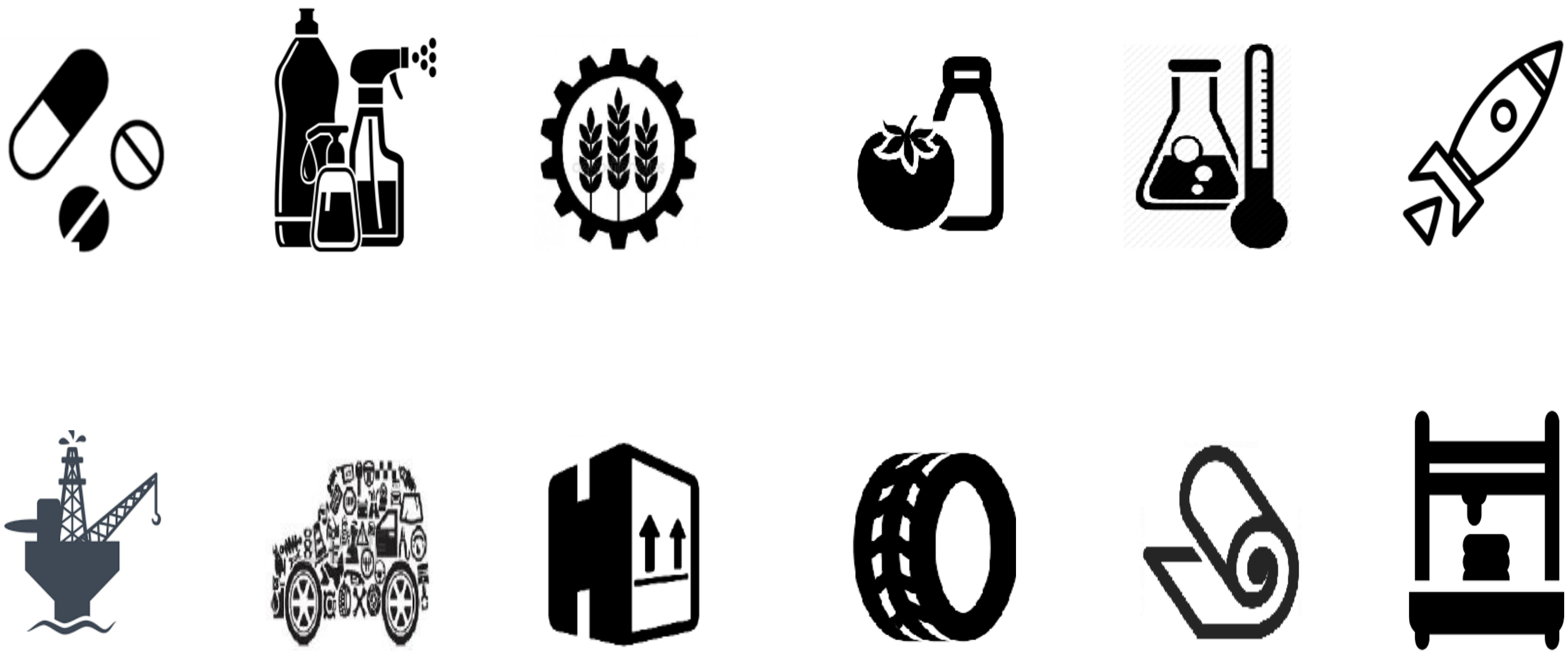


KERONE

Complete Engineering Solutions...

Who are we…

Conceptualized and shaped in 1976

One of the most admired and valuable company for customer satisfaction.

We are pioneer in application and implementation engineering

40+ years experience in engineering excellence.

Immense expertise in providing engineering solutions.

Witnessed growth in revenue and team strength YoY

We are accredited by...

Member of AIMCAL	Member of IHEA	Strategic Partners of Emitech Italy	IRQAO Certified For Quality
Recognized and Rated by CRISIL	CRISIL Verified	Member of A.M.P.E.R.E. (Europe)	ASCB(E) Certification for Best practice

ISO 9001:2008 | ISO 9001:2015 | OHSAS 18001 | EMS 14001

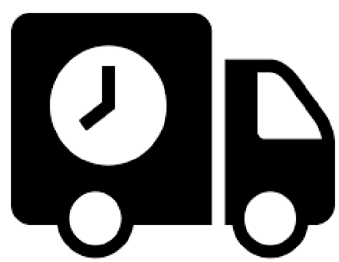
Why We...

Highly Customized Product

Adherence to Standards

Cost Effective Solutions

Sound Infrastructure



Timely Delivery

Great After Sale Support

Food Processing

- Need of food processing - to avoid the spoilage of foods due to various reasons; to increase shelf life; to make food products available through out the year
- The spoilage could be due to physical damage, chemical damage, microbial attack
- Various food processing methods – Freezing, canning, preserving in syrup, food irradiation, salting, vacuum packaging, **dehydration**
- canning and freezing – best way to retain the taste, appearance, and nutritive value of fresh food (Cost involvement)
- Drying/Dehydration – very much cost-effective; product takes much less storage space than canned or frozen foods; Some dehydrated products have very good rehydration properties

Drying Fundamentals

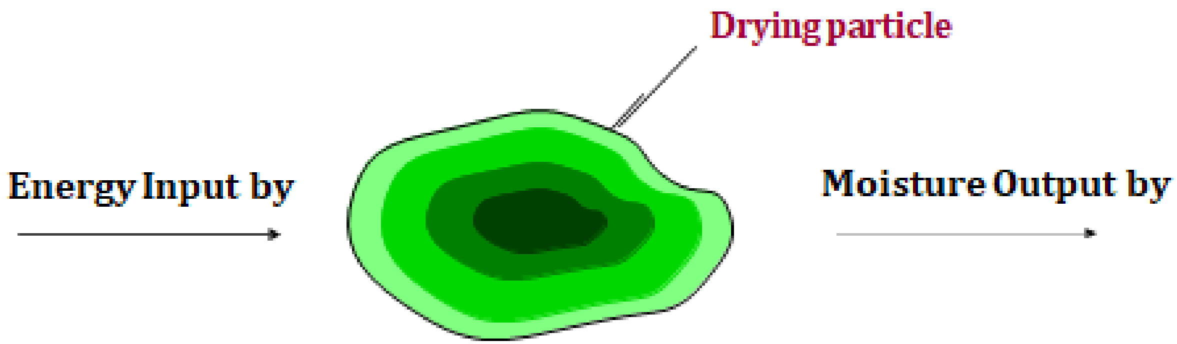
Removal of a liquid from a solid/semisolid/liquid to produce solid product by thermal energy input causing phase change (Sometimes converts solid moisture into vapor by sublimation eg. Freeze drying with application of heat.)

Needed for the purposes of preservation and storage, reduction in cost of transportation, etc.

Most common and diverse operation with over 100 types of dryers in industrial use

Competes with distillation as the most energy intensive operation

Drying Fundamentals



- Conduction
- Convection
- Radiation
- Microwave and Radio Frequency Fields
- Combined mode

- Liquid diffusion
- Vapor diffusion
- Capillary flow(Permeability)
- Knudsen diffusion (Mean free path < pore dia.)
- Surface diffusion
- Poiseuille flow
- Combination ofabove

Transport of moisture within the solid may occur by any one or more of the following mechanisms of mass transfer:

Liquid diffusion, if the wet solid is at a temperature below the boiling point of the liquid

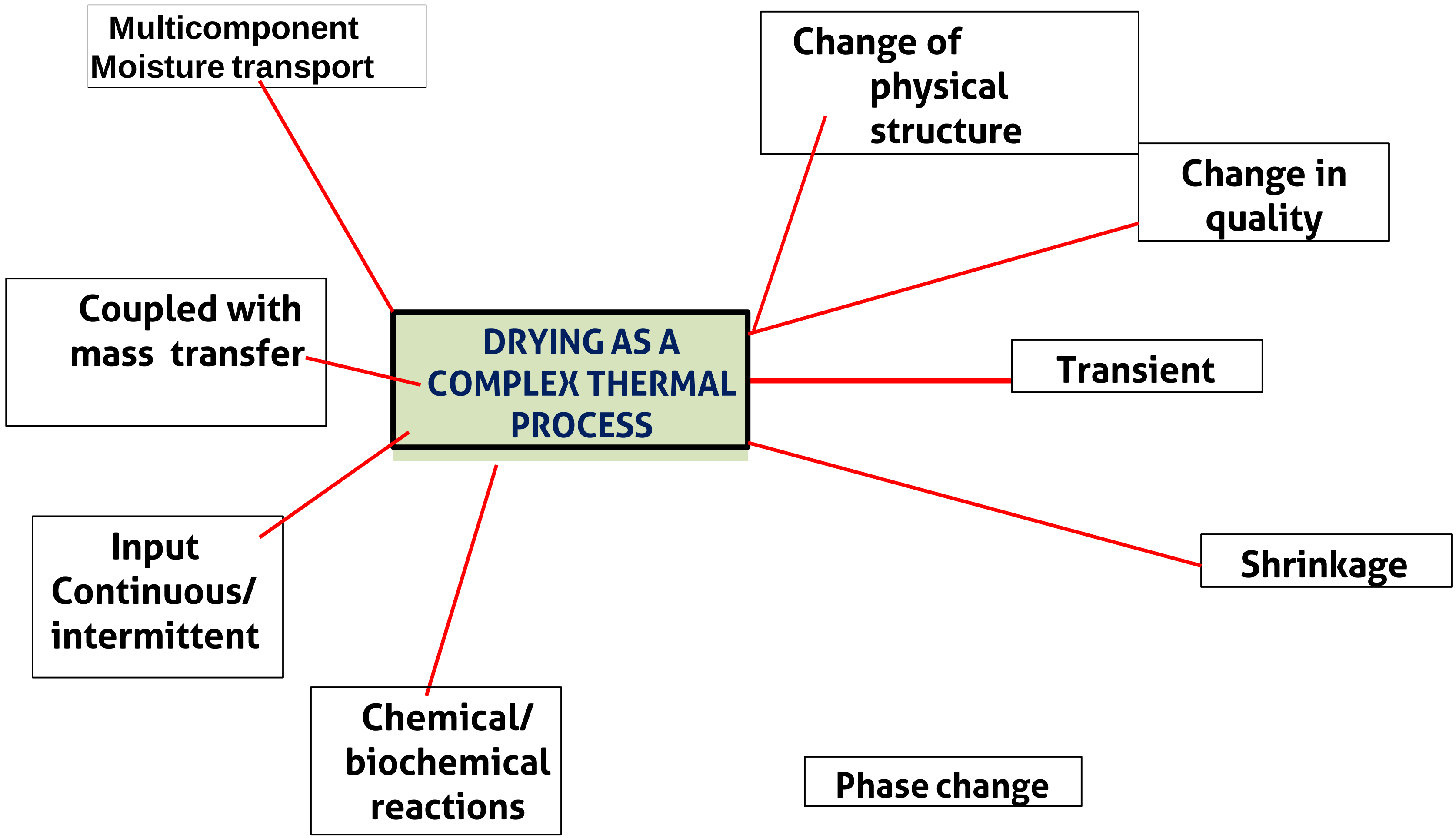
Vapor diffusion, if the liquid vaporizes with in material

Knudsen diffusion, if drying takes place at very low temperatures and pressures, e.g., in freeze drying

Surface diffusion (possible although not proven)

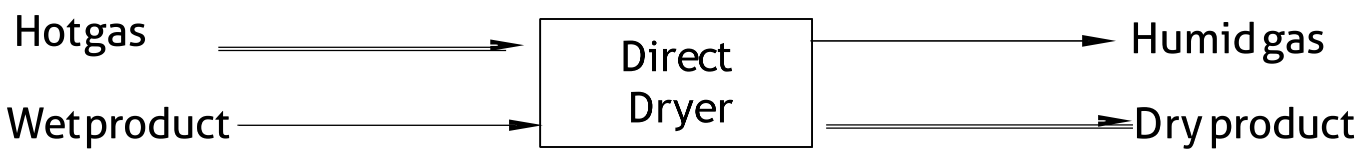
Hydrostatic pressure differences, when internal vaporization rates exceed the rate of vapor transport through the solid to the surroundings

Drying a Complex Process



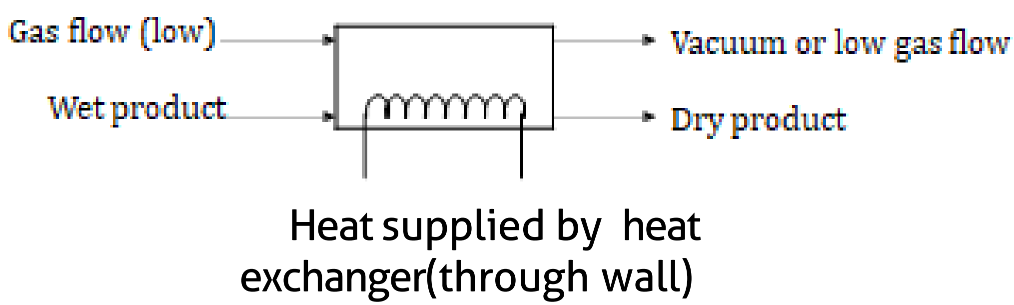
Drying based on heat input

I. Direct (Convective)



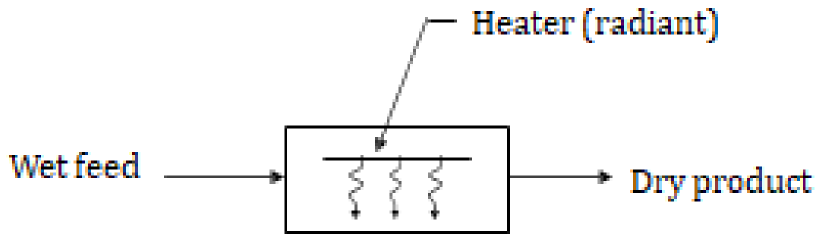
Drying medium directly contacts material to be dried and carries evaporated moisture.

II. Indirect (Contact, Conduction)



Drying based on heat input

III. Radiant



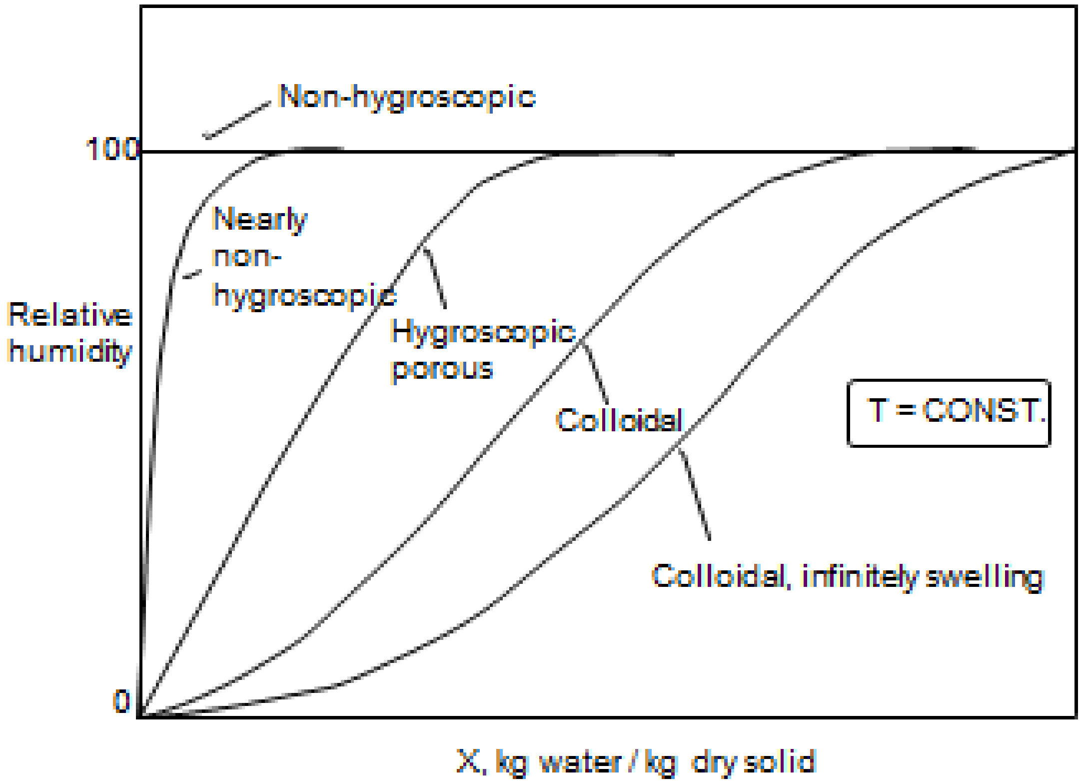
Vacuum or low gas flow to carry evaporated moisture away.

IV. Microwave or RF

Electromagnetic energy absorbed selectively by water (volumetric heating)

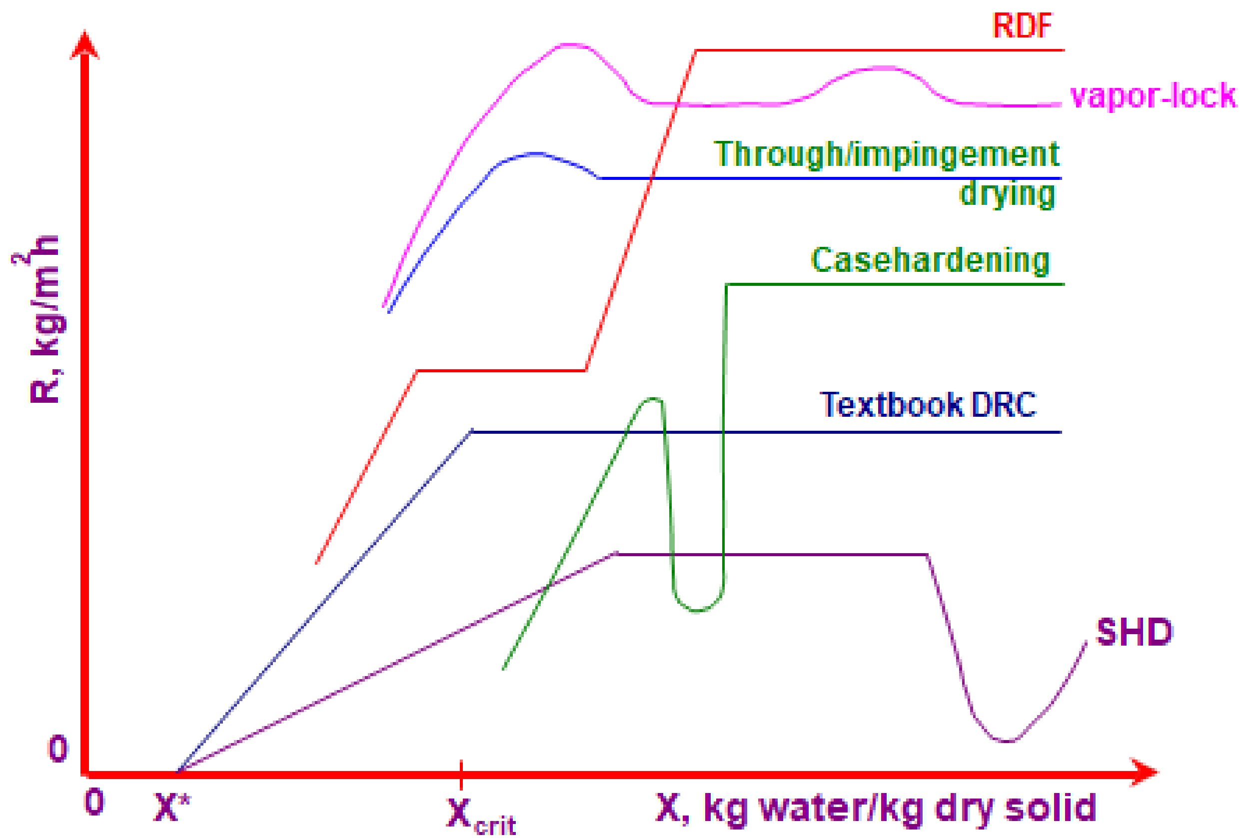
Typically less than 50% of total heat supplied in most direct dryers is used for evaporation. Water is the most common solvent removed in dryers.

Basic terms

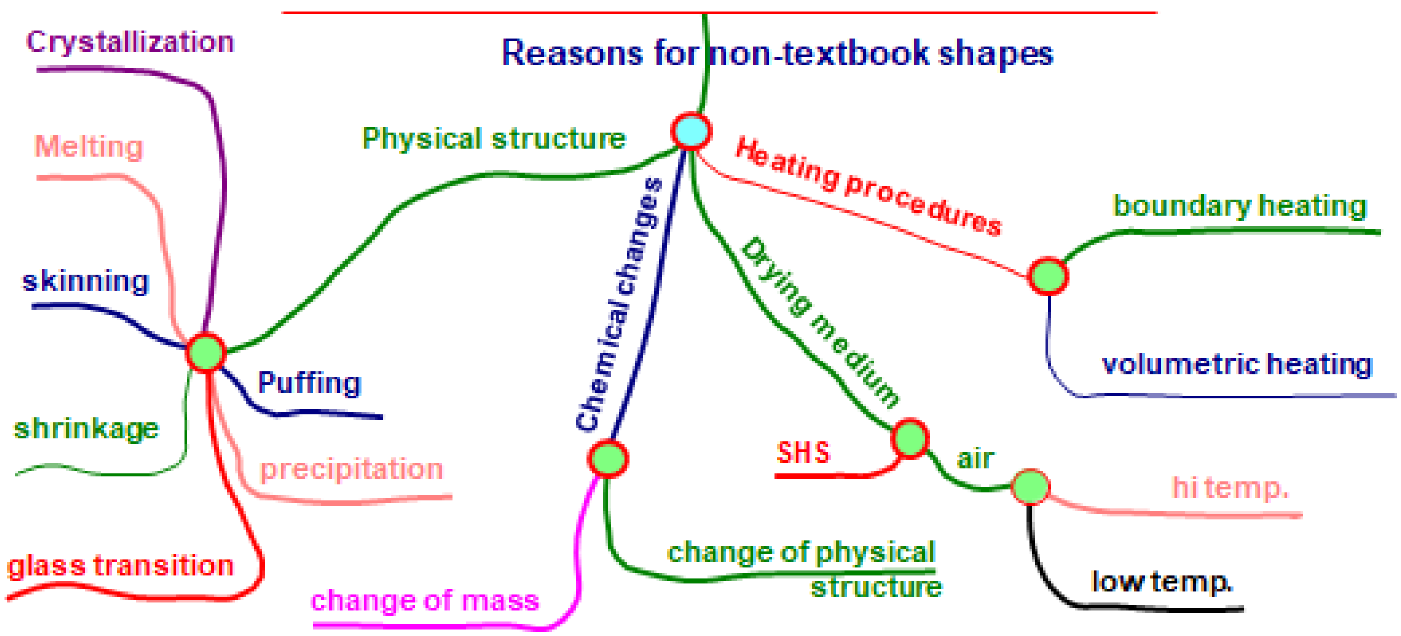


Equilibrium moisture content curves for various types of solids

Unusual Drying Rate Curves



Unusual Drying Rate Curves*



* Constant drying conditions

Basic terms (water activity)

WATER ACTIVITY (a_w):

$$a_w = \frac{\text{Partial pressure of water over wet solid}}{\text{Equilibrium vapor pressure of water at same temp.}}$$

State of water in bio-product:

-Free water - intra-cellular water; nutrients and dissolved solids needed for living cells

-Bound water - water built into cells or biopolymer structures Needs additional energy to break "bonds" with solid. Bound water also resists freezing

For safe storage, bio-products must be dried to appropriate levels and stored under appropriate conditions

Why so many dryer types?

- Over 500 reported in literature studies; over 100 commercially available
- Over 50,000 materials are dried commercially at rates of a few kg/hr to 30 T/hr or more

•Drying times (residence times within drying chamber) can range from 1/3 sec. tomonths

- Temperature and pressure range from below triple point to super- critical
- Numerous constraints on physical/chemical properties of feed as well

as dried product require a bewildering array of dryer designs

- Wide range of feeds (liquid, solid, semi-solid, particulate, pasty; sludge- like; sticky etc); wide specs on dried product

Why so many dryer types?

- Different sources of energy input(conduction, convection, radiation, MW,RF etc)
- Energy input continuous or intermittent
- Batch, continuous orsemi-continuous operation
- **Quality** is key parameter for many products
- Limited number used in pharma industry
- Need to reduce thecost
- Need to consider drying system rather than dryer, i.e. Pre- and post-drying stages are important and often cost more than dryer
- Environmental regulations demand new drying techniques

Dryer Selection
And classification

Criterion for selection of dryers

- Numerous criteria ,with differentweights
- Many dryers can typically meet specs; hence several dryers can do a given job in general.
- Choice depends on mode of operation, physical form of feed and dried product desired; heat sensitivity; quality requirements; production rate; whether non-aqueous solvents are present in feed; whether material is toxic/inflammable or friable etc
- Key criterion- dryer must be able to handle the product- move it from feed to exit! Other criteria follow
- **For pharma products quality is NO 1 criterion!**

Criterion for selection of dryers

- **Dryer Selection: A black art or science?**
- Little published work on subject
- In view of tremendous diversity of dryers, buyer must know more about dryers and drying
- Most vendors specialize in selected dryer types; so buyer needs to make choice
- Multiple choices are possible and can make selection process complex
- Expertise needed to make right choice!
- Energy, environment, safety and cost are important considerations in selection.
- **Special care needed when handling nonaqueous solvents in wet materia**

Some notes for dryer selection

- Must examine <u>drying system</u> cost rather than <u>dryer</u> cost for final selection.
- Largely untested in industrial practice – trend is to "repeat history"
- Do not copy dryer or dryer system used elsewhere without critical evaluation from square 1!
- Nickel ore concentrate is dried in different places using spray, fluid bed, rotary and flash dryers/ Which one do you COPY?
- Local fuel availability and relative costs of different energy sources, environmental requirements as well as legislation can change selection of dryerfor same application

Main dryer classification criteria

Criterion	Types
Mode ofoperation	• Batch • Continuous*
Heat input-type	• Convection*, conduction, radiation, electromagnetic fields,combination of heat transfer modes • Intermittent or continuous* • Adiabatic or non-adiabatic
State of material in dryer	• Stationary • Moving, agitated,dispersed
Operating pressure	• Vacuum* • Atmospheric
Drying medium (convection)	• Air* • Superheated steam • Flue gases

Main dryer classification criteria

Criterion	Types
Drying temperature	• Below boiling temperature* • Above boiling temperature • Below freezing point
Relative motion between drying medium and drying solids	• Co-current • Counter-current • Mixed flow
Number of stages	• Single* • Multi-stage
Residence time	• Short (< 1 minute) • Medium (1 – 60 minutes) • Long (> 60 minutes)

*** Most common in practice**

Typical checklist for selection of industrial dryers

Physical form offeed	• **Granular, particulate, sludge, crystalline, liquid, pasty, suspension, solution, continuous sheets, planks, odd-shapes (small/large)** • **Sticky, lumpy**
Average throughput	• kg/h (dry/wet); continuous • kg perbatch (dry/wet)
Expected variation in throughput (turndownratio)	
Fuel choice	• Oil • Gas • Electricity
Pre- and post-drying operation s (if any)	
For particulate feed products	• Mean particle size • Size distribution • Particle density • Bulk density • Rehydration properties

Chemical/biochemical/ microbiological activity	
Heat sensitivity	• Melting point • Glass transition temperature
Inlet/outlet moisture content	• Dry basis • Wet basis
Sorption isotherms (equilibrium moisture content)	
Drying time	• Drying curves • Effect of process variables
Special requirements	• Material of construction • Corrosion • Toxicity • Non-aqueous solution • Flammability limits • Fire hazard • Color/texture/aroma requirements (if any)

More guidelines for Dryer Selection

Principal Data Needed

Include as much relevant data as possible

Solids throughput	**Mass flow W_s Turndownratio**
Moisture content	Inlet X1, Outlet X0, variation
Particle properties	Size, size distribution Density, r_p, r_s
Drying kinetics	Drying curves E.M.C. data
Temperature limits	long-term Instantaneous
Gas and solvent	Identity Physical properties
Other features	Safety, ease of handling, attrition, etc. Quality aspects Toxicity, flammability

Additional Qualitative Data Needed

Fires and dust explosions Toxicity

Potential for environmental damage Productvalue Need for

containment Capital cost

Attrition, hardness and friability Cohesion, adhesion,

agglomeration Operating time

Need for size reduction/enlargement Post-drying operations and

Pre-drying factors

Small Scale Lab Tests

Small scale tests give valuable information:

- Drying kinetics – drying rates (parametric effects)
- Equilibrium moisture content – effect of T,humidity
- Microscopic examination – surface, agglomeration
- Lab-scale rotary evaporator – overheating, balling, adhesion
- Rotating drum tester – attrition, dustiness
- Cohesion and adhesion – handling, sticky point
- Vital to have a representative sample of final material
- Not necessary to carry out all of above tests in all cases

Basic Choice: Form of Feed

Feed and product can be in one of these main basic forms:

- Particulate solids (bed/layer/or dispersed)
- Sheet or film
- Block or slab
- Slurry or solution (feed only) or paste

- Mostly require completely different types of dryer
- Widest choice available for particulate solids
- Specification of final product also critical in selection

Basic Choice: Batch or Continuous

Batch dryers favored by :

- Low throughput (under 50 kg/h)
- Long residence time (i.e. mainly falling rate drying)
- Batch equipment upstream and downstream
- Requirement for batchintegrity

Continuous dryers favored by

- Opposite conditions

Match production made of feed where possible

Basic Choice: Information From Kinetic Data

Interpretation of drying curves assists choice:

- Unhindered drying period – favors convective/dispersion
- Long hindered drying period – favors contact drying
- Estimate of required solids residence time
- Maximum likely dryingrate
- Indication of mechanisms controlling drying
- Difference between initial and final drying rates *

* (If high, favors well-mixed, parallel flow or two-stage)

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Dryers: Solid Exposure to Heat Conditions

Dryers		Typical residence time within dryer			
	0 10 sec	10 30 sec	5 10 min	10 60 min	1 6 hr
Convection					
Belt conveyor dryer				X	
Flash dryer	X				
Fluid bed dryer				X	
Rotary dryer				X	
Spray dryer		X			
Tray dryer (batch)					X
Tray dryer (continuous)				X	
Conduction					
Drum dryer		X			
Steam jacket rotary dryer				X	
Steam tube rotary dryer				X	
Tray dryer (batch)					X
Tray dryer (continuous)				X	

Product Classification and Dryer Types

Dryers	Evap. Rate (kg/m2/hr)	Fluid, liquid suspension	Pastes	Powders	Granules, pellets	Operation
Forced Convection (through flow)	7.5	-	-	-	Good	Batch
Double Cone	10	-	Poor	Fair	Poor	Batch
FBD	130	-	-	Good	Good	Continuous
Band	30	-	Fair	-	Good	Continuous
Film Drum	22	Good	Fair	-	-	Continuous
Flash	750	-	Fair	Good	Fair	Continuous
Rotary (indirect)	33	-	Poor	Good	Fair	Continuous
Spin Flash	185	-	Good	Good	Fair	Continuous
Spray	15	Good	-	-	-	Continuous

Different Industrial Dryer Types

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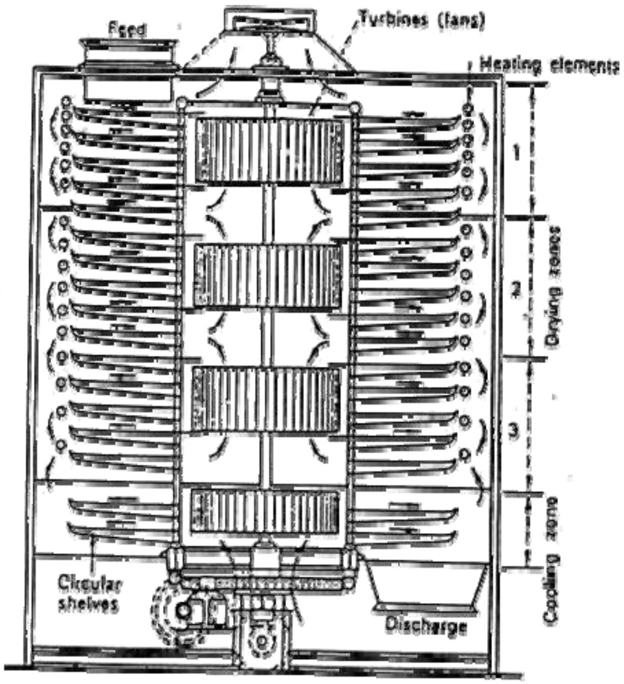
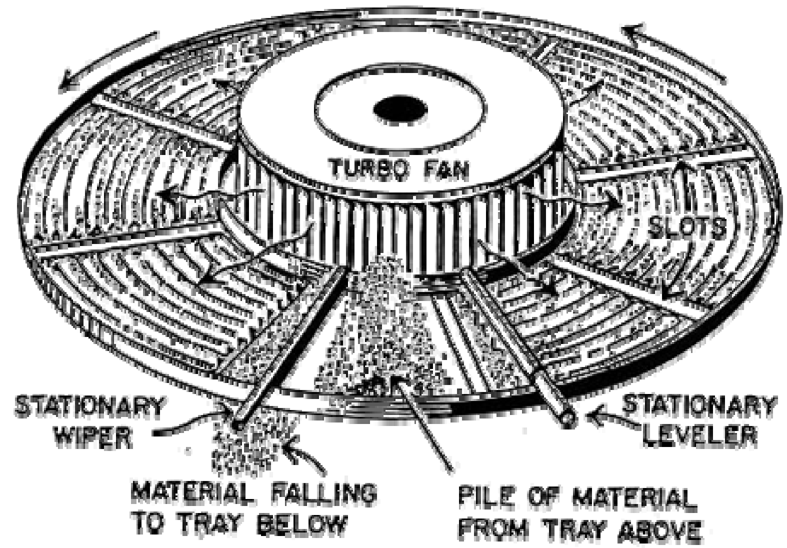
Turbo Tray Dryers



(a) Turbo-tray tower dryer



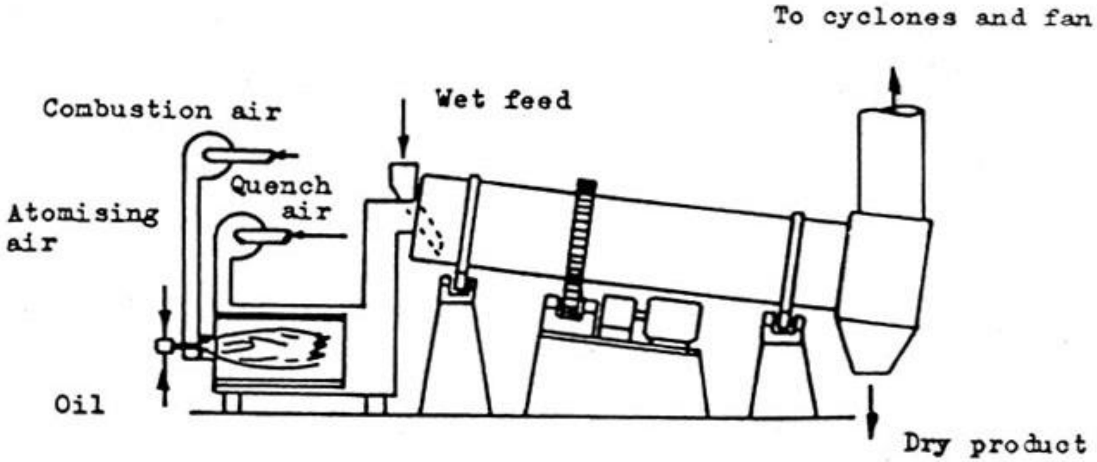
(b) Detail of annular shelf

Rotating-shelf dryers

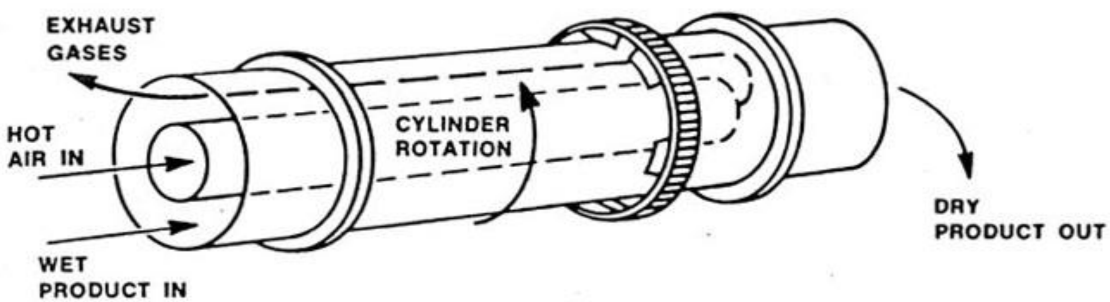
- Suitable for granular feeds, operate with rotating shelves and force convection of air above the shelves.
- The Dryer can have 30+ trays and provide large residence time.
- Hermetic sealing is possible for solvent recovery.

Rotary Dryer

Direct-Heat Rotary Drying



Typical cascading direct rotary dryer arranged for cocurrent operation. (From Nonhebel and Moss, 1971.)

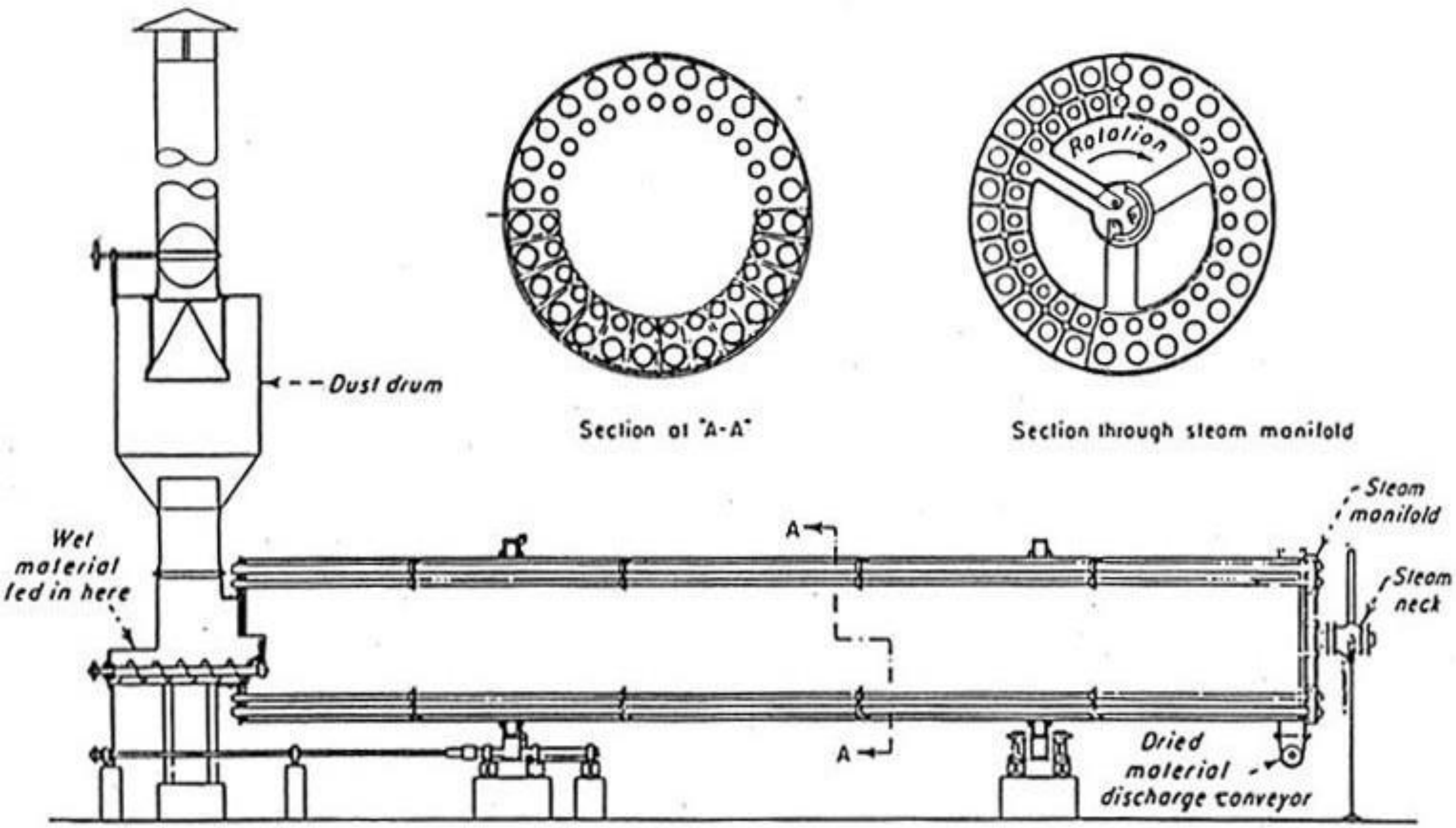


Indirect-direct rotary dryer. (Courtesy of C-E Raymond, Combustion Engineering, Inc., Chicago, Illinois.)

- Combined cascademotion with heat & mass transfer.
- Large capital & operating cost.
- Used in fertilizers, pharmaceutical, lead &zinc concentrate for smelting, cement.

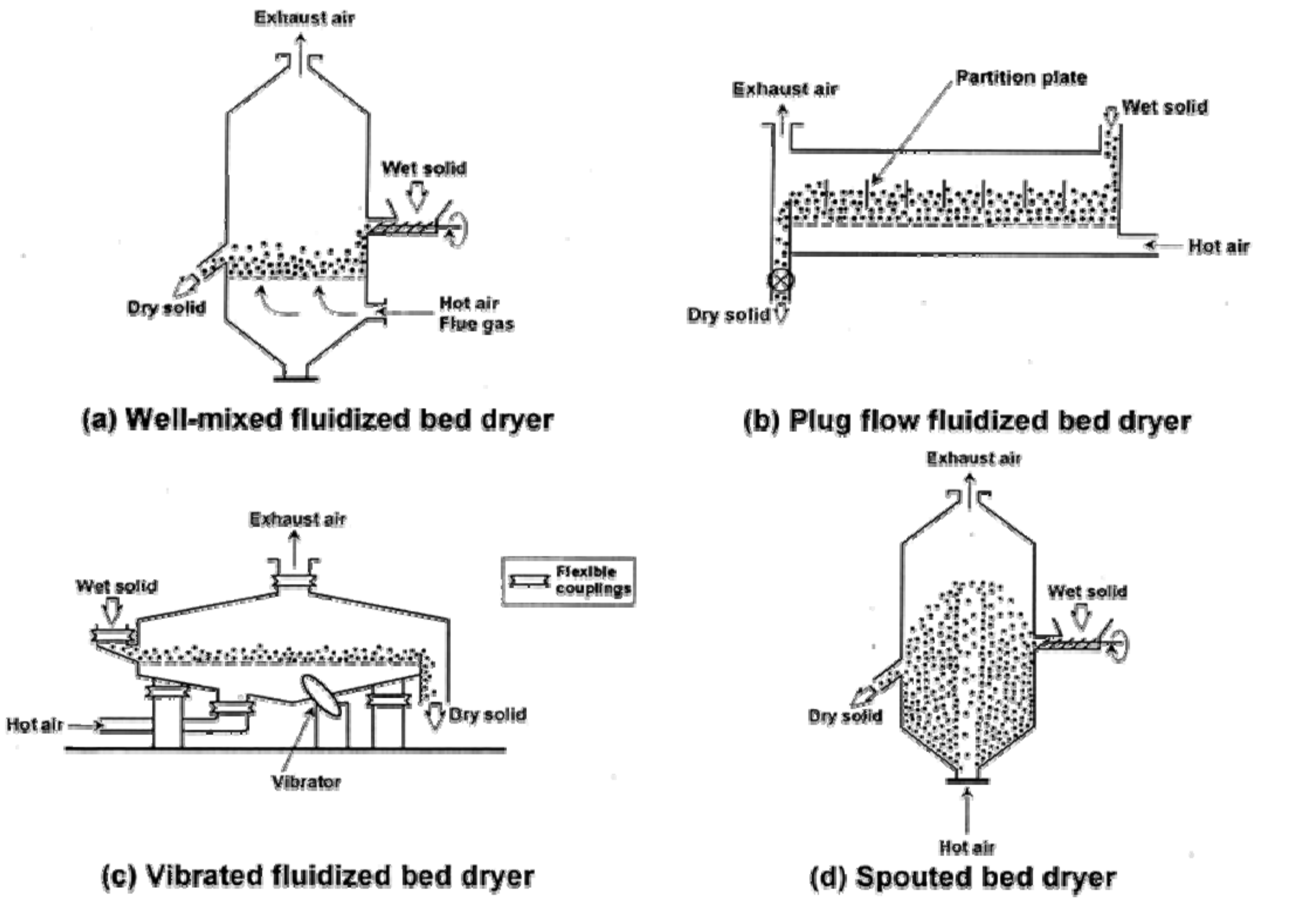
- Size 0.3 to 5 m diameter & 2 to 90m length.

Steam Tube Rotary Dryer



Indirect-heat, steam-tube, rotary dryer

Fluid Bed Dryers Variations



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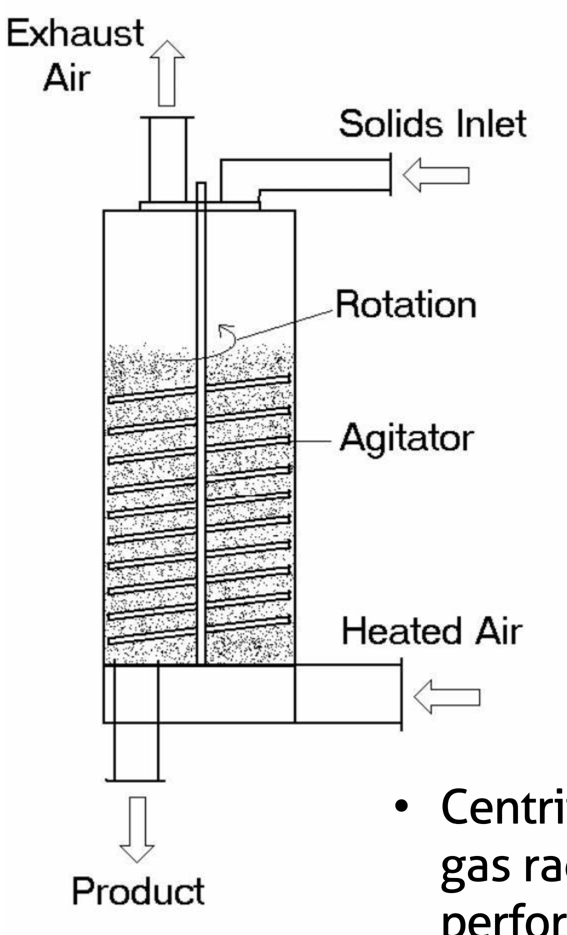
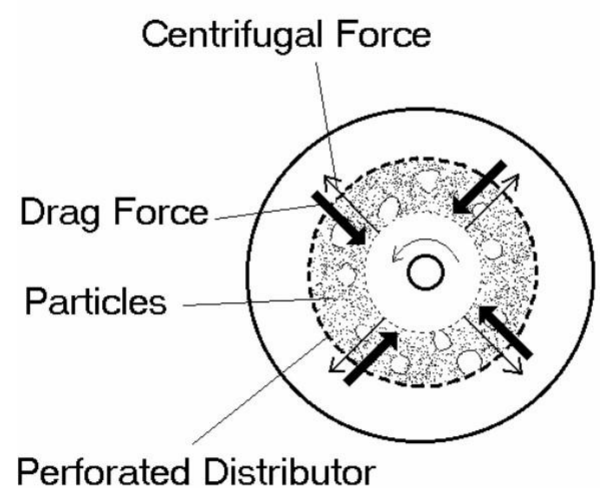
Fluid Bed Dryers Modifications

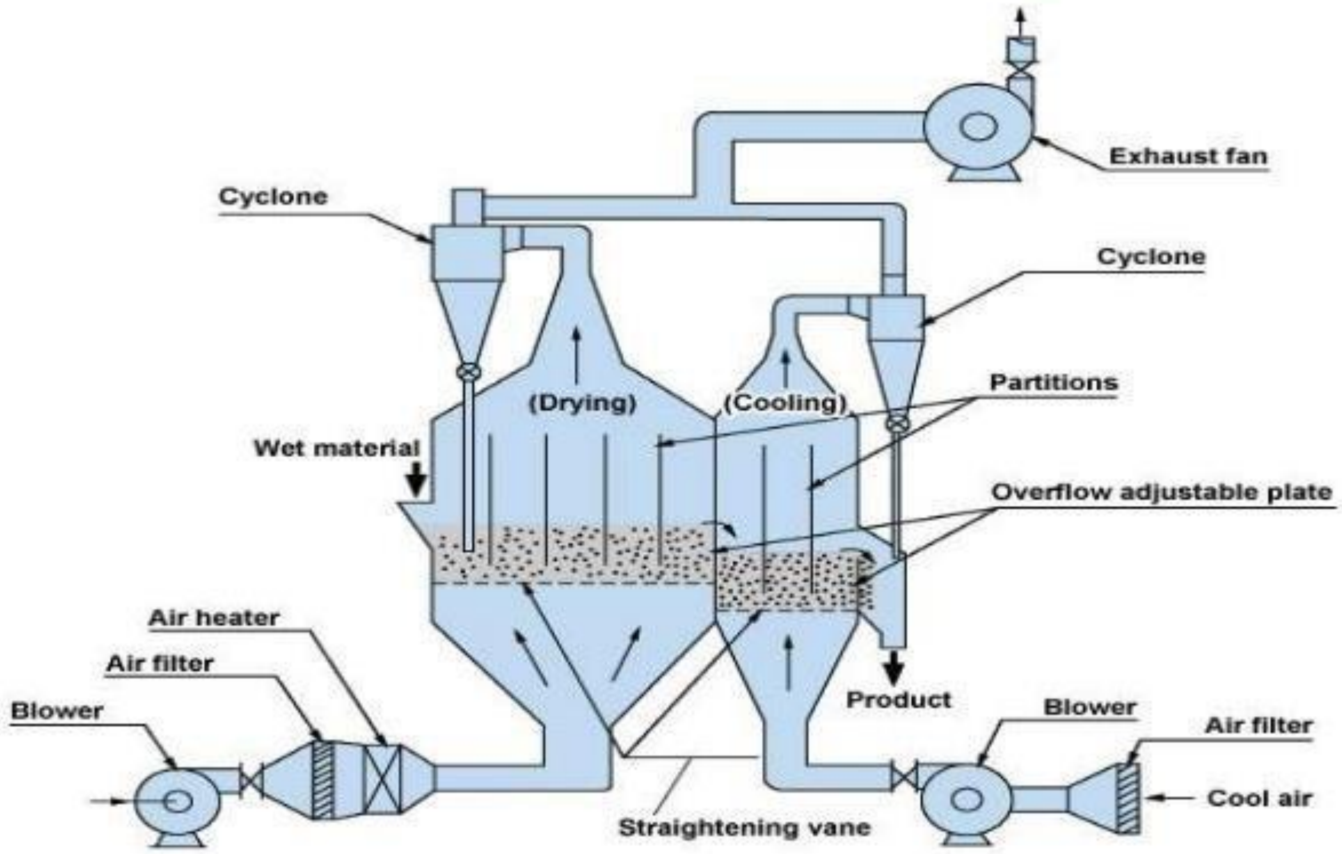


Homogeneous FB without channeling or bubbles; high gas velocity possible
Deeper bed depth is possible if the bed is agitated-Not commonly used



- Centrifugal / rotating FB - flowing gas radially - rotating cylindrical perforated distributor.
- promising contacting U_{mf} and U_t can be controlled

Continous Fluid Bed Dryer



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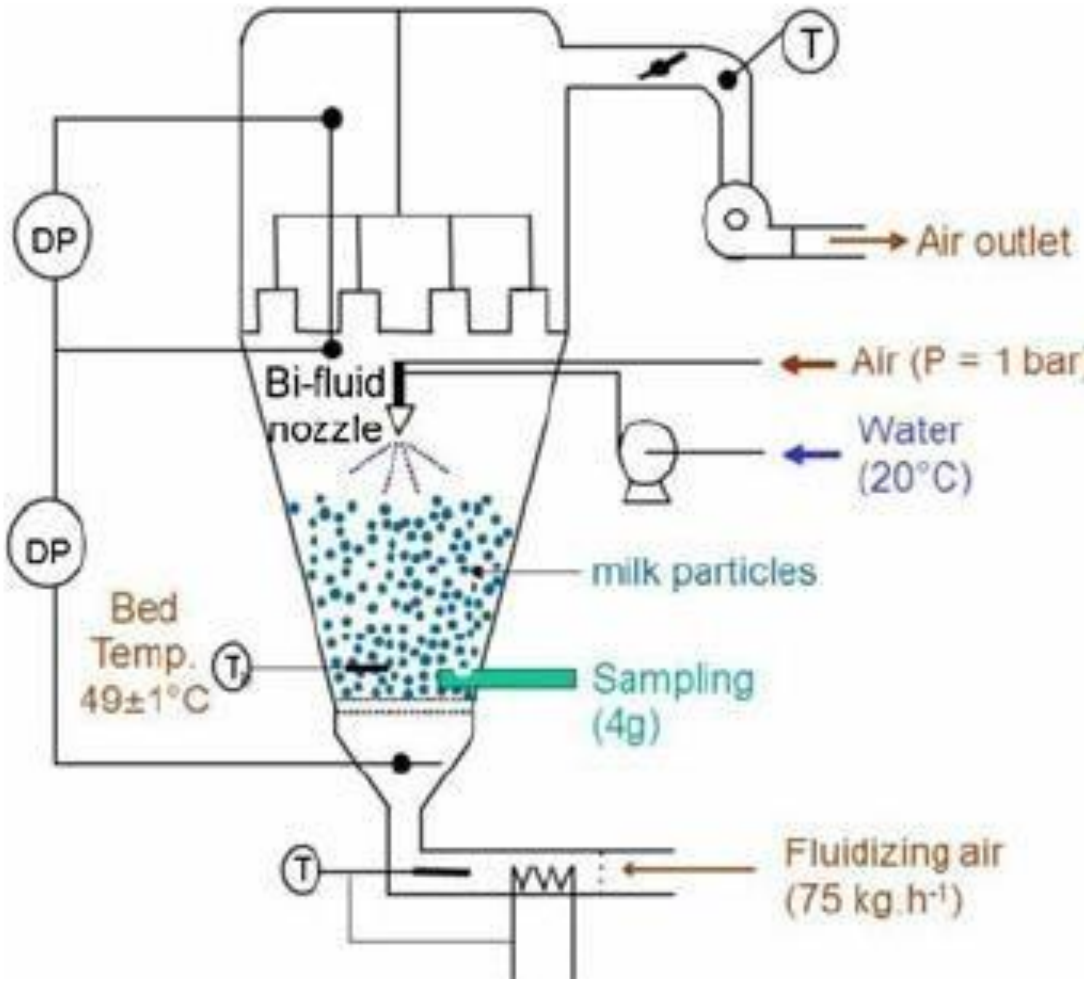
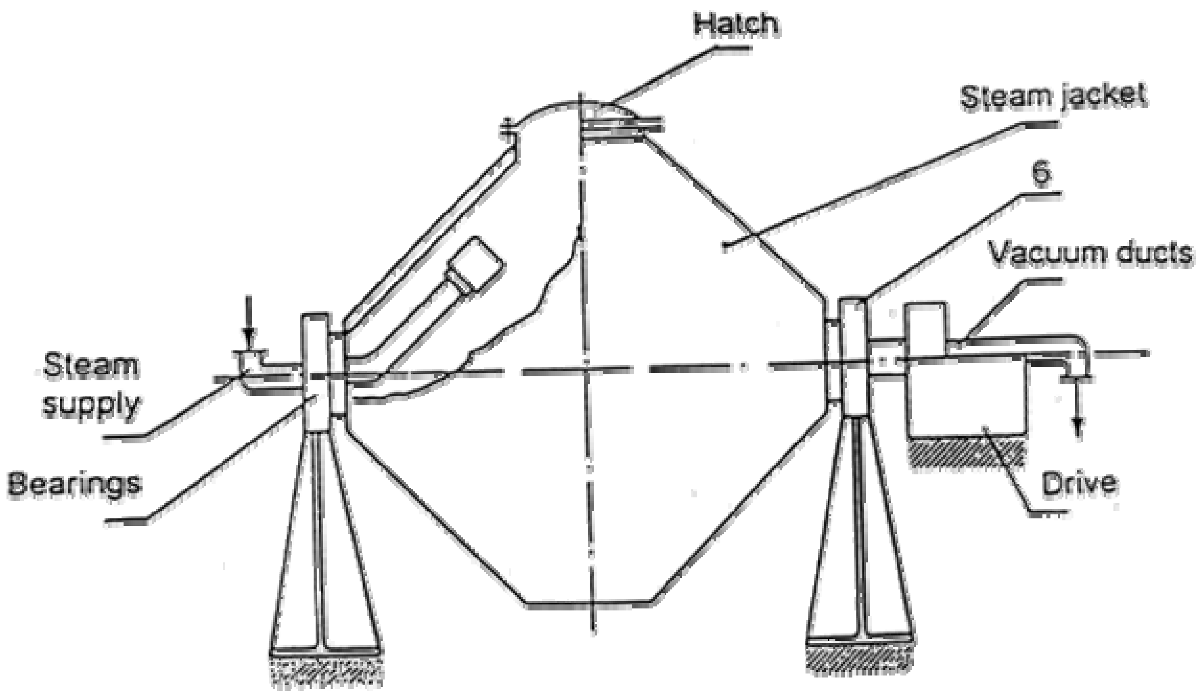


Batch-fluidized-bed-granulator

Rotocone Dryers (Batch)



- Drying of pharmaceuticals - tableting formulation
- Maximum capacity 10 m^3.
- Evaporation rate 2-7kg/hr.m^2

Microwave Dryers

Used in ceramics industries, foods & pharmaceuticals to drive off final traces of moisture.

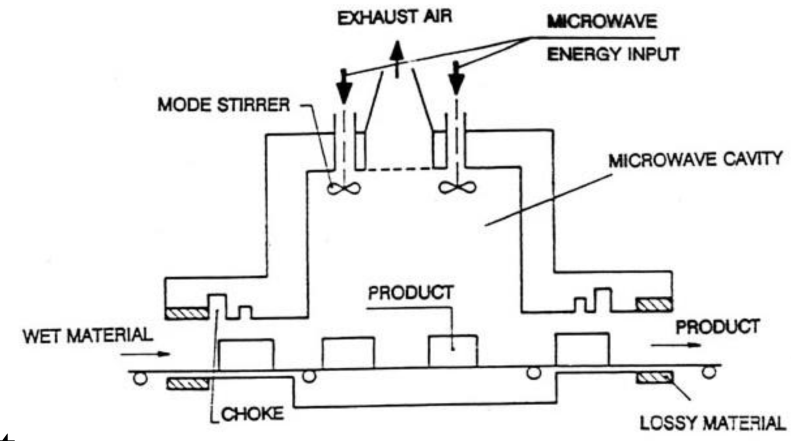


Fig. Band-type microwave dryer

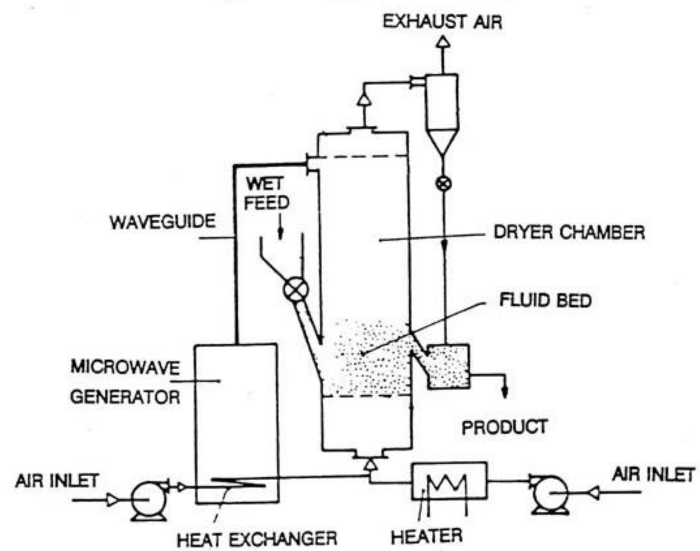
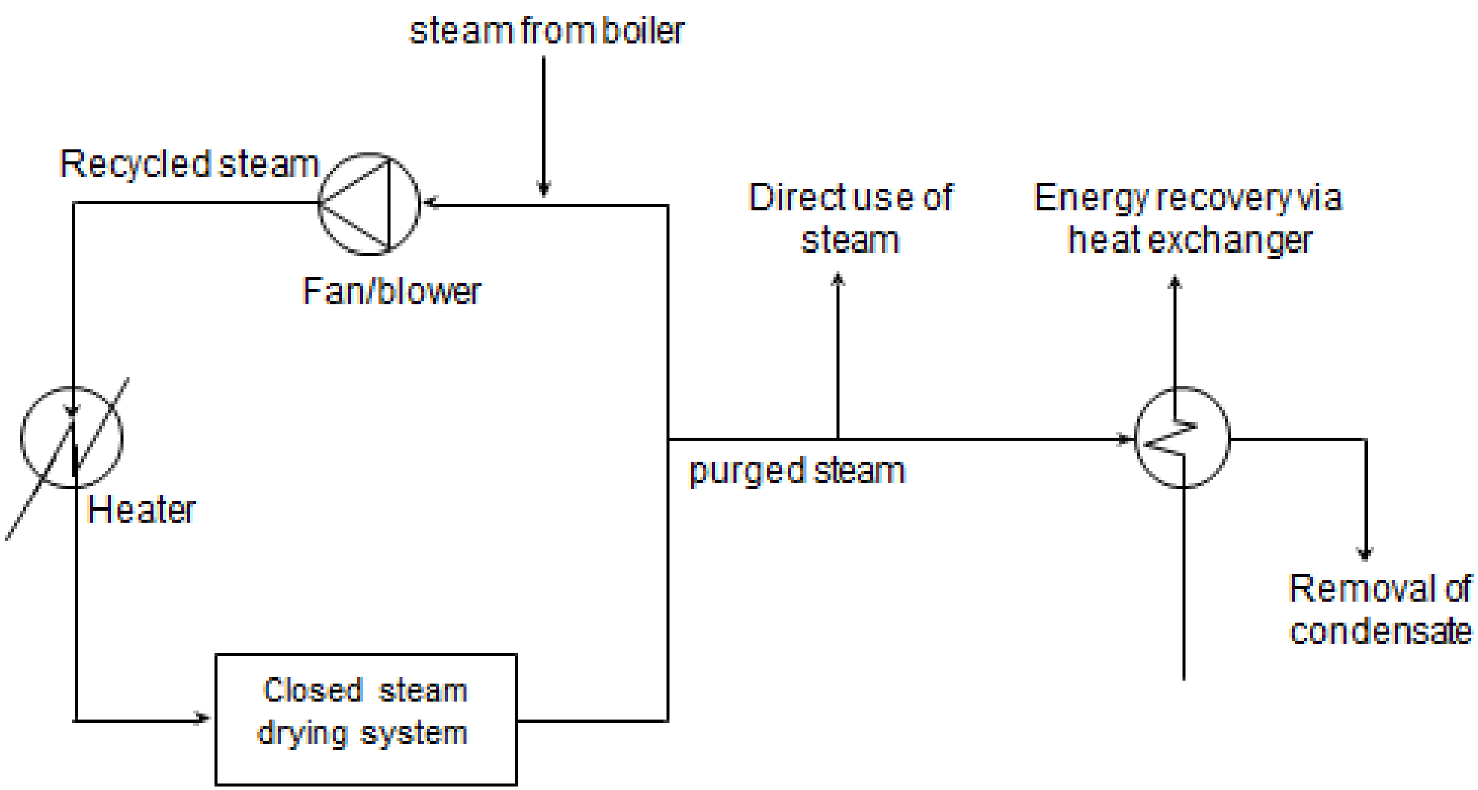


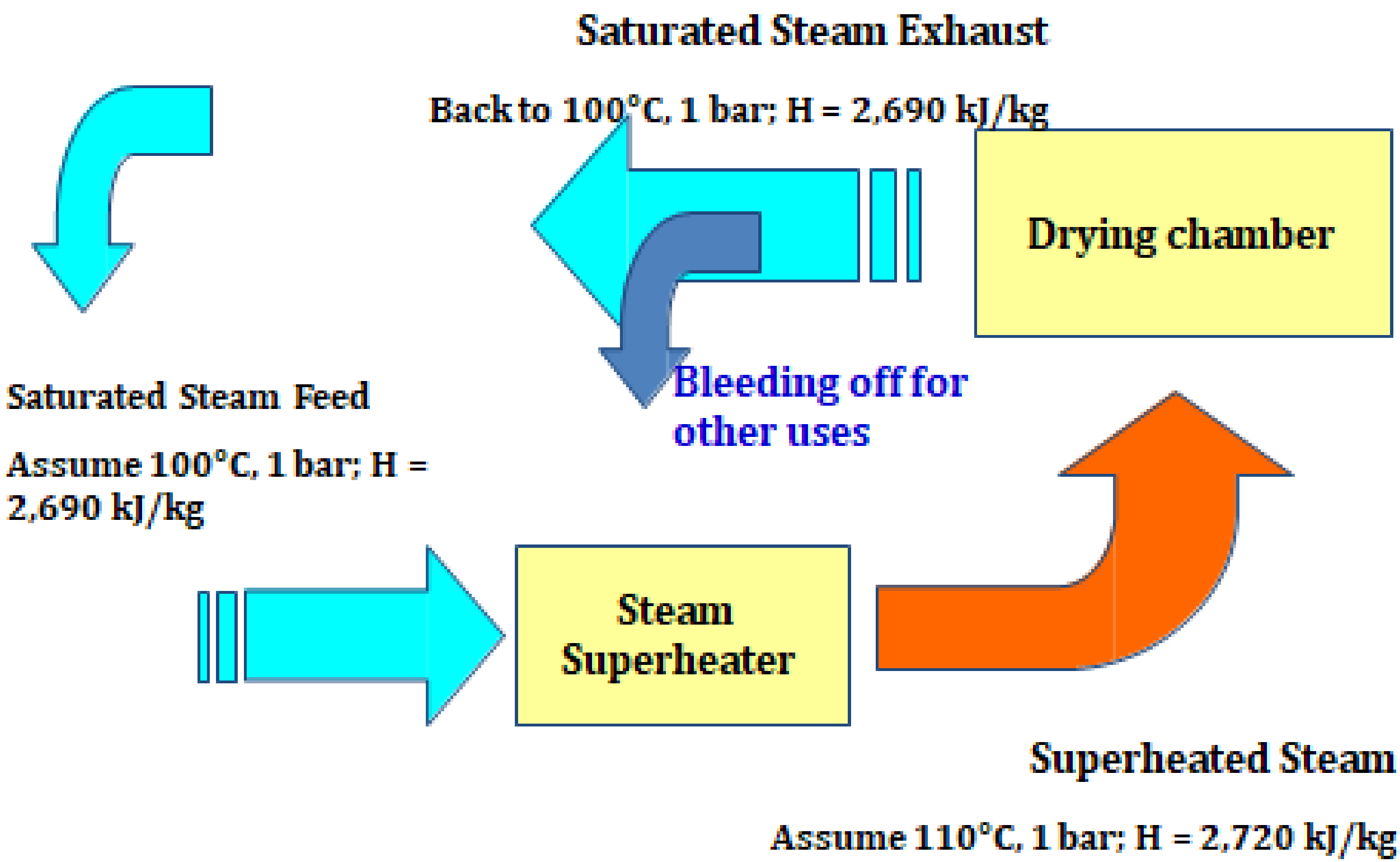
Fig. Microwave dryer for particulate materials

Superheated Steam Drying

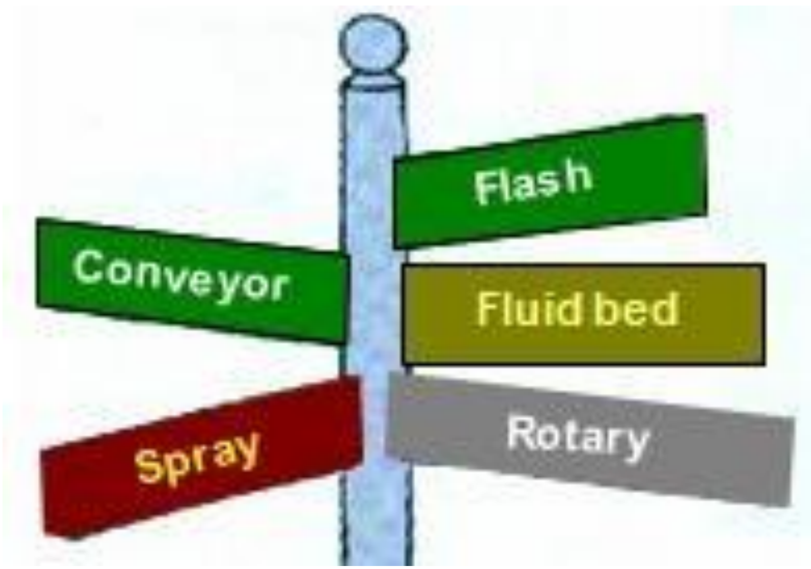


Typical SSD set-up

Superheated Steam Drying



Superheated Steam Drying
Possible Types of SSD



- Flash dryers with or without indirect heating of walls
- FBDs with or without immersed heat exchangers
- Spray dryers
- Impinging jet dryers
- Conveyor dryers
- Rotary dryers
- Impinging stream dryers

Selection of Fluid Bed Dryer
Some case studies

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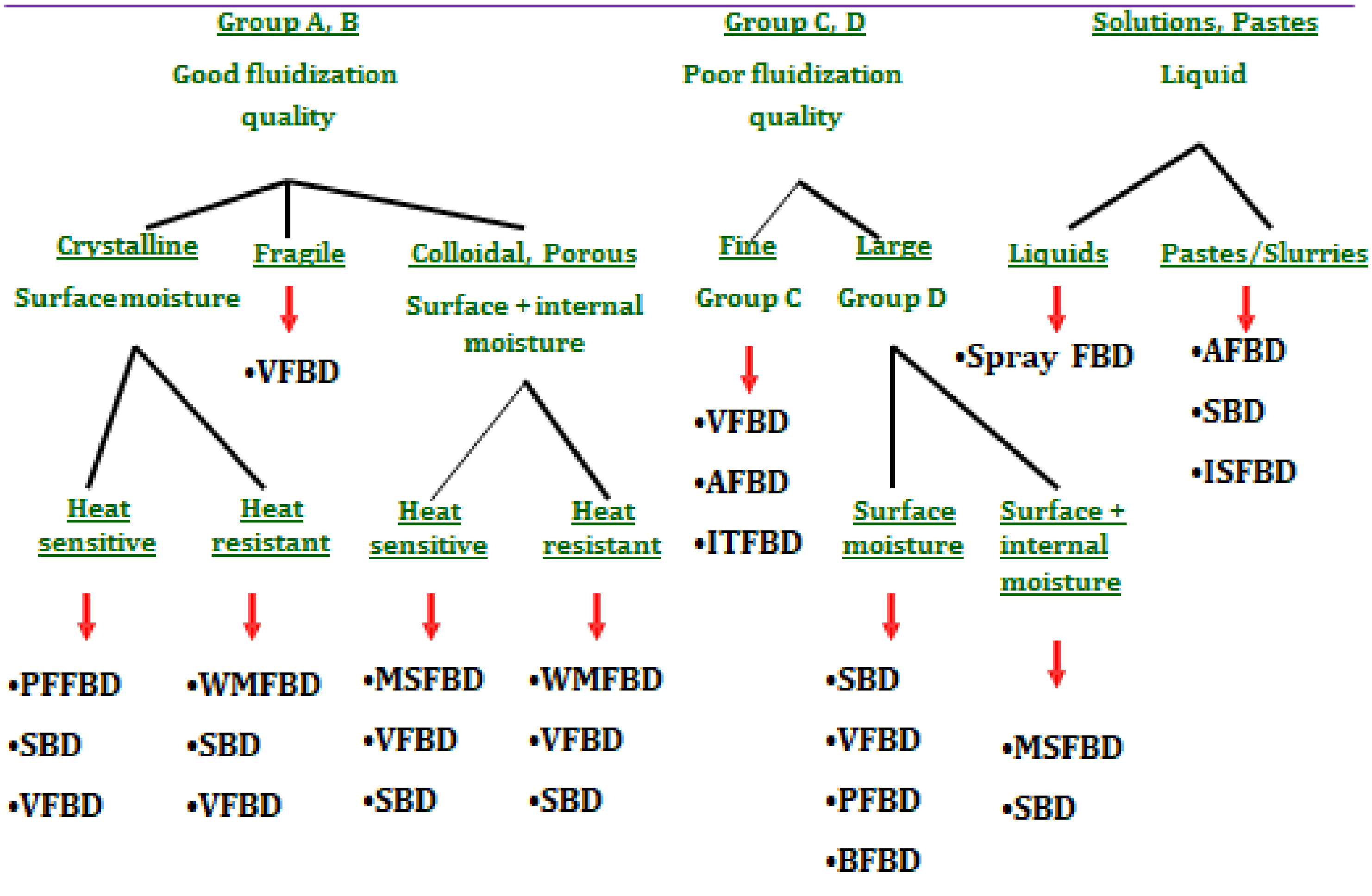
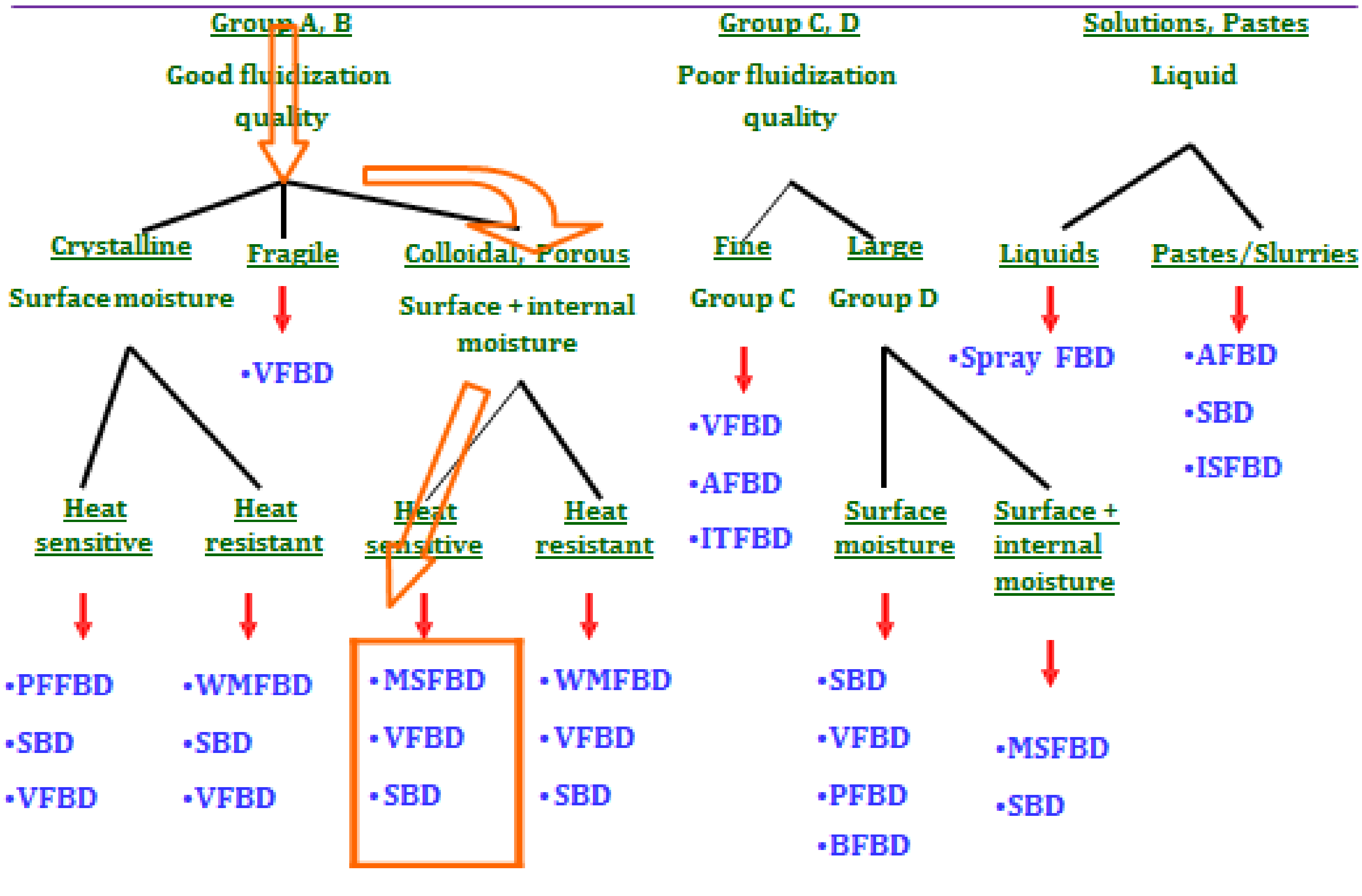
FBD Selection – Complex Procedure



FBD Selection Example – Drying of Yeast

- Good fluidization quality when dry
- Contains surface andinternal moistures
- Heat sensitive
- Mono-sized, particle size = 200μm (aeratable)
- Note other dryer types can also be used for this application

FBD Selection Example – Drying of Yeast



FBD Selection Example – Drying of Yeast

- FBD to be selected from following alternates:
- Multi-stage fluidized beddryer
- Vibrated Fluidized beddryer
- Spouted Fluidized beddryer

- Mono-sized,
- Particle size = **200µm (aeratable); density = ???**

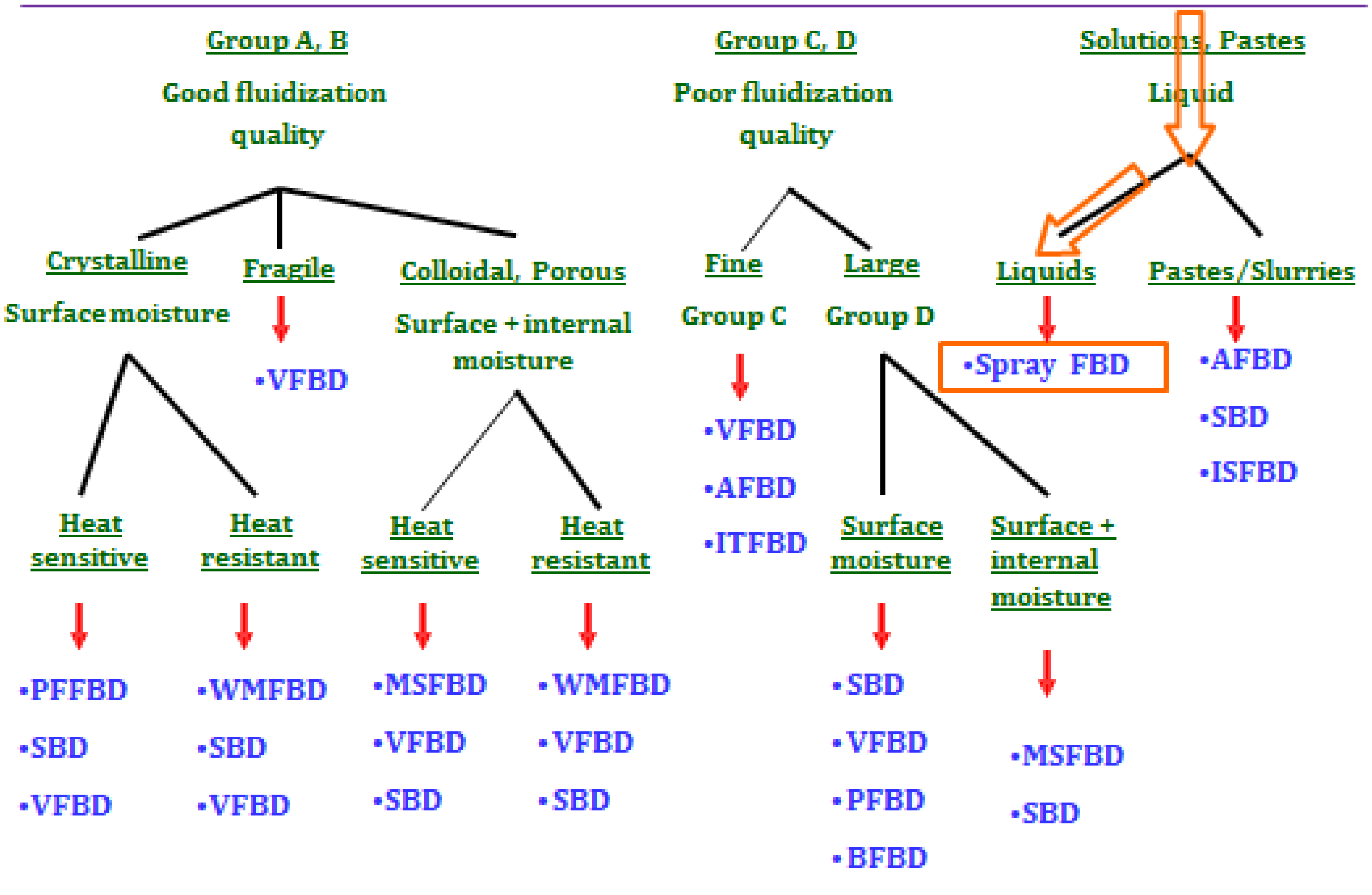
- **Use a multistage fluidized bed dryer**
- Can consider well mixed fluidized bed dryer followed by plug flow fluidized dryer and cooler at the final stage

FBD Selection Example – Drying of Dairy Products

- Solution
- Liquid

- Note: Aside from physical form ,mode of operation, capacity required, heat sensitivity affect the dryer choice. In fact the initial and final M.C., drying kinetics, toxicity, fragility of material also influence dryerselection.

FBD Selection Example – Drying of Dairy Products

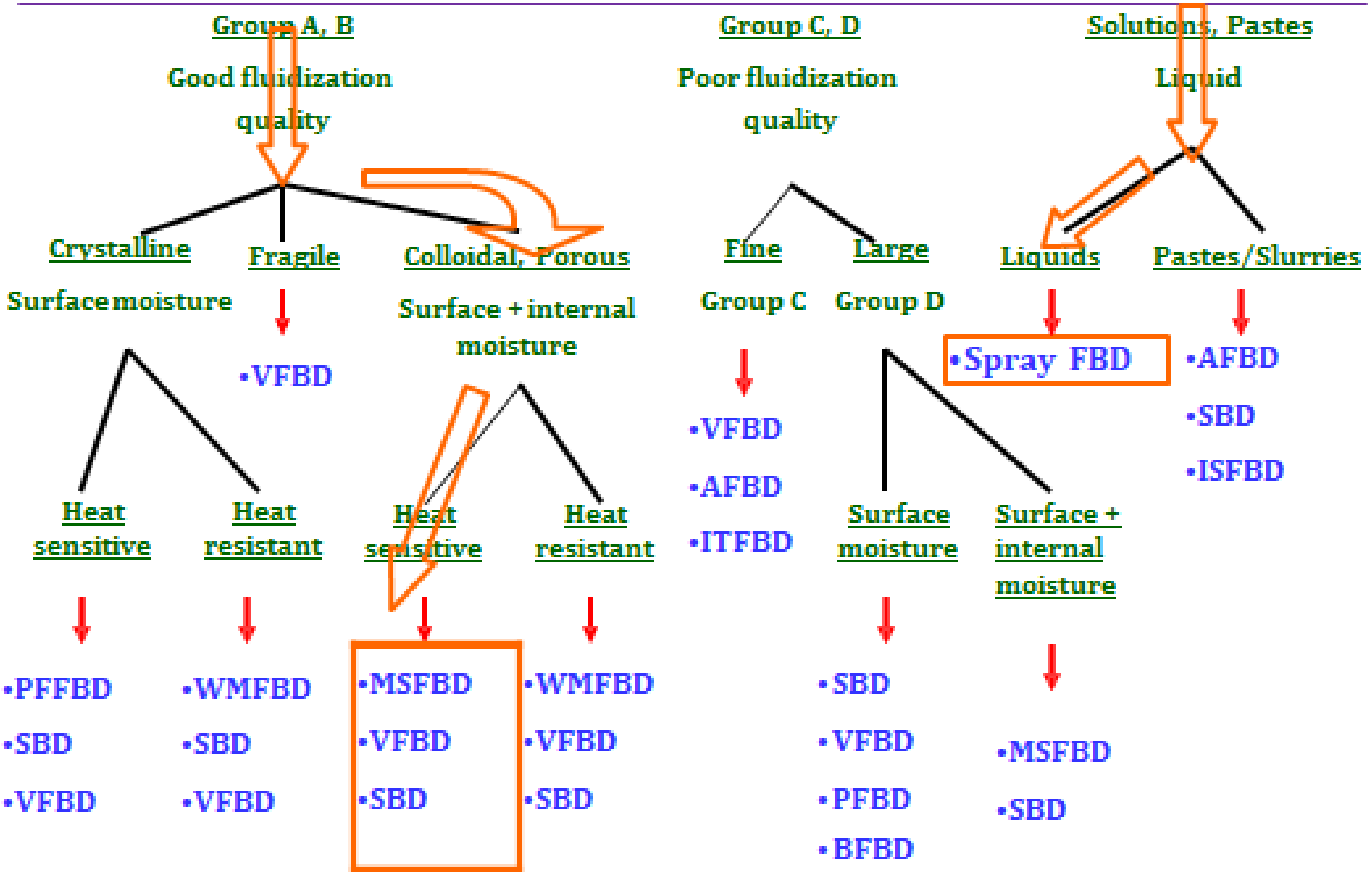


FBD Selection Example – Drying of Dairy Products

- FBD toselect:
- **Spray – FBD**
- What type ofFBD?

- **Note following:**
- Powders contain internal moisture, porous
- Heat sensitive

FBD Selection Example – Drying of Dairy Products



FBD Selection Example – Drying of Dairy Products

FBD toselect:

- **Multi stage fluidized bed dryer**
- **Vibrated fluidized bed dryer**
- **Spouted bed dryer**

- Poly dispersed
- **Use vibrated fluidized bed dryer**
- Need to sieve products; fines recycled, coarse crushed and recycled, sized productcollected

Advanced Drying Methods

Advanced Drying Methods

Atmospheric freeze drying

Heat pump drying Hybrid drying

Intermittent drying Spray freeze

drying

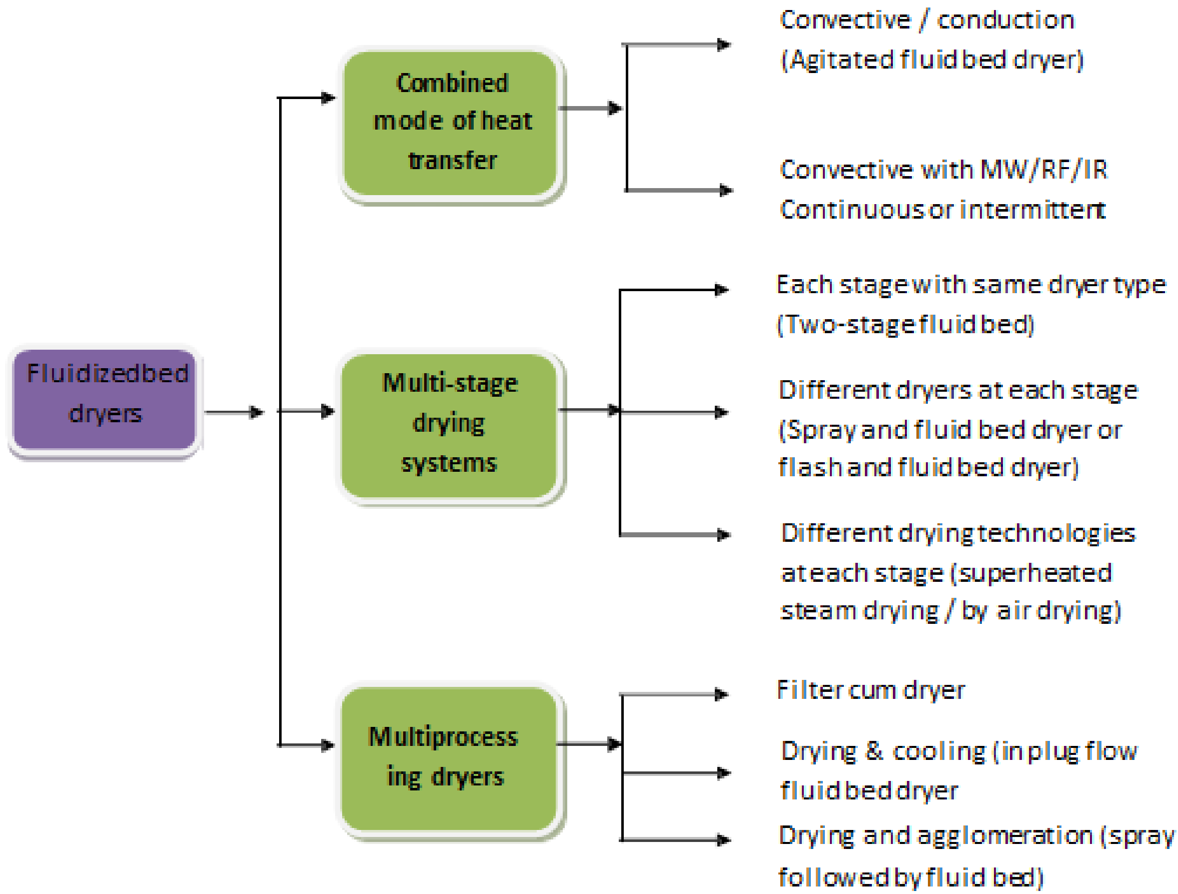
Pulse combustion dryers

Multi-stage dryers

Multi-processing dryers

Advanced Drying Methods

Hybrid Drying Technologies



- Very important step (after establishing need to dry and optimal flow sheet for nonthermal dewatering)
- Wrong choice leads to severe penalties – start-up costs, downtime and need to replace
- User must do "homework" fist; vendors valuable thereafter
- Several dryers may do the job – same quality, cost etc.
- Selection does depend on cost of fuel, relative cost of different energy sources; geographical location; legislative regulations; emission control; safety, etc.
- Consider new technologies as well – when available and proven
- Expert systems now available (e.g. SPS) to aid in selection – still a combination of art (experience) and science!
- Selection may be dominated by just one criterion in some cases e.g. quality for pharma products
- Several different dryers can do same job at same cost in some cases
- Choice can depend on geographic location, cost of energy etc

- Energy is a important point to be considered in drying which is highly energy intensive unit operation
- Different routes can be used to minimize the energy losses
- Carbon foot prints can be minimized by making the drying system energy efficient
- Developing energy intensive methods with sustainability – need to develop innovative drying techniques
- Some of the advanced/innovative ways of drying are discussed

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Banco	Haden international group	Fiat	murugappa	Piramal Healthcare	Firmenich	Cipla	
Cairn Energy for India	GE	Lupin Pharmaceuticals, Inc.	Bharat Petroleum	Reliance Industries Limited	Cairn Energy for India	Camlin	Pidilite
BKT Growing Together	IndianOil	Nippon Paint	Dr. Reddy's	Medreich	Essar	IFF	Torrent
Sarda	SAF	L&T Power	Aditya Birla Group	Aditya Birla Hindalco	Voltas Limited	IOT	ACG Worldwide
moserbaer Technologies	Hindustan Unilever Limited	Arvind	Papyrol		HP Pelzer Automotive Systems, Inc.	Vertellus	
Cumi	heubach	Jindal Steel & Power	Nestlé	Signode	Unitex		

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