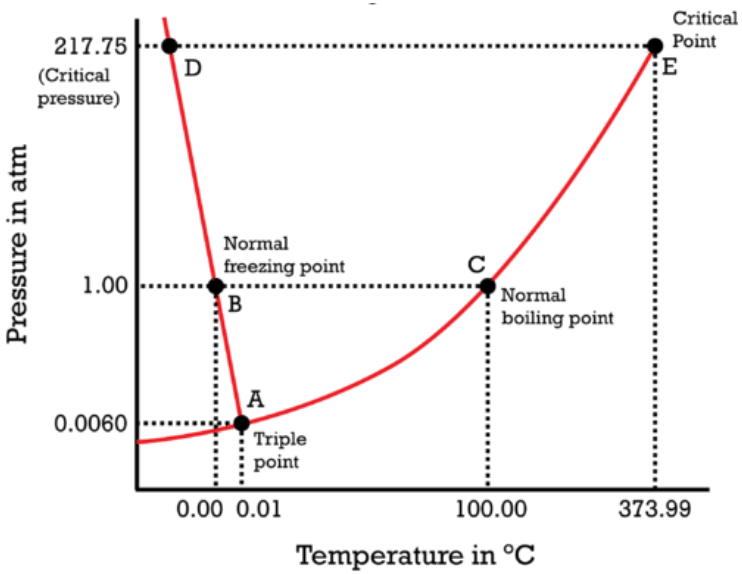
Energy consumption in drying

Drying at lower temperature is possibble by pressure reduction

Absolute pressure (kPa)	Water boiling temp. [°C]
2.3385	20
4.2461	30
7.3837	40
12.350	50
19.941	60
31.188	70
47.390	80
70.139	90
101.325	100

Lower pressure - possible to boil water at lower temperature when compared to atmospheric drying

At atmospheric pressure water boils at 100°C



Energy consumption in drying

Parameters used to characterize the energy consumption of drying process

1. The specific energy consumption

The energy consumed per unit mass of product

2. The efficiency of energy usage η

$$\eta = \frac{Q_{evap}}{Q_{in}}$$

Proportion of the energy used for evaporation of water

Q_{evap} – the energy used for water evaporation from product

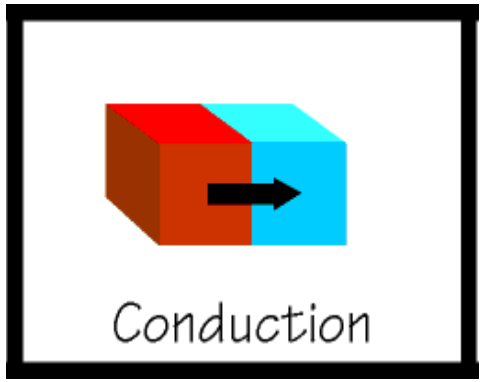
Q_{in} – the total input energy

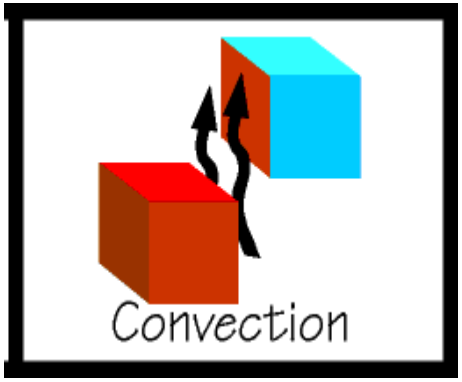
$$\eta = \frac{Q_{evap}}{Q_{in} - Q_{rec}}$$

Q_{rec} – the energy recovered in the system

Energy consumption in drying

Conductive drying	Convective drying
Heat is supplied directly to the material being dried	Drying heat is supplied to air, which transfers heat to the material being dried
The energy usage efficiency 35-80%	**The energy usage efficiency 20-50%**



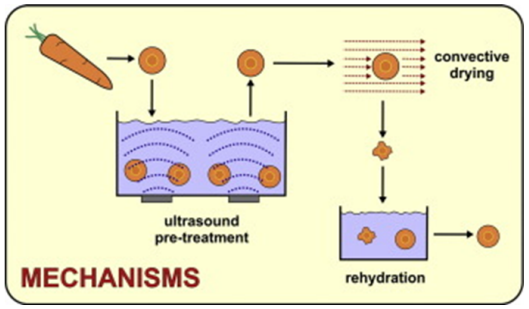


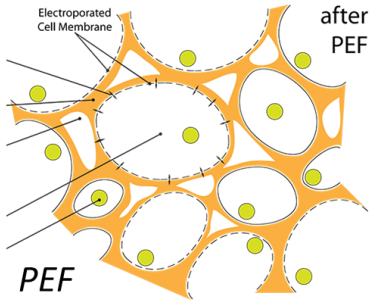
Energy consumption in drying

Possible methods to save energy

- ❑ Pretreament to increase drying rate

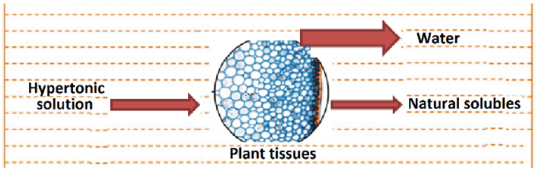
ultrasound





- ❑ Removal of part of water

liquids - pre-concentration

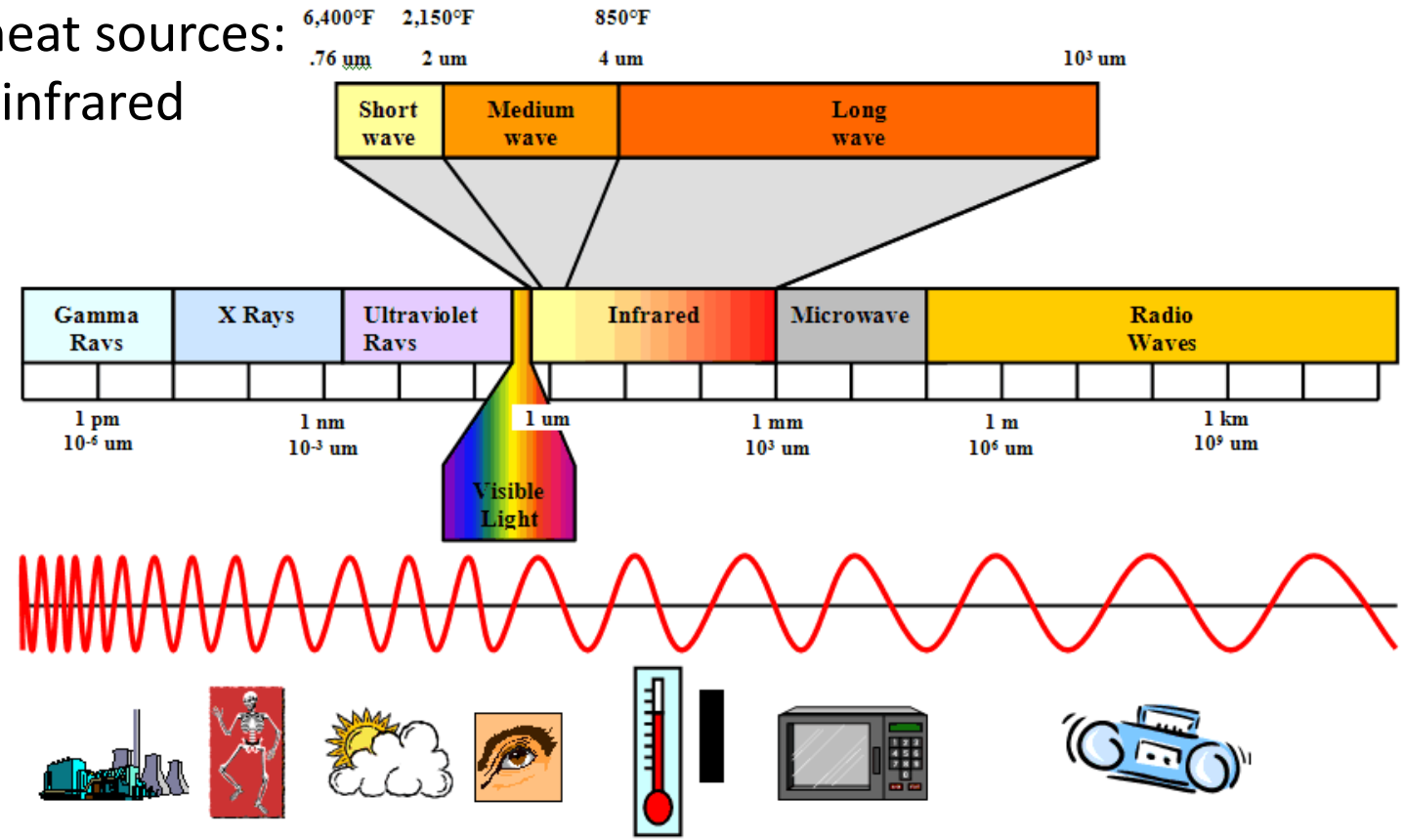


solids – i.e. osmotic dehydration

Energy consumption in drying

Possible methods to save energy

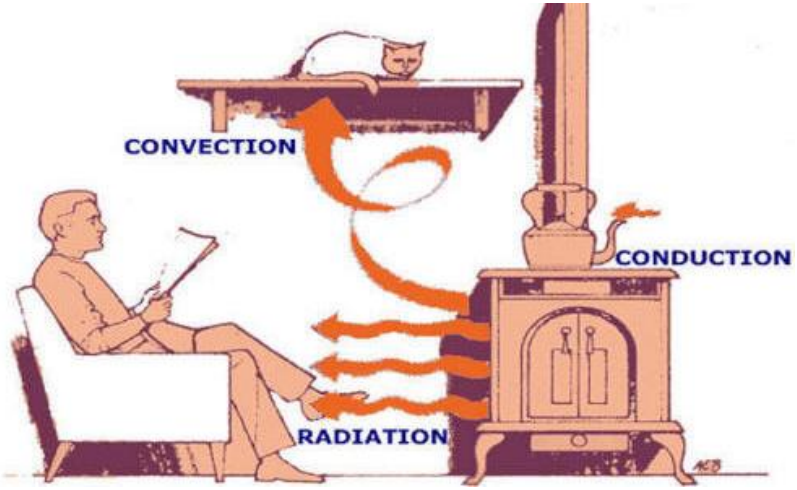
- Additional heat sources: microwave, infrared



Drying methods

The numerous types of dryers in use in the food industry may be classified in relation to different criteria:

- ❑ by **method of operation**: batch, continuous
- ❑ by the **movement of the material during drying**: static, moving, fluidized



- ❑ by the **mechanism of heat transfer**: convection, conduction, radiation (infrared, microwave)

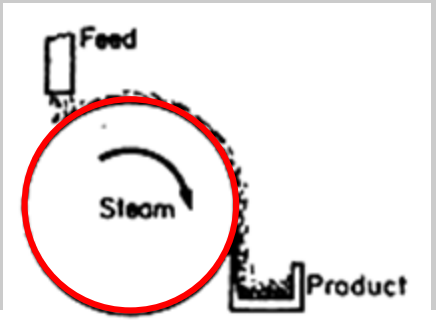
- ❑ by **pressure** of operation: vacuum, atmospheric, high pressure.

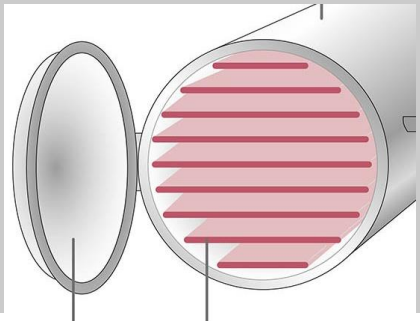
- ❑ by the **physical state of the feed material**: solid, liquid, paste

Basic classification of drying methods is based on heat transport mechanism:

HEAT CONDUCTION - contact drying

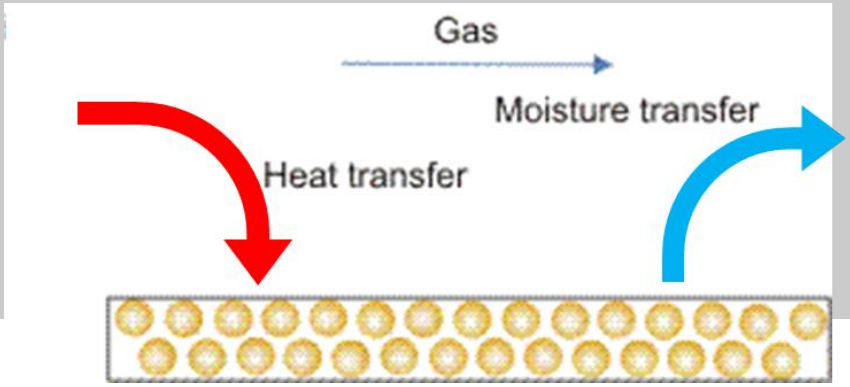
Heat is supplied directly to the material being dried





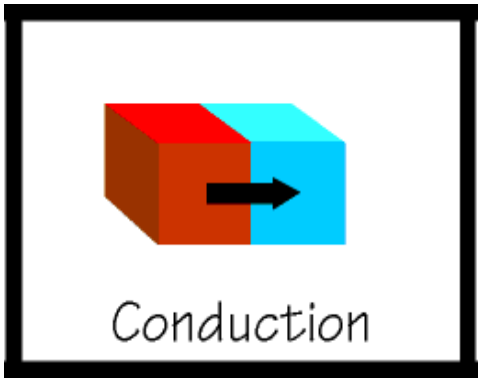
HEAT CONVECTION – convective hot air drying

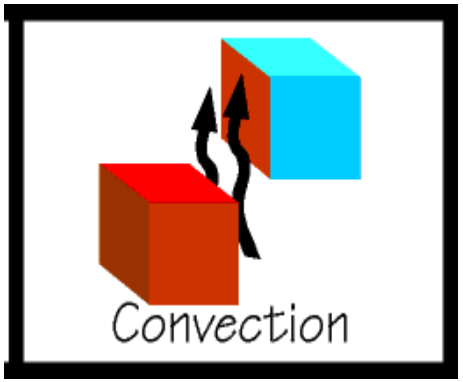
Drying heat is supplied to air, which transfers heat to the material being dried



Main advantages compared to hot air dryers:

- **less air volume** is required
- **higher thermal efficiency**
- process may be carried out in the **absence of oxygen**





DRYING METHODS

CONVECTIVE

Cabinet/chamber/tray drying
Tunnel drying
Belt drying
Rotary drying
Fluidized bed drying (vibro)
Spouted bed drying
Pneumatic drying
Bin drying
Spray drying 

CONDUCTIVE

Drum drying 
Freeze-drying 

RADIATION

Infrared
Microwave

Drying methods (CONVECTION)

Cabinet/compartment/tray dryers

- cheap and simple to construct
- solid materials loaded in trays on trucks or shelves
- batch drying at small to moderate scale (2 to 20 t per day)

Depending on the product and the conditions, the duration of a batch is typically **2 to 10 h**

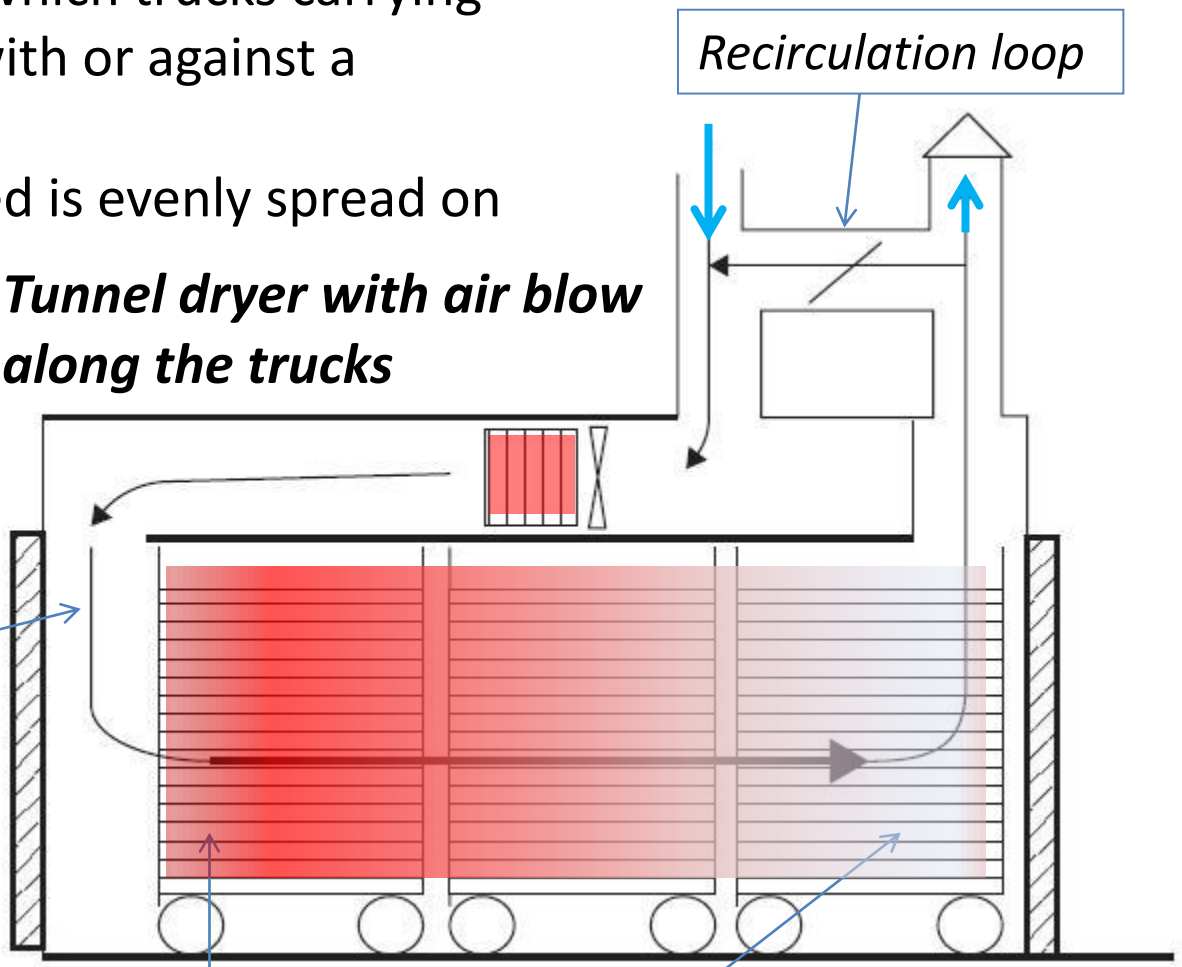
60-80°C

Drying methods (CONVECTION)

Tunnel dryers

- long tunnels through which trucks carrying stacks of trays travel with or against a stream of drying air
- the material to be dried is evenly spread on the trays
- typical trolley loading for wet vegetables is 10-30 kg per m^2

Tunnel dryer with air blow along the trucks

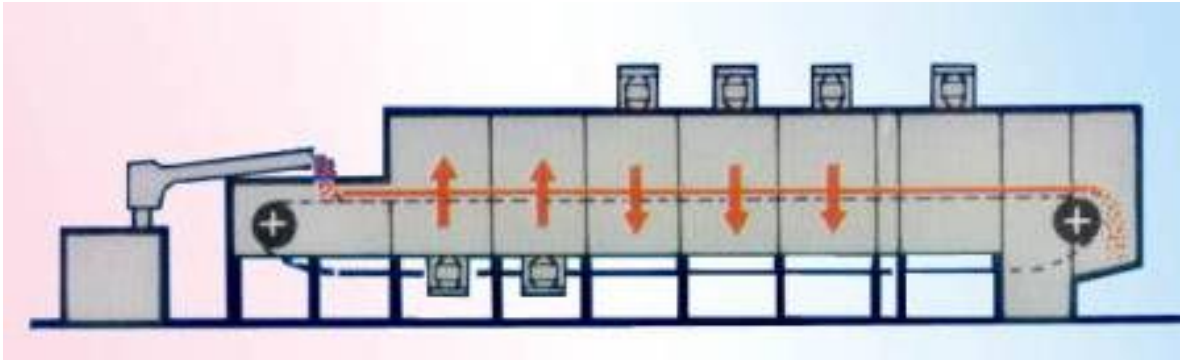


as one truck with wet material is introduced into the tunnel at one end, another truck, carrying dehydrated product, exits at the other end

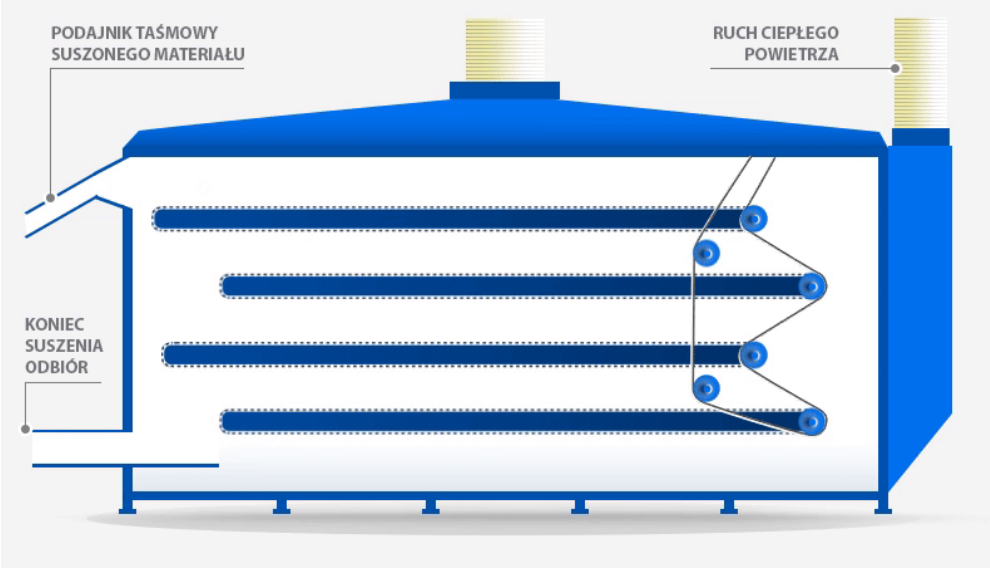
Drying methods (CONVECTION)

Belt dryers

- among the most versatile continuous dryers for solid foods
- extensively used, mainly for large-scale dehydration of vegetables



Single-stage belt dryer with through-flow mode

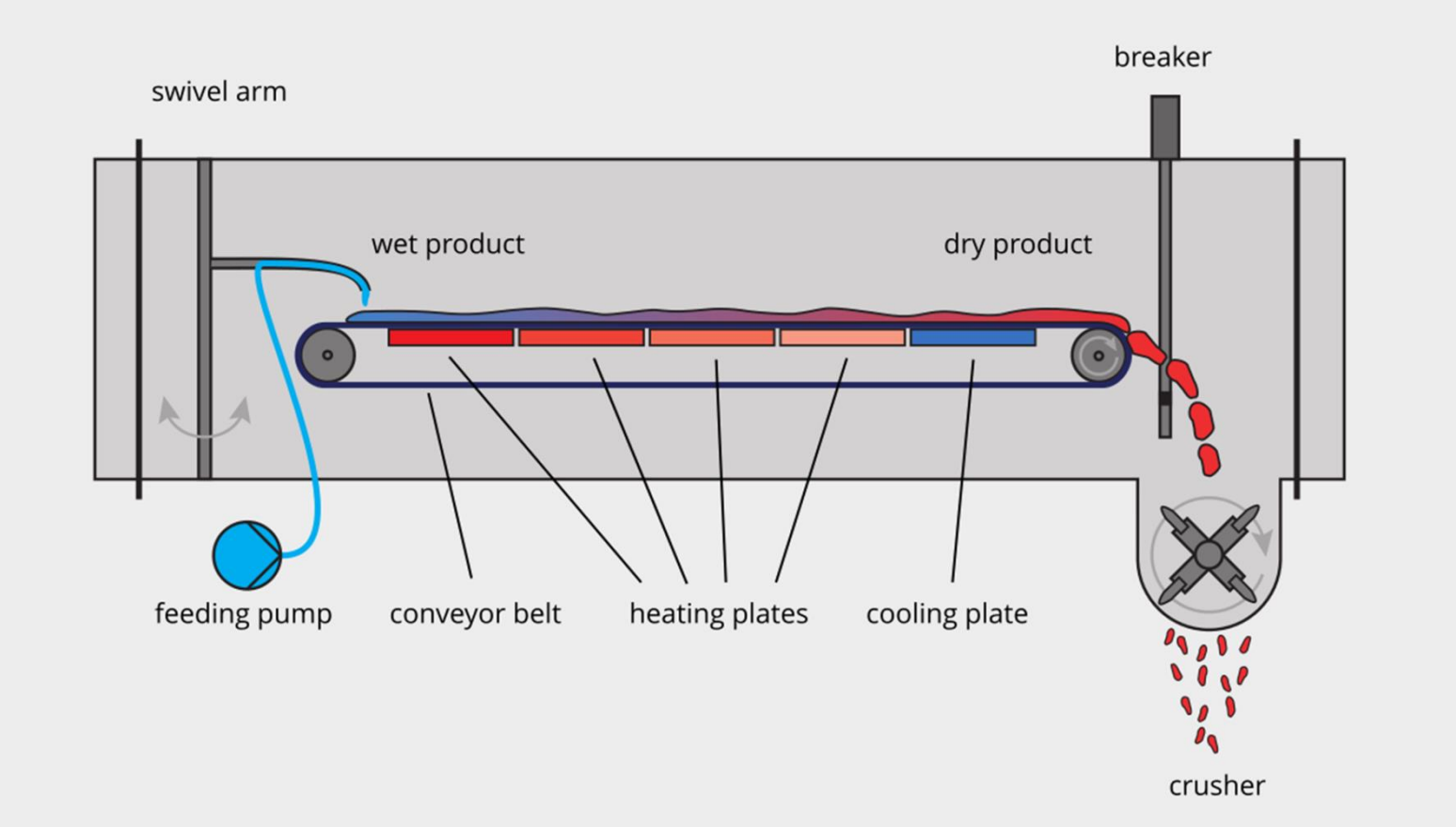


Drying methods (CONDUCTION)

Belt dryers

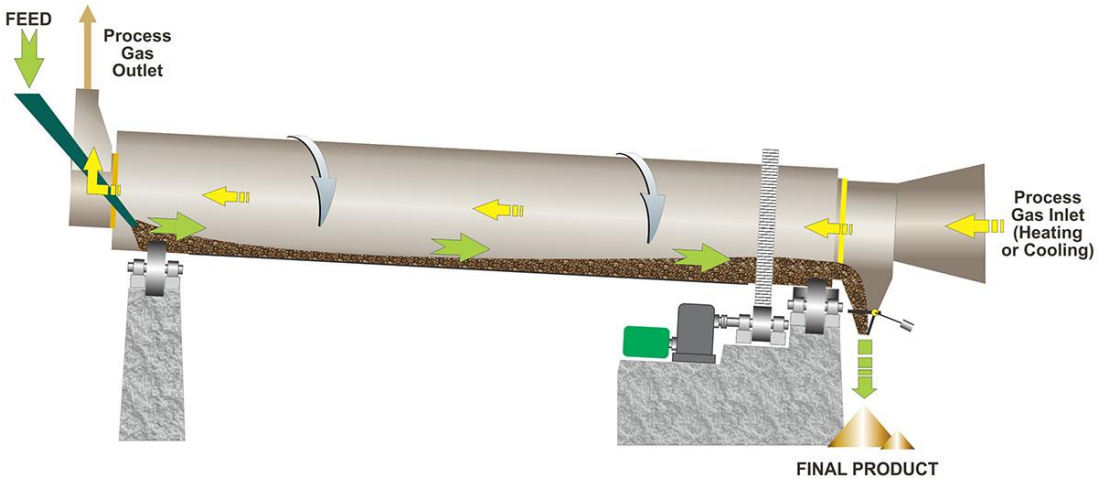
heated surface - metal belt
conveyor heated by conduction by hot elements installed below

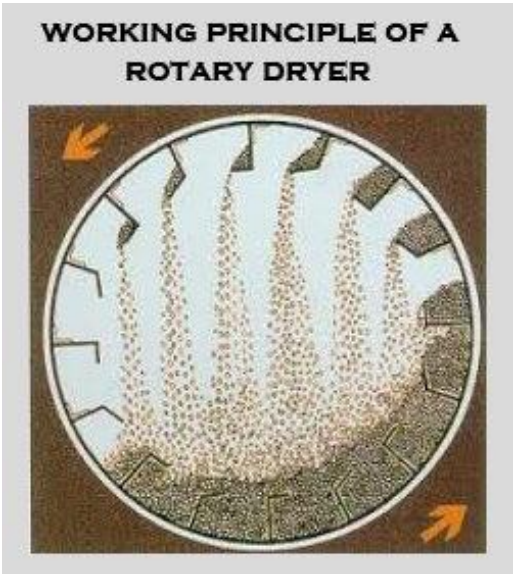
FOAM-MAT DRYING



Drying methods (CONVECTION)

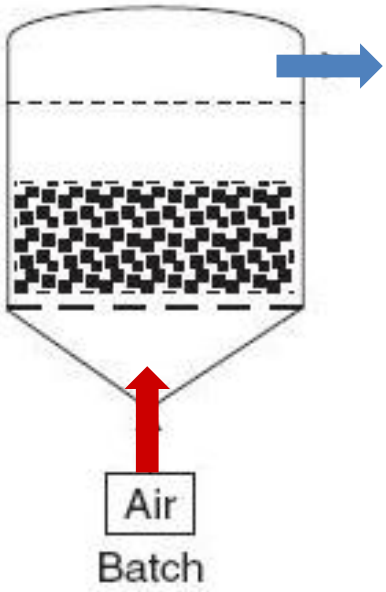
Rotary dryers



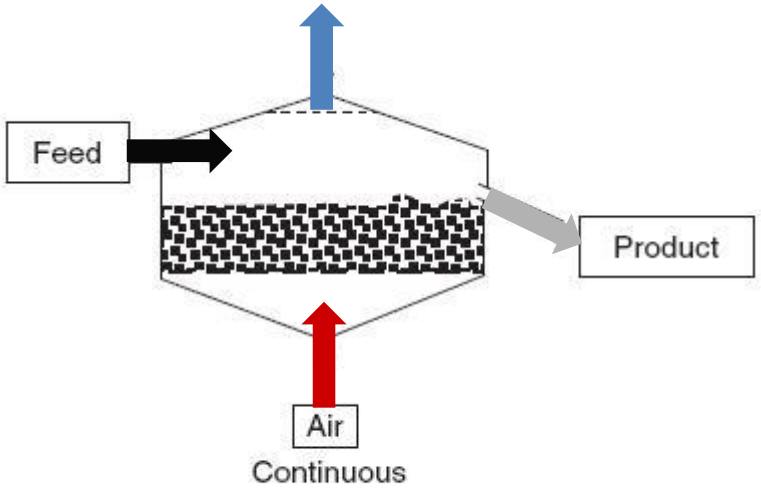


Drying methods (CONVECTION)

Fluidized bed dryers



Batch fluidized dryer

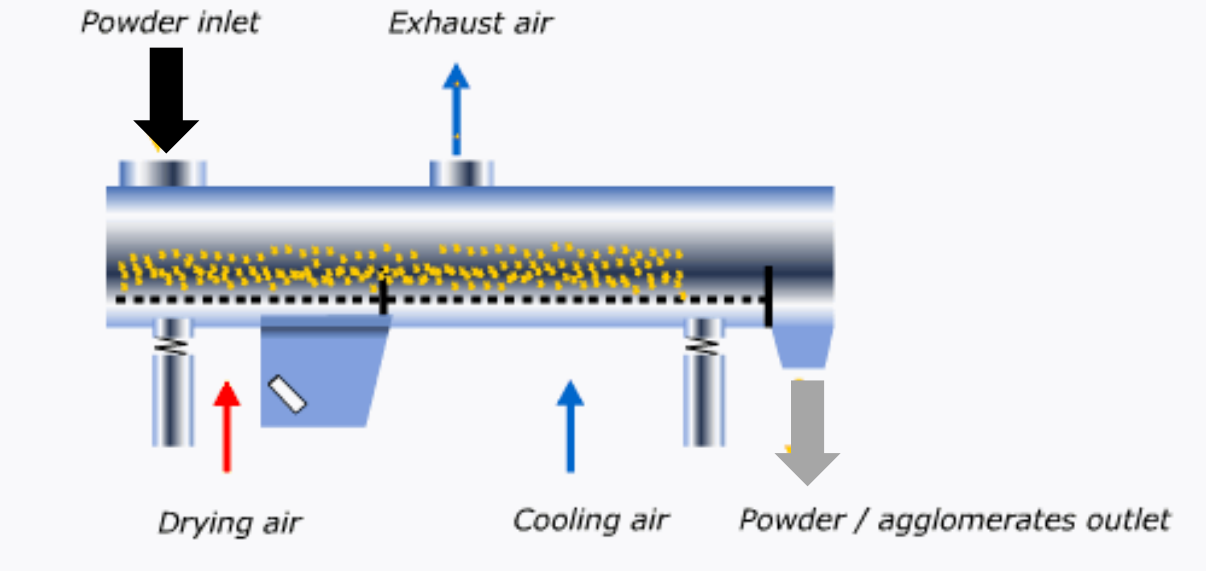


Trough continuous fluidized dryer

Drying methods (CONVECTION)

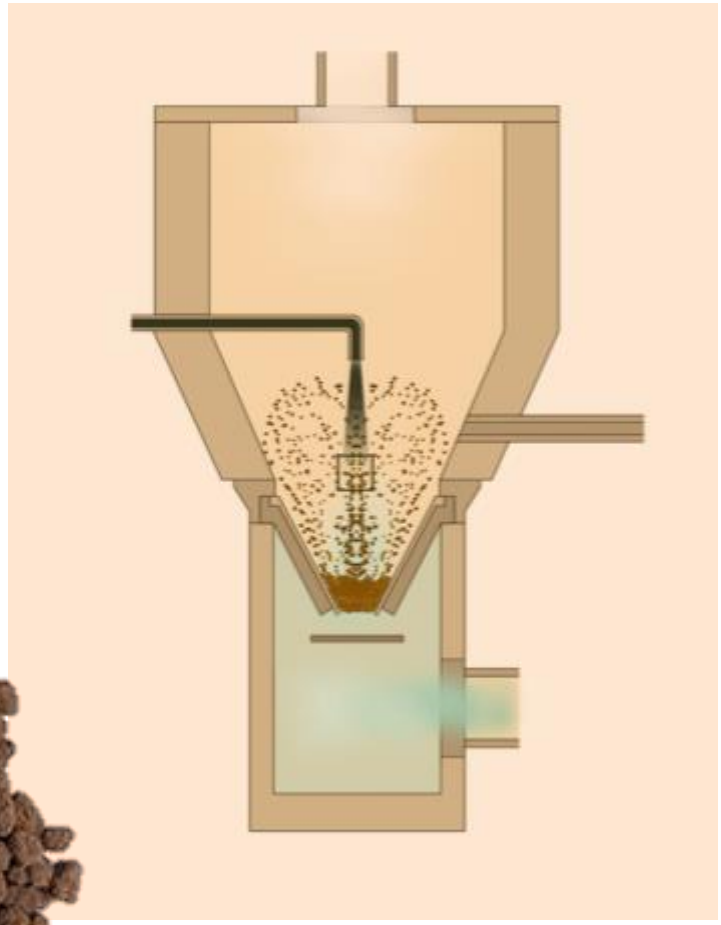
Vibro-fluidized bed drying VFB

Mechanical vibration allows “pseudo-fluidization” of the sticky and polydisperse materials at much lower air flow rates



Drying methods (CONVECTION)

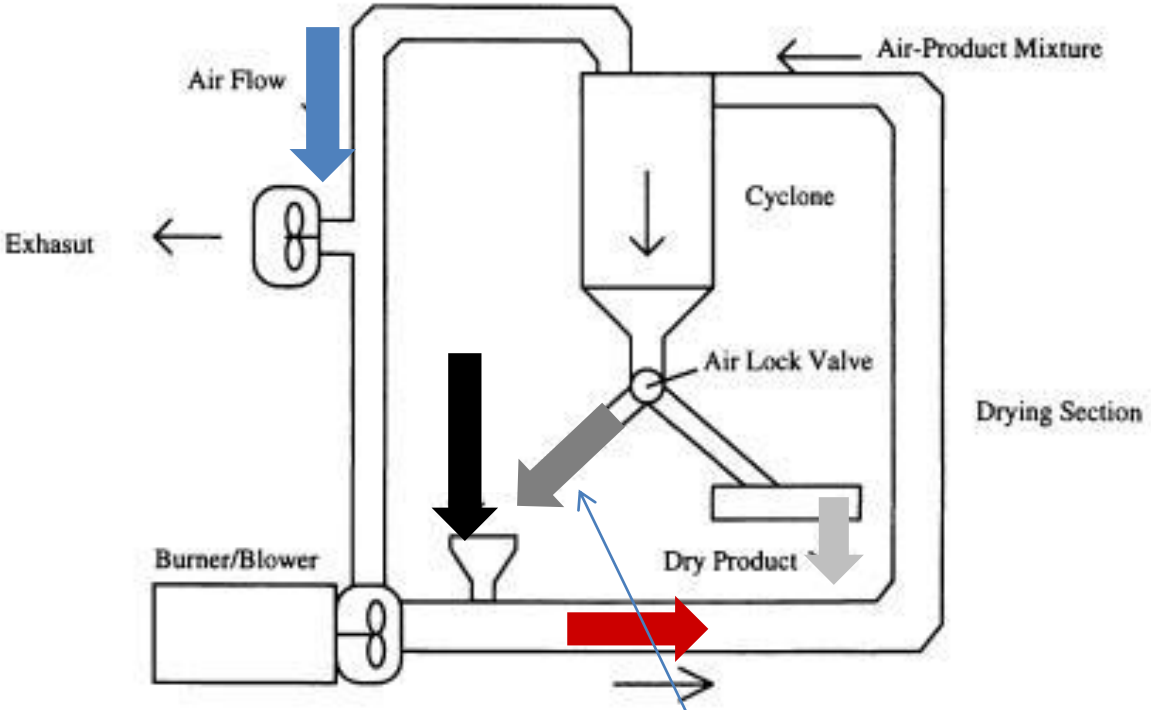
Spouted bed dryers



Drying methods (CONVECTION)

Pneumatic dryers

The use of pneumatic drying in the food industry is limited to the drying of flours, starch, gluten powder, casein powder etc.

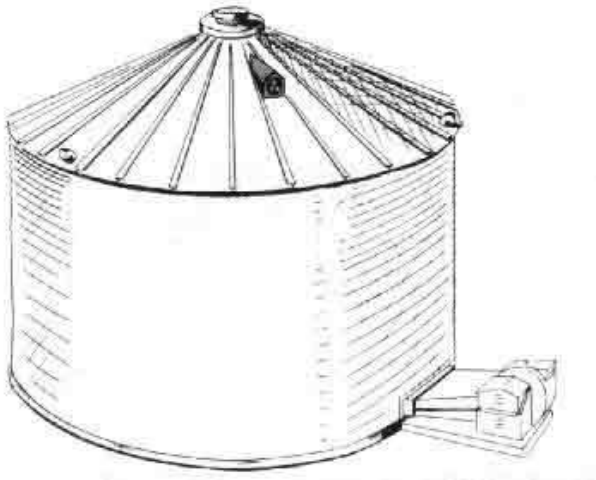


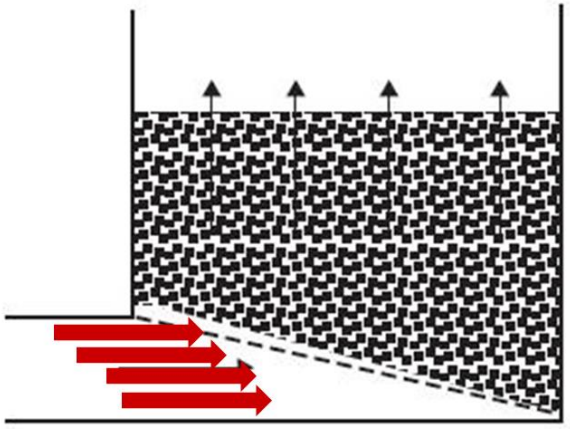
Pneumatic dryier with product recirculation

It is also possible to recycle part of the product in order to achieve the desired final moisture content.

Drying methods (CONVECTION)

Bin dryers



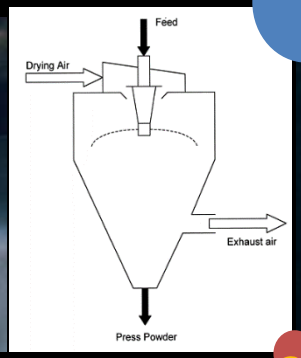


Bin dryers provide the ideal solution for **‘finishing’ the process** to the desired final moisture content of 3-6%

in terms of tonnage - grain drying is probably the largest drying operation in food industry and agriculture

Drying methods (CONVECTION)

Spray drying



PRINCIPLE - atomization of liquid to fine droplets and their drying in a hot air stream

2022 – 150th anniversary of spray drying invention

Drying methods (CONVECTION)

Spray drying

FEED

ATOMIZATION

180-220°C

INLET AIR

Outlet air

Bag filter

Cyclone

Drying chamber

EVAPORATION 70-90°C

SEPARATION OF PRODUCT

AIR-DROPLETS CONTACT AND EVAPORATION

POWDER COLLECTION

Fines

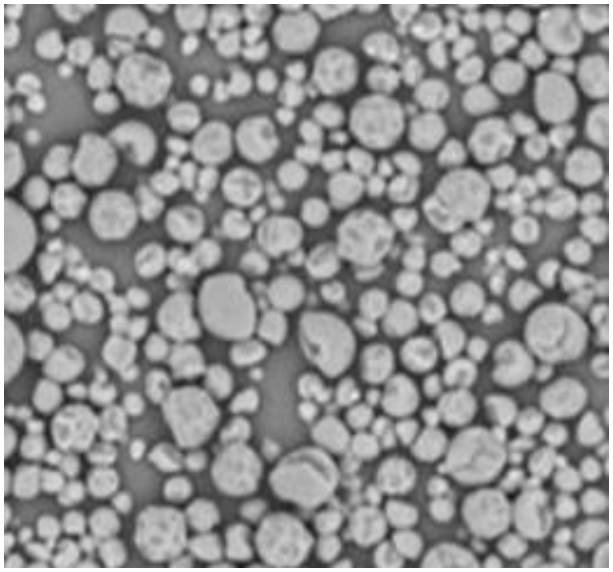
FEED PREPARATION

Drying of liquid solutions, emulsions, suspensions to produce light, porous powders

Drying methods (CONVECTION)

Spray drying

- capacity can vary from a few grams to several tonnes per hour
- high tonnage production up to 22 t/h milk powder (about 23 t/h evaporative capacity)

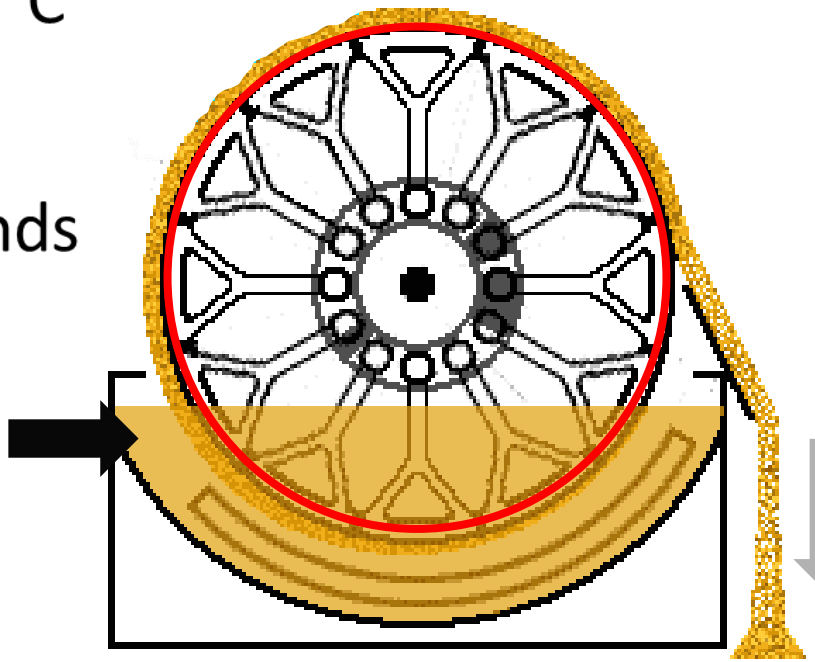


Drying methods (CONDUCTION) | Drum dryers

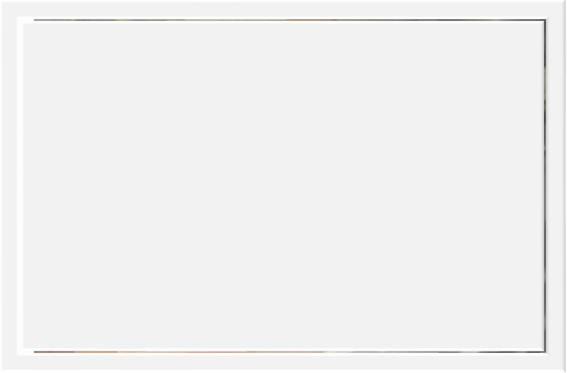
- heated surface - the envelope of a rotating horizontal metal cylinder, heated by steam condensing inside
- dried product is removed from the drum by a blade

120 - 150°C

seconds



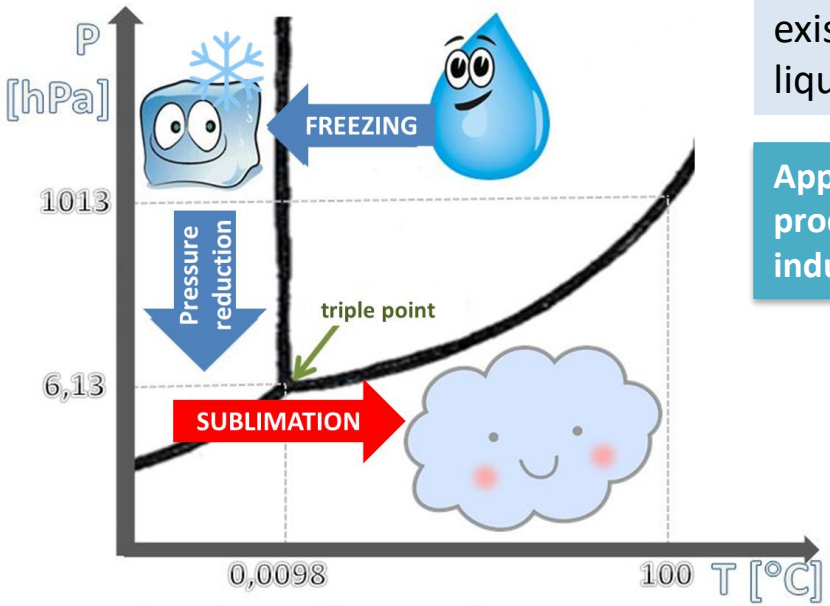
- applied food has to be in a liquid or slurry form



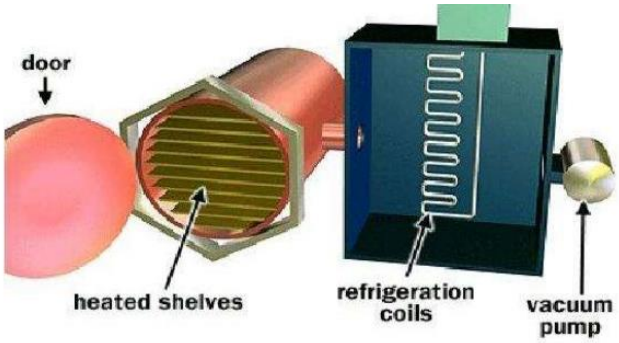
Configurations
- feeding system
- single drum, double-drum
- vacuum drying

Drying methods (CONDUCTION)

Freeze drying



The phase diagram for water



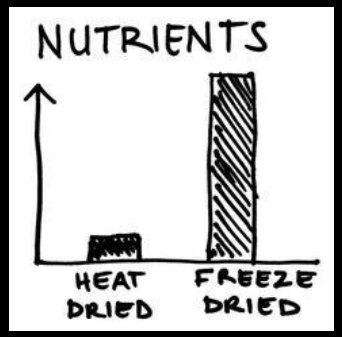
DAYS!

At pressures below the triple point liquid water cannot exist - in a process known as **sublimation**, ice skips the liquid stage and becomes steam when heated

Applied for products with high added-value and heat sensitivity, produced by pharmaceutical, biotechnological and food industries

ADVANTAGES:
1. Drying at low temperature
2. Virtual absence of air
3. Absence of liquid water
4. Shape maintenance
5. High porosity – easy rehydration

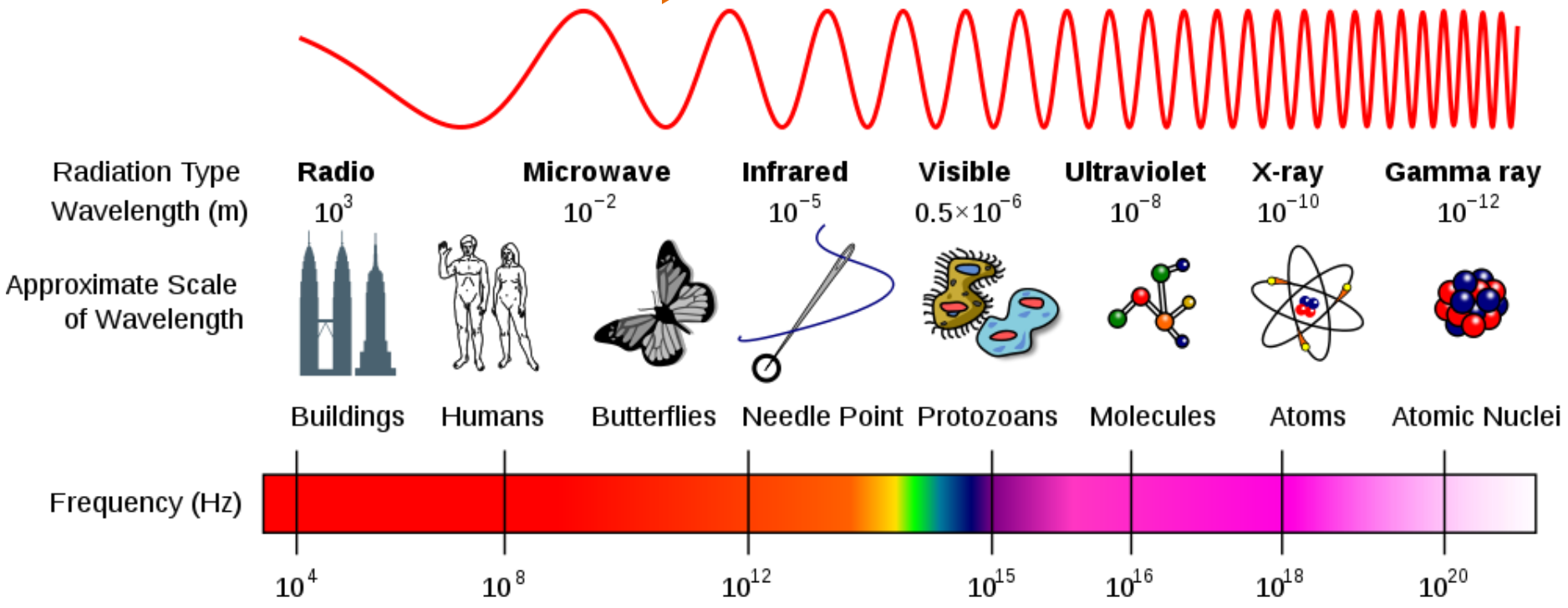
LIMITATIONS
1. **long process duration**
2. **high energy consumption**
3. **complicated equipment**
4. **mechanical damages (freezing)**
5. **risk of oxidation**



the most expensive process for manufacturing a dehydrated product

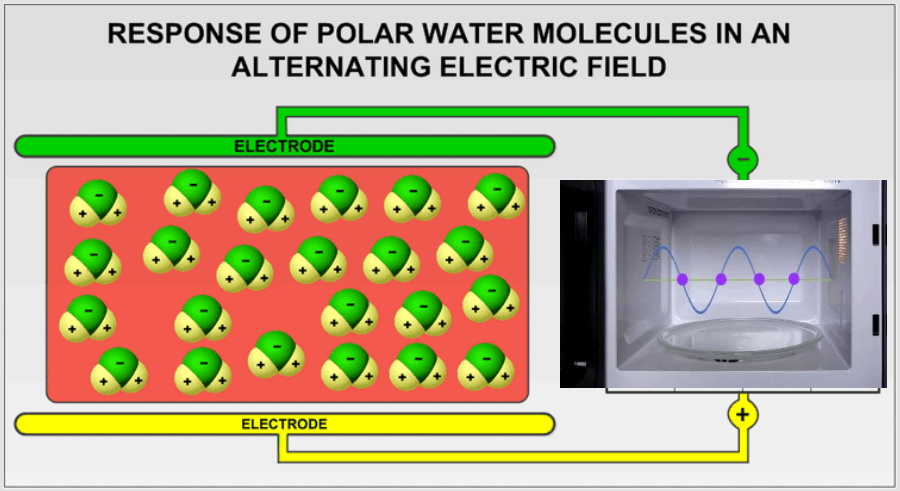
Drying methods (RADIATION)

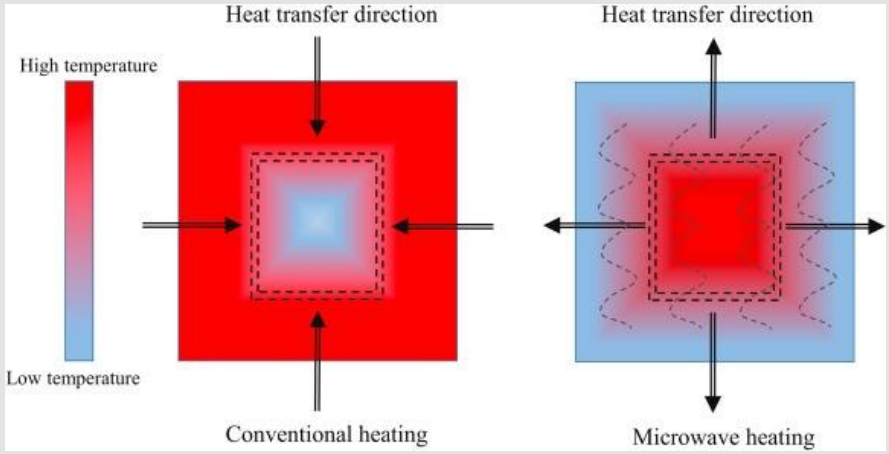
Infrared and microvawe drying



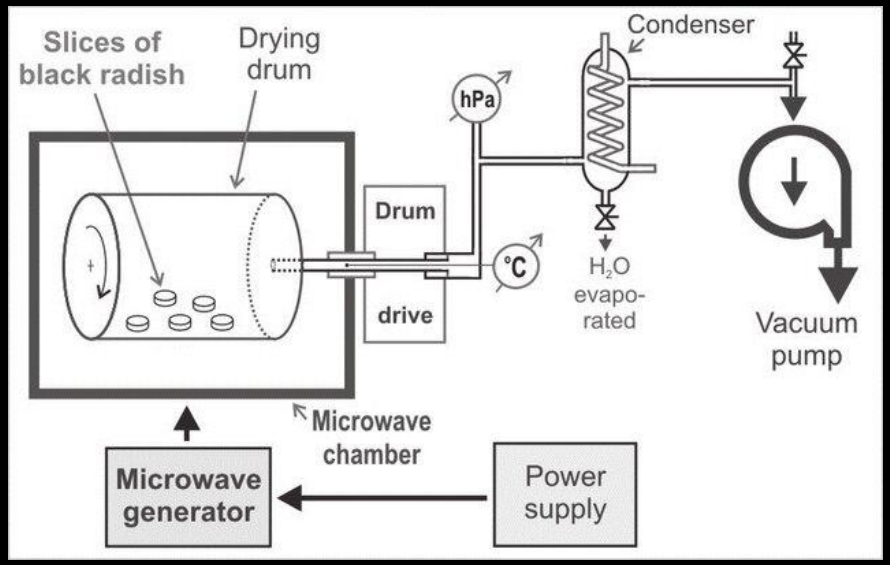
Application of an electromagnetic radiation for heating

Drying methods (RADIATION)

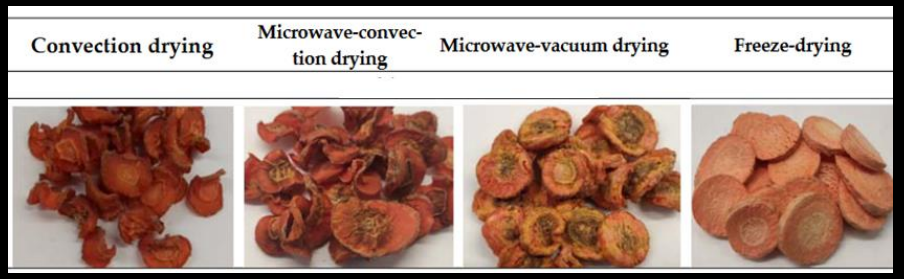




Microvawe drying



Combination with vacuum



Drying methods (RADIATION)

Infrared drying