تصميم المجفف الرذاذ وتطبيقاته في الصناعات الغذائية والدوائية

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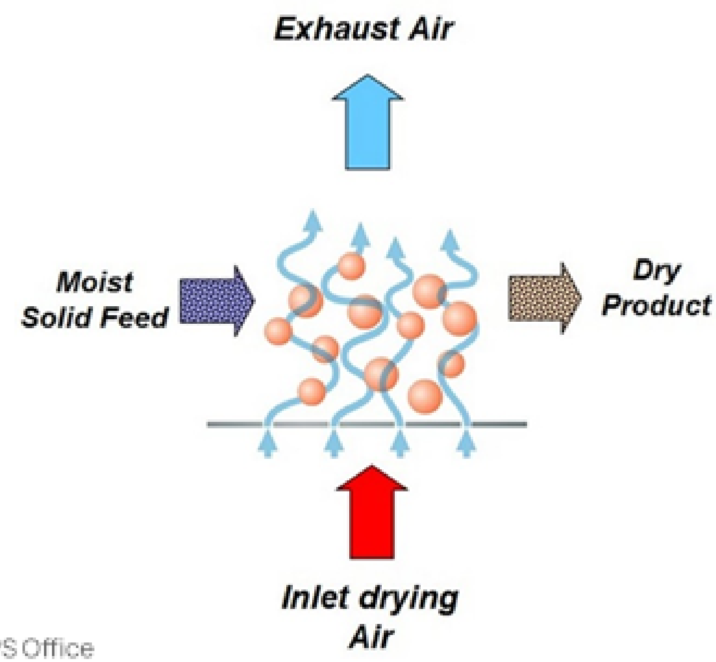
WHAT IS DRYING

- Drying refers to the removal of relatively small amount of a liquid from a solid material.
- In general, drying is concerned with the removal of water.
- However, the term also refers to removal of other organic liquids such as benzene, hexane, alchohol from solids.
- Drying is different from evaporation in that evaporation involves the removal of relatively large amount of water.
- The purpose of drying is to reduce the residual liquid to an acceptable level.

Purpose of drying

- ✓ Easy-to handle free-flowing solids
- ✓ Preservation and storage
- ✓ Reduction in cost of transportation
- ✓ Achieving desired quality of product



CLASSIFICATION OF DRYERS

Dryers can be classified based on a number of criteria.

- Mode of operation
  - Batch
  - Continuous
- Pressure
  - Vacuum
  - Pressurized
- Solid handling
  - Steady
  - Fluidized bed
- Means of heat addition

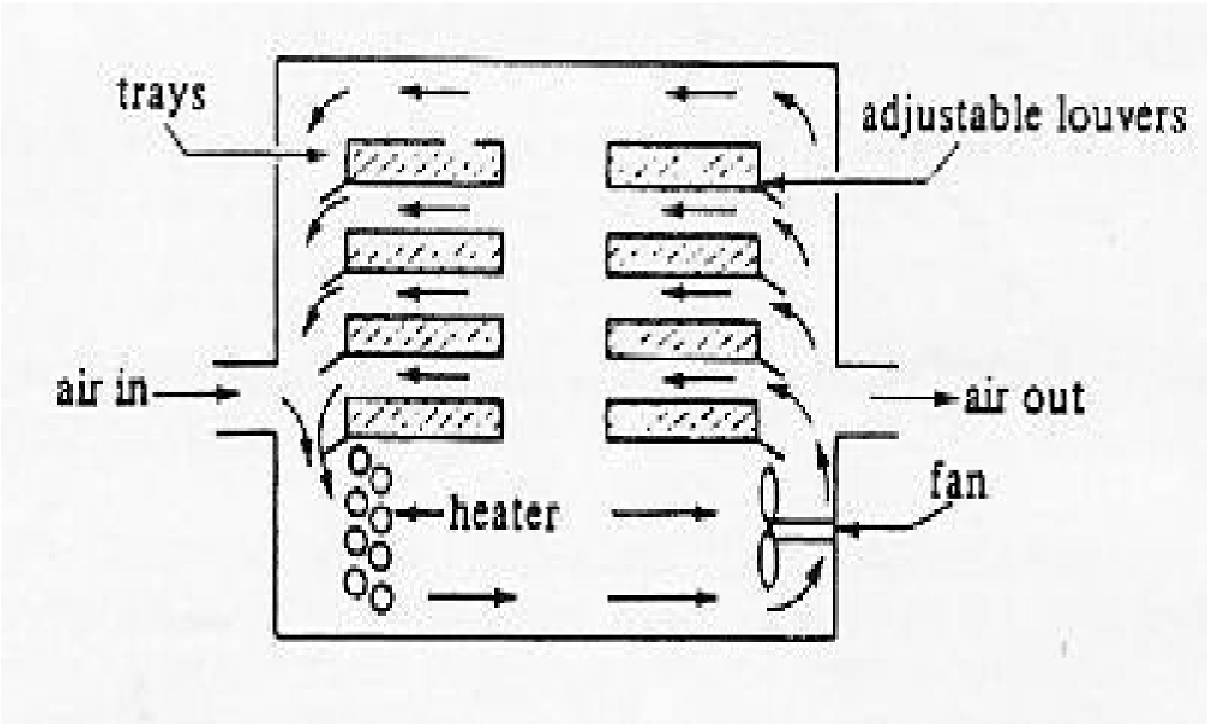
INDUSTRIAL DRYERS

As categorization of dryers involves a large number factors we will discuss a number of industrial dryers without properly categorizing those into any type.

Tray Dryer

Also know as shelf , cabinet and compartment dryer its used for batch operation

- Contains removable shallow trays on which the solid is spread
- Hot air is circulated by a fan over and parallel to the surface of the trays
- Some moist air is continuously vented and fresh make up air is added
- Useful for low production rate e.g. pharmaceutical products
- May be operated under vacuum, often with indirect heating

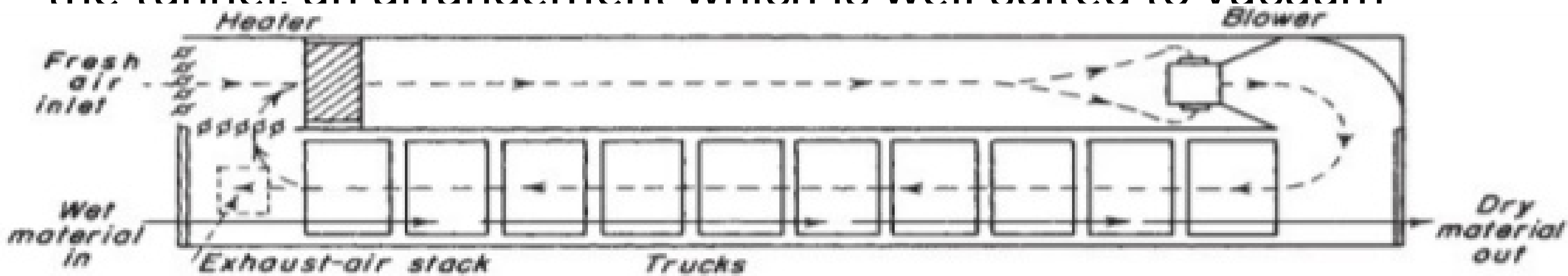


Size	80" W x 34" D x 77" H
Trolley	2 Nos. of trolleys having capacity of holding 48
Tray Size	16" x 32" x 1 1/4 "
Tray Space	1/2 "
Operating Temperature	From Ambient to 100 C / 150 C / 200 C/ 250 C /300 C

❑ CONTINUOUS TUNNEL DRYER

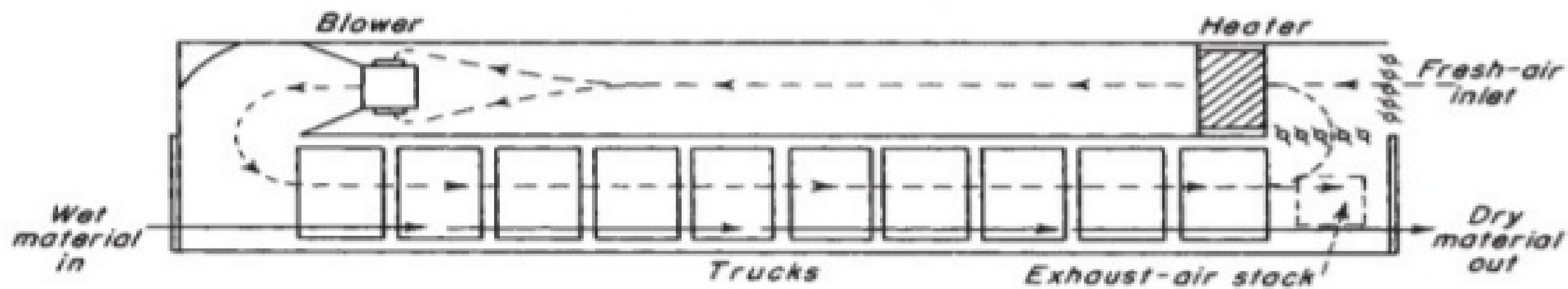
A series of trays or trolleys is moved slowly through a long tunnel, which may or may not be heated, and drying takes place in a current of warm air.

- Used for drying paraffin wax, gelatin, soap, pottery ware, and wherever the throughput is so large that individual cabinet dryers would involve too much handling.
- Alternatively, material is placed on a belt conveyor passing through the tunnel, an arrangement which is well suited to vacuum



Countercurrent Tunnel Dryer

(a) Countercurrent Tunnel Dryer



Parallel Current Tunnel Dryer

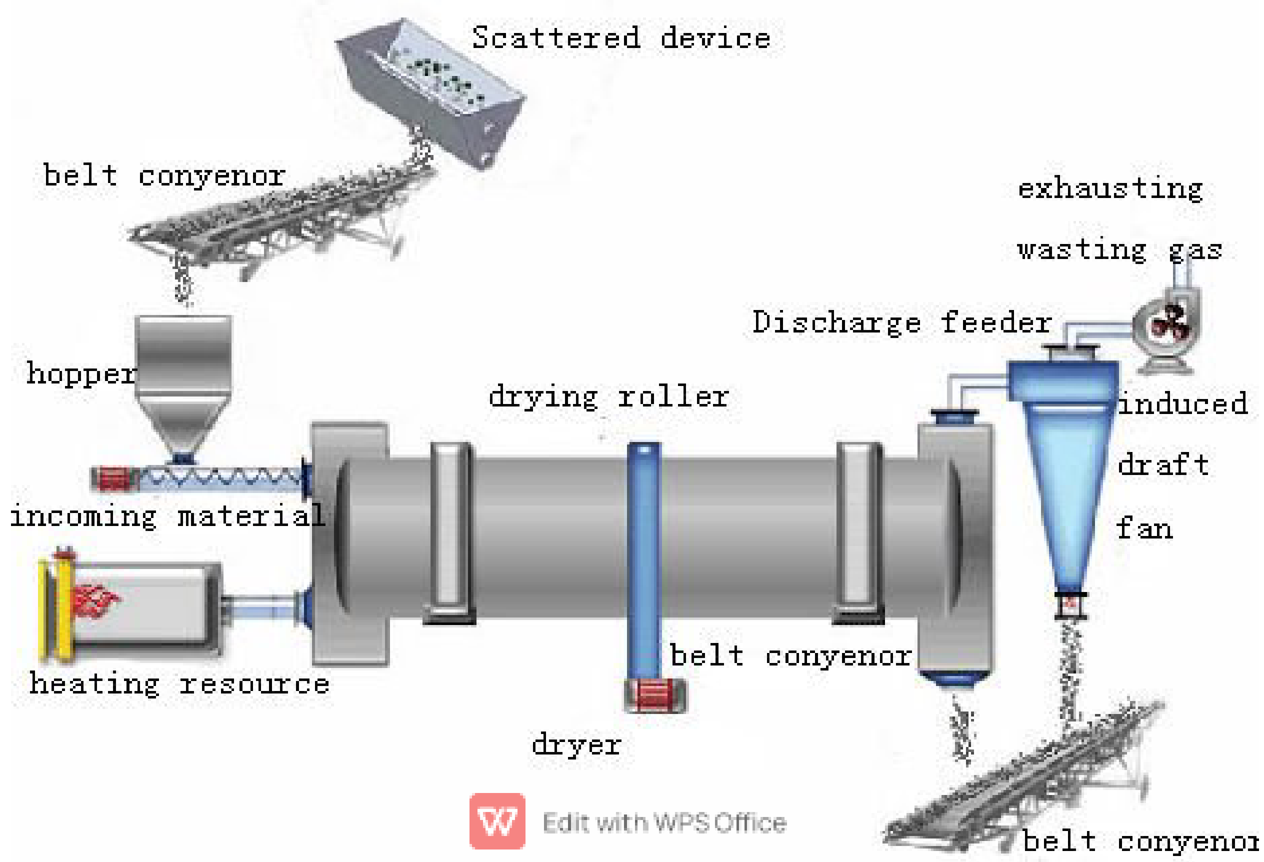
(b) Parallel Current Tunnel Dryer

ROTARY DRYER

Consists of a revolving hollow cylindrical shell, horizontal or slightly inclined towards the outlet.

As the shell rotates, internal flights lift the solids and shower them down through the interior of the shell.

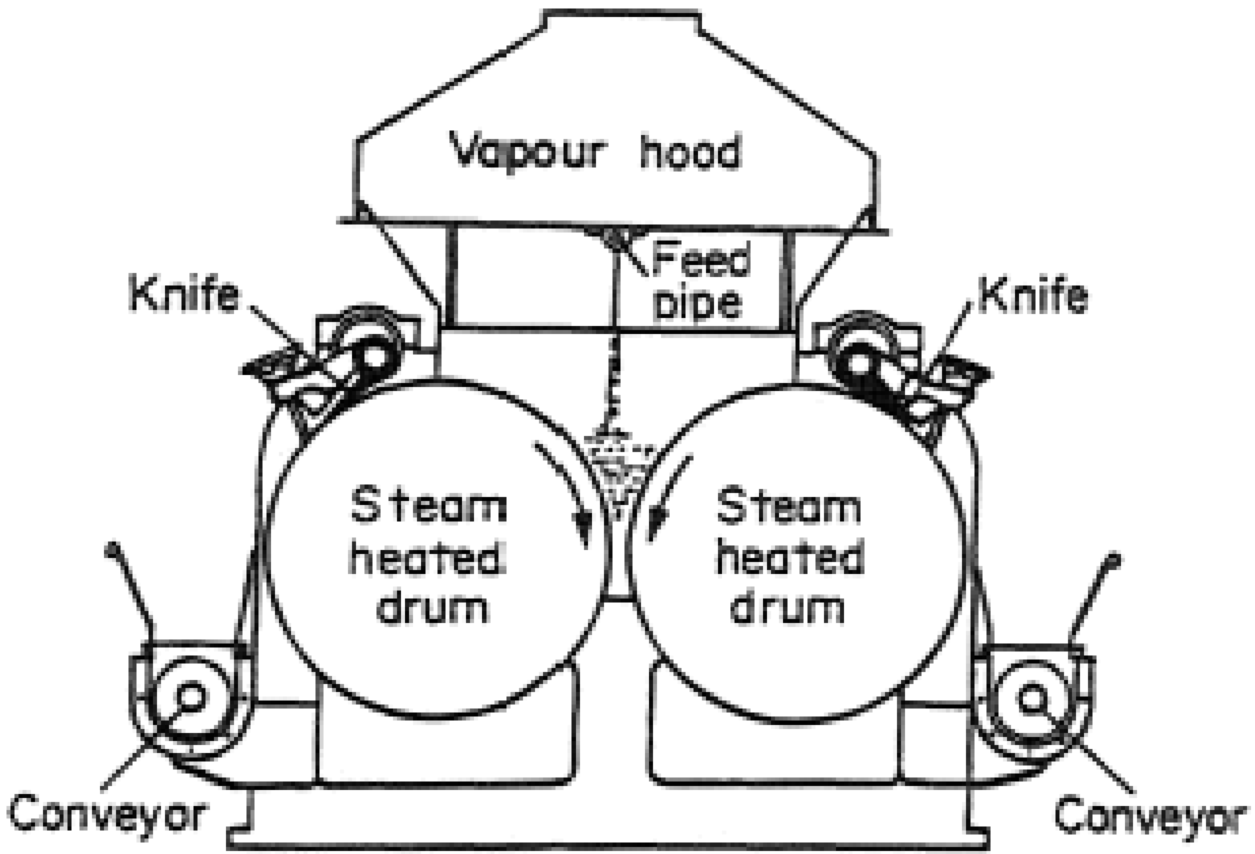
- May be direct or indirect contact or a combination of both.
- Suitable for large scale continuous operation



DRUM DRYER

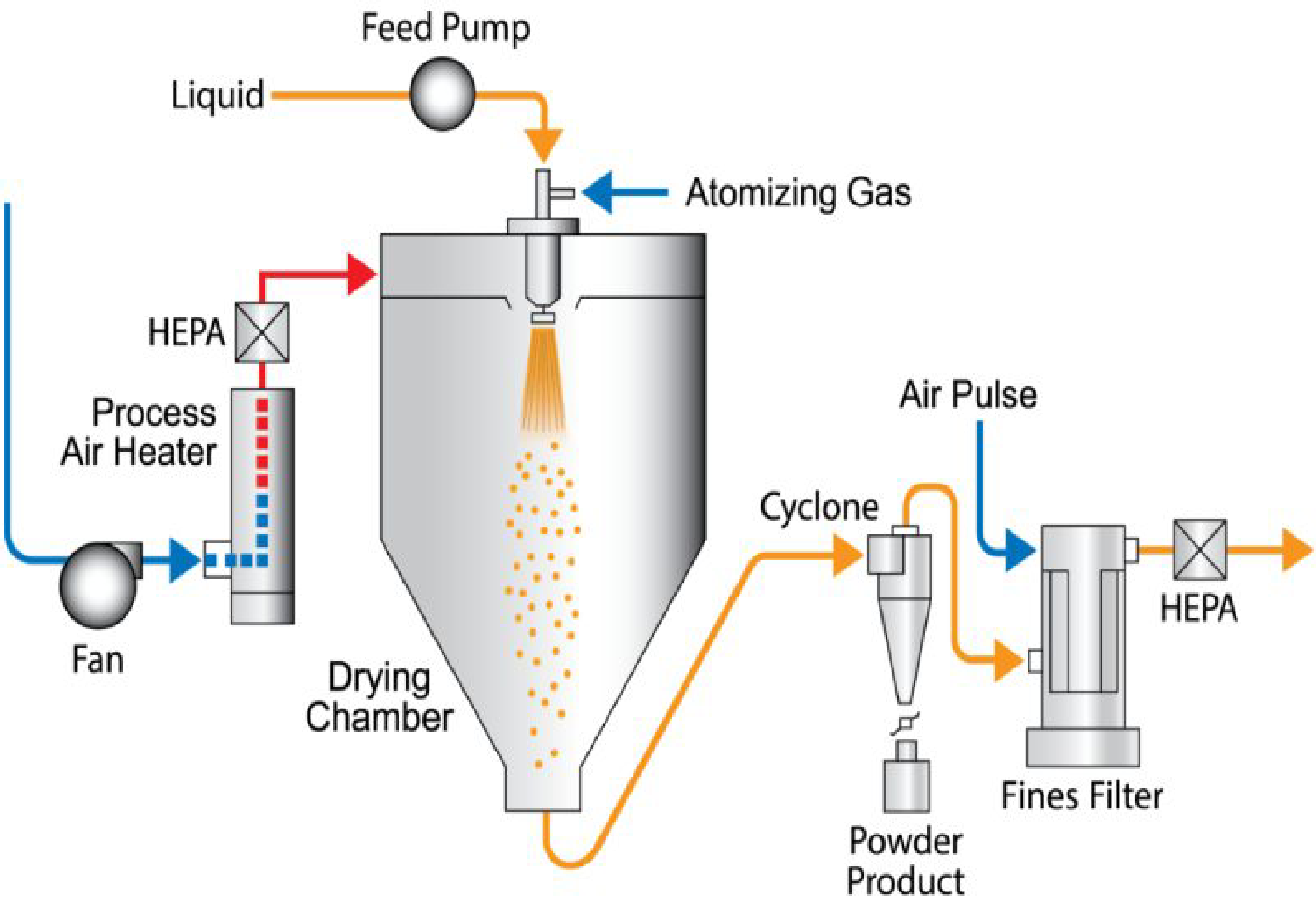
- Consists of a slowly revolving heated metal roll.
- Outside the roll, a thin layer of liquid or slurry is evaporated to dryness. The final dry solid is scraped of the roll.
- Suitable for handling slurries or pastes of solids.

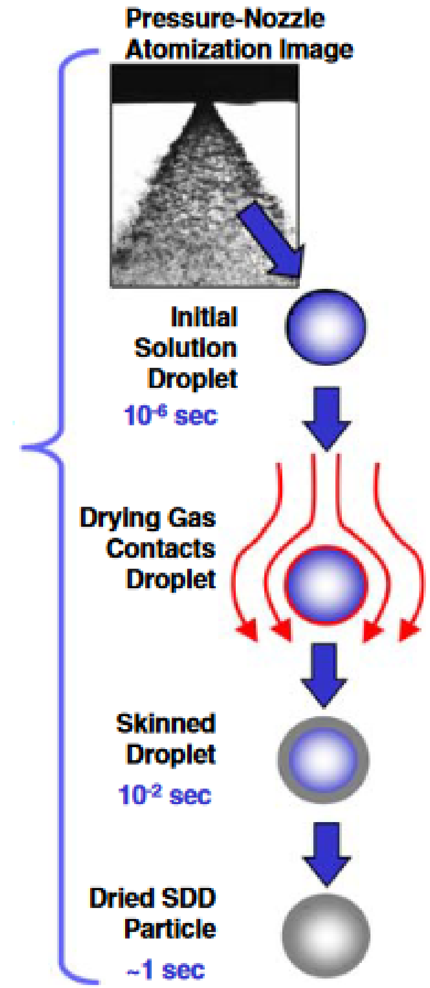
A suspension of solid particles is sprayed into a vessel through



SPRAY DRYER

- **Spray drying** is a method of producing a dry powder from a liquid or slurry by rapidly drying with a hot gas. **This is the preferred method of drying many thermally-sensitive materials such as foods and pharmaceuticals.**
- It is highly suited for the continuous production of dry solids in either powder, granulate, or agglomerate form liquid feedstocks as solutions, emulsions, and pumpable suspensions. Therefore, spray drying is an ideal process where the end product must comply with precise quality standards regarding particle size distribution, residual moisture content, bulk density, and particle shape.


Feed Pump
Liquid
Atomizing Gas
HEPA
Process Air Heater
Fan
Drying Chamber
Air Pulse
Cyclone
HEPA
Powder Product
Fines Filter


Pressure-Nozzle Atomization Image
Initial Solution Droplet
10^{-6} sec
Drying Gas Contacts Droplet
Skinned Droplet
10^{-2} sec
Dried SDD Particle
~1 sec

ATOMIZER

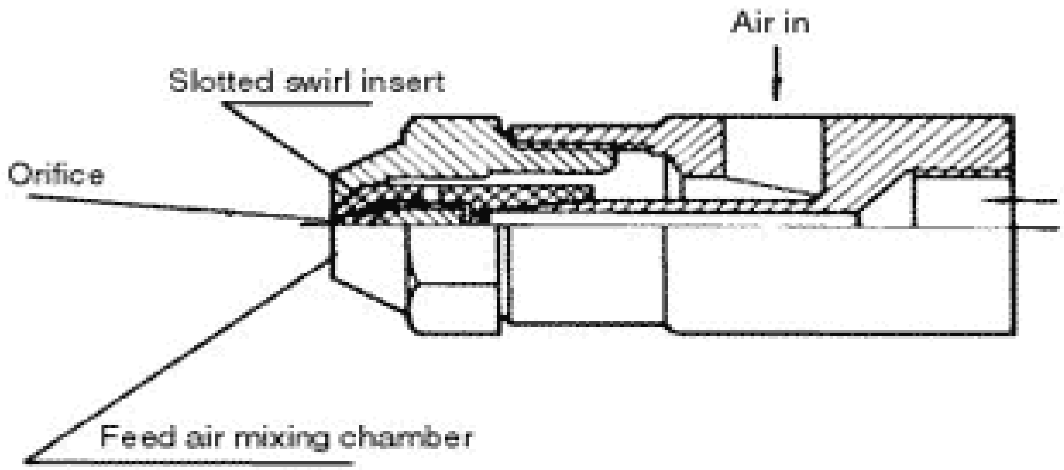
- Atomization is used to obtain particles of high surface/ weight ratio. It is acquired by passing the liquid through a nozzle.
- To disperse the liquid or slurry into a controlled drop size spray.
- Depending on the process needs drop sizes from 10 to 500 micron can be achieved with the appropriate choices.
- Types of atomizer
  - Single fluid Pressure Nozzle Atomizer
  - Two-Fluid Nozzle Atomizer
  - Centrifugal (Disk) Atomizer

PRESSURE NOZZLE ATOMIZER

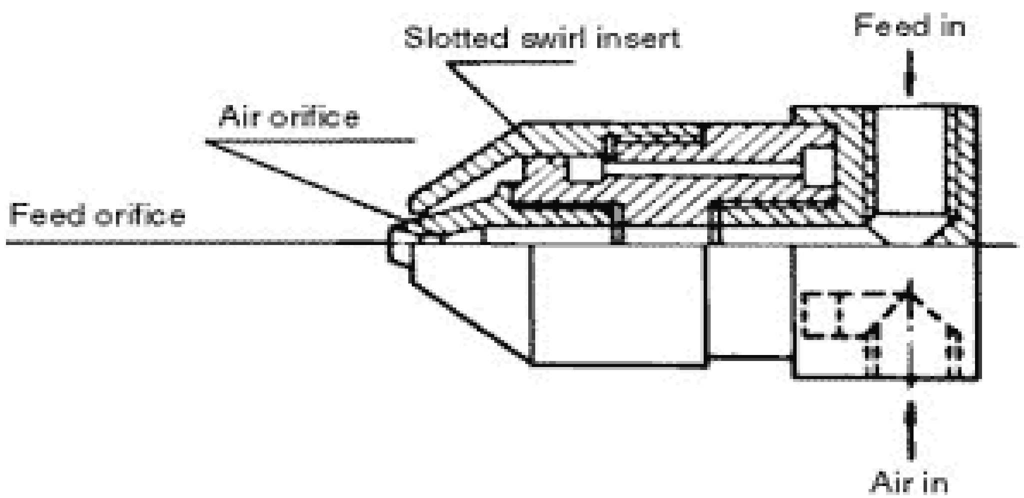
- Pressure nozzle or single fluid nozzle use pressure energy for atomization, with feed pressures in the range of 200 to 600 psi. The pressure energy is converted into kinetic energy and the feed issues from the nozzle has a high- speed film which readily breaks. The pressure nozzles are suitable for feed with relatively low viscosity and free of lumps.

TWO-FLUID NOZZLE ATOMIZER

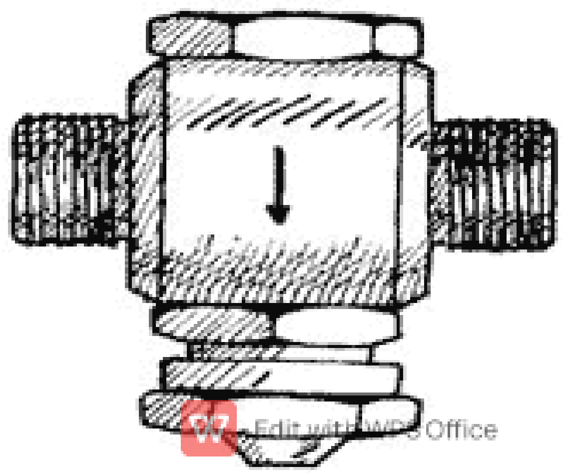
- The available energy for atomization in two fluid atomizers is independent of liquid flow and pressure. The necessary (kinetic) energy for atomization is supplied by compressed air in the range 50-100 psig. The atomization is created due to high frictional shearing forces between the liquid surface and the air having a high velocity even at sonic velocities and sometimes rotated to obtain maximum atomization.
- In pneumatic nozzle the feed can be mixed with compressed air either internally or externally. The external mixing types are used for abrasive feeds. Two Fluid Nozzle atomizer are convenient for low capacity application and popularly used for high quality ceramic powders: Alumina, Bentonite, Carbides, Clays, Ferrites, Steatites, Titanates and Zirconias.



A) Internal mixing

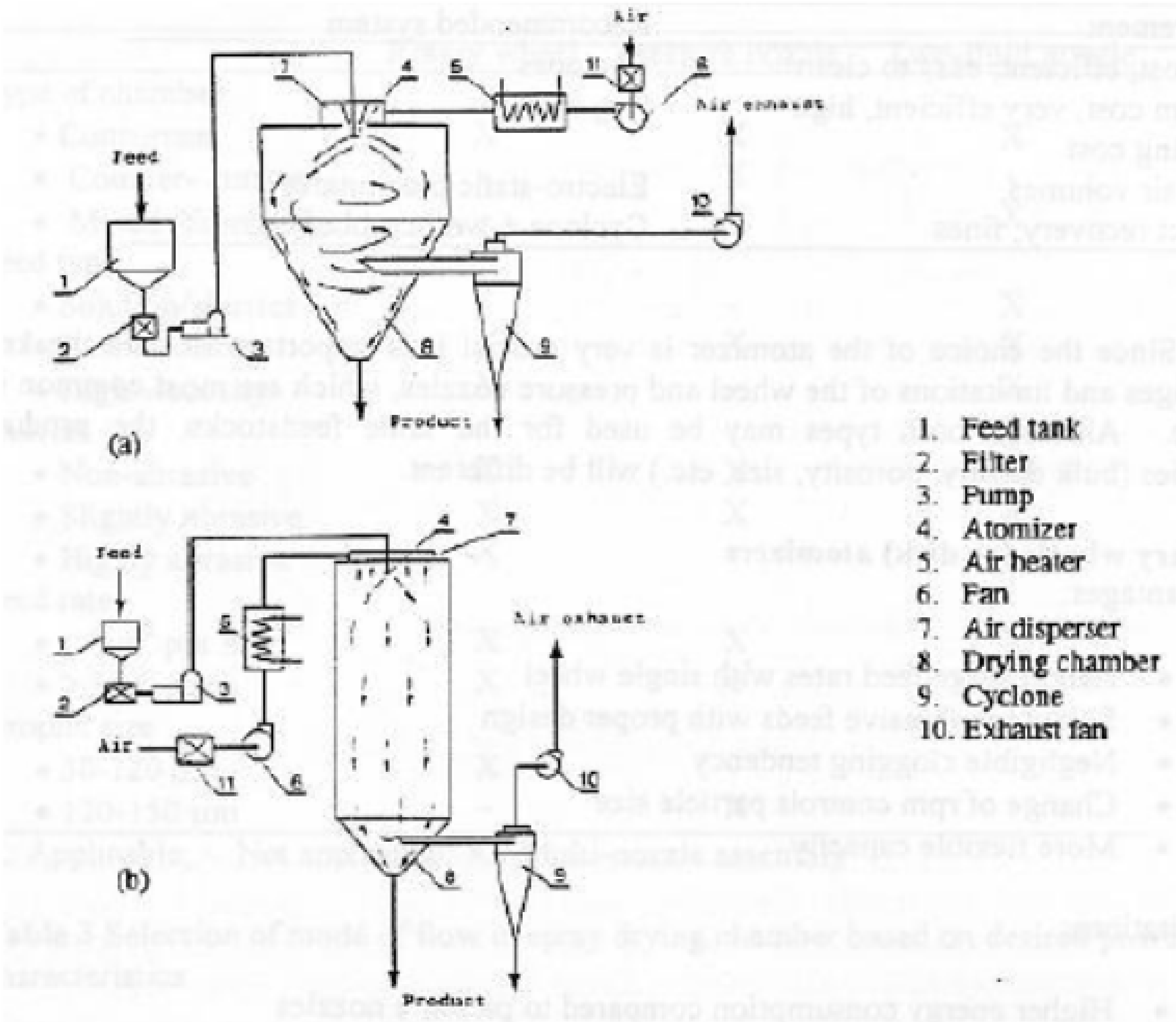


B) External mixing



CENTRIFUGAL DISK ATOMIZER

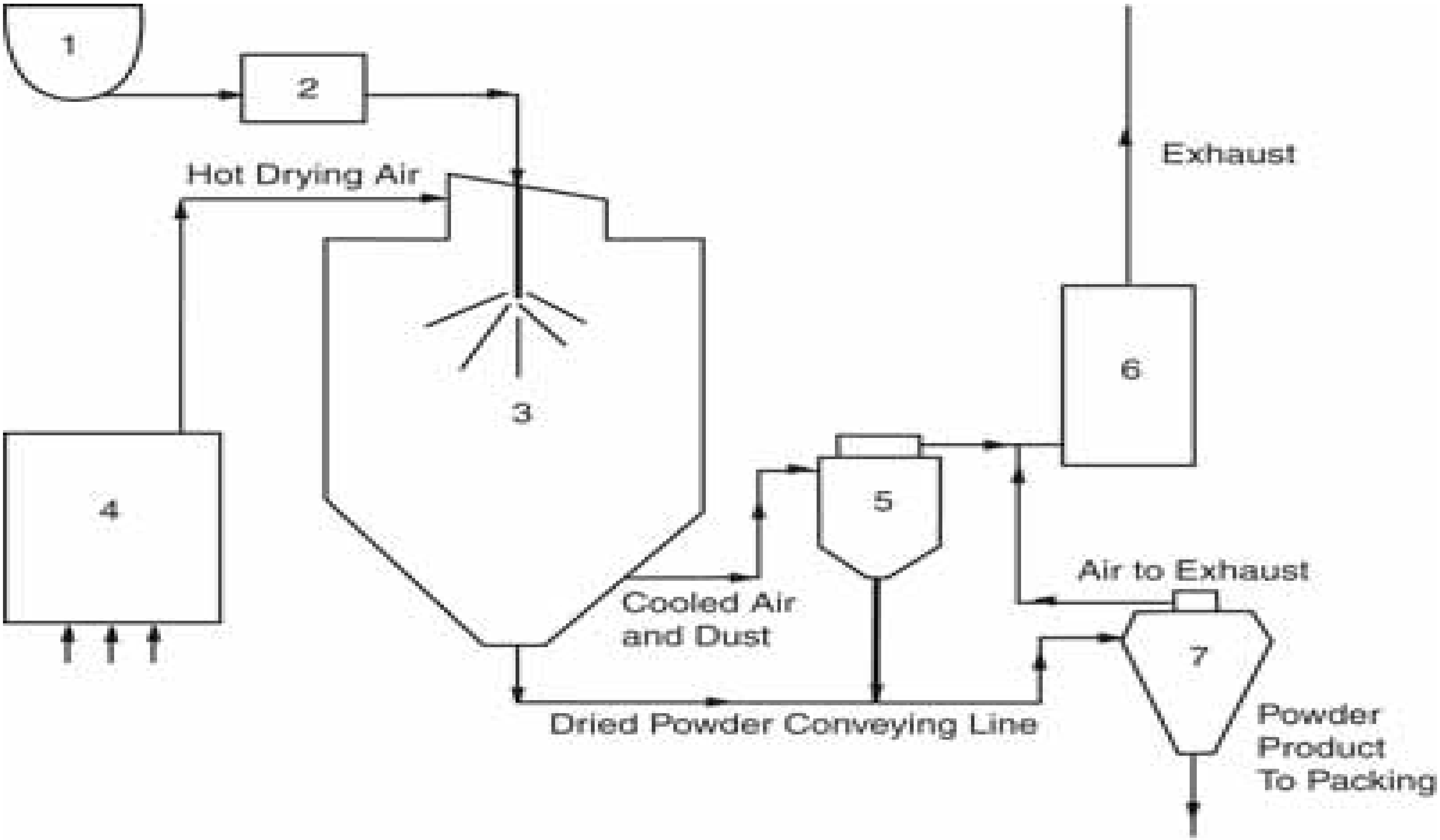
- A spray is created by passing the fluid across or through a rotating wheel or disk. The energy required for atomization is supplied by the atomizer motor.



(a) Wheel atomizer (b) Single or two fluid nozzle

SPRAY CHAMBER

- The atomized feed is introduced into a large chamber where droplets are dispersed into the stream of hot air.
- Drying takes place by contacting the droplets with hot air in a spray chamber. Evaporation of moisture from the droplets and formation of dry particles proceed under controlled temperature and airflow conditions. Powder is discharged continuously from the drying chamber.
- Evaporation takes place from the surface of the drops and solid material form an impervious shell at the surface which collapses inward due to internal pressure.



1. feed storage
2. pump
3. drying chamber
4. air heater
5. Cyclone
6. gas scrubber
7. separator

MODE OF CONTACT

- The hot drying gas can be passed as a **co-current or counter current flow** to the atomizer direction.
- The co-current flow enables the particles to have a lower residence time within the system and the particle separator (typically a cyclone device) operates more efficiently.
- The counter-current flow method enables a greater residence time of the particles in the chamber and usually is paired with a fluidized bed system.

ADVANTAGES

- Very short drying time, which permits drying of highly heat sensitive products.
- Product particle size & density are in controllable limits
- Relatively low operating cost.
- Air is the heated drying media; however, if the liquid is a flammable solvent such as ethanol or the product is oxygen sensitive then nitrogen is used.

SPRAY DRYER APPLICATION

- **Food:** milk powder, coffee, tea, eggs, cereal, spices, flavorings
- **Pharmaceutical:** antibiotics, medical ingredients, additives
- **Industrial:** paint pigments, ceramic materials, catalyst supports

ATOMIZER POWER CONSUMPTION

- $\mathbf{P} = 1.02 \times 10^{-8} \times m_{slurry} \times (N\ d)^2$

Where

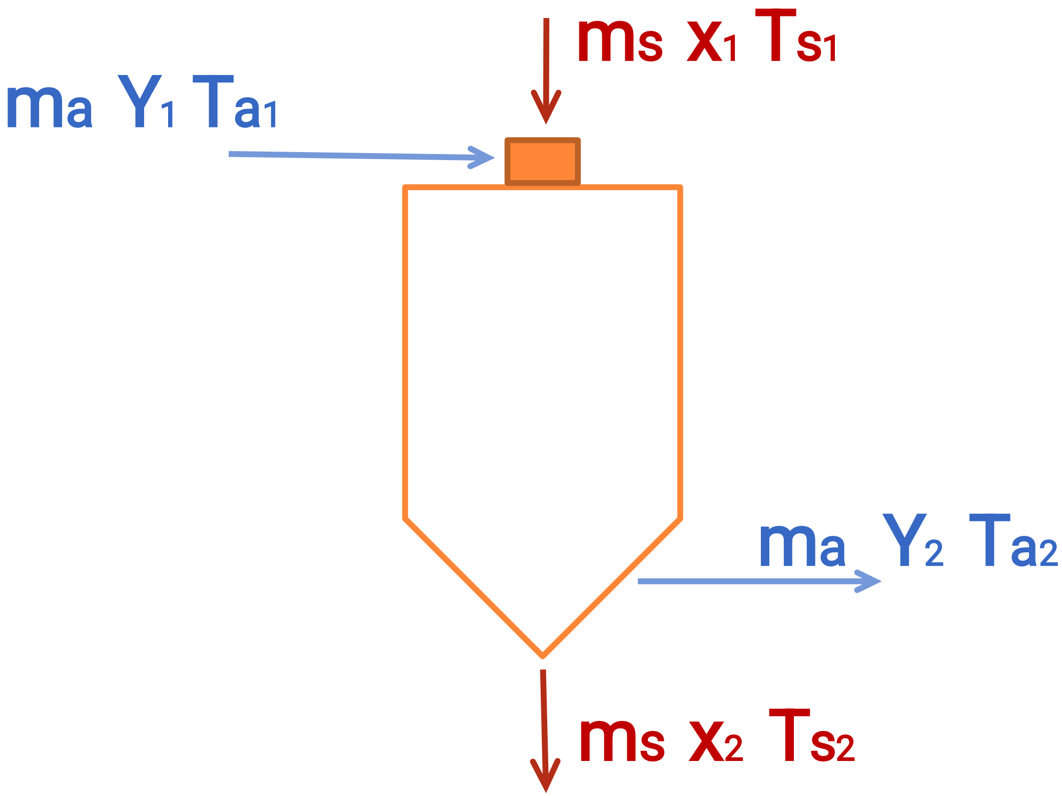
m_{slurry} = Feed rate of slurry in lb/min

N = Rotational speed in rpm

d = Radius of disk atomizer in ft

P = power in hp

SPRAY CHAMBER



m_a = Heated Gas Flow Rate in kg/hr

m_s = Solid Flow Rate in kg/hr

X_1 = Moisture content in the entering solid (kg moisture / kg solid)

X_2 = Moisture content in the exit solid (kg moisture / kg solid)

Y_1 = Humidity of entering air (kg moisture / kg air)

Y_2 = Humidity of outlet air (kg moisture / kg air)

Ta_1 = Temperature of inlet air

Ta_2 = Temperature of outlet air

Ts_1 = Temperature of inlet solid

Ts_2 = Temperature of exit solid

EQUATIONS (SPRAY CHAMBER)

- Mass Balance end :

$$m_s X_1 + m_a Y_1 = m_s X_2 + m_a Y_2 \text{ ----- } (1)$$

$$m_s (X_1 - X_2) = m_a (Y_2 - Y_1) \text{ ----- } (1)$$

- Enthalpy Balance eqn :

$$m_s Q_{s1} + m_a Q_{a1} = m_s Q_{s2} + m_a Q_{a2} + Q_{loss} \text{ -----} (2)$$

Q_{s1} = Enthalpy of entering solid in kJ/kg of dry solid

Q_{s2} = Enthalpy of exit solid in kJ/kg of dry solid

Q_{a1} = Enthalpy of entering air in kJ/kg of dry air

Q_{a2} = Enthalpy of exit air in kJ/kg of dry air

- $Q_{s1} = (C_{ps} + X_1 C_{pw})\,Ts1$
- $Q_{s2} = (C_{ps} + X_2 C_{pw})\,Ts2$
- $Q_{a1} = (C_{pa} + Y_1\,C_{pv})\,Ta1 + Y_1\lambda$
- $Q_{a2} = (C_{pa} + Y_2 C_{pv})\,T_{a2} + Y_2\lambda$

C_{ps} = Specific heat of solid = 1.3395 kJ/kg°C
C_{pw} = Specific heat of water = 4.2 kJ/kg°C
C_{pv} = Specific heat of water vapor = 1.89 kJ/kg°C
C_{pa} = Specific heat of air at avg. temperature = 1.0312 kJ/kg°C
λ = Latent heat of vaporization @ 100 °C = 2257 kJ/kg

X_1 = Moisture content in the entering solid (kg moisture / kg solid)
X_2 = Moisture content in the exit solid (kg moisture / kg solid)
Y_1 = Humidity of entering air (kg moisture / kg air)
Y_2 = Humidity of outlet air (kg moisture / kg air)
Ta_1 = Temperature of inlet air
Ta_2 = Temperature of outlet air
Ts_1 = Temperature of inlet solid
Ts_2 = Temperature of exit solid

$$Humid\ Volume\ (V) = 8315 \times \left(\frac{1}{M_a} + \frac{Y}{M_w}\right) \times \left(\frac{T_a + 273.15}{P}\right)$$

M_a = Molecular wt of air =29 g/mol

M_w = Molecular wt of water 18 g/mol

T_a = Temperature of air in ^0C

P = Pressure in N/m^2

Y= kg of moisture/ kg of dry air

- Humid Volume :

$$V_{in} = 8315 \times \left(\frac{1}{29} + \frac{Y_1}{18}\right) \times \left(\frac{150+273.15}{1.0135\times10^5}\right) \text{ m}^3\text{/kg dry air}$$

$$V_{out} = 8315 \times \left(\frac{1}{29} + \frac{Y_2}{18}\right) \times \left(\frac{120+273.15}{1.0135\times10^5}\right) \text{ m}^3\text{/kg dry air}$$

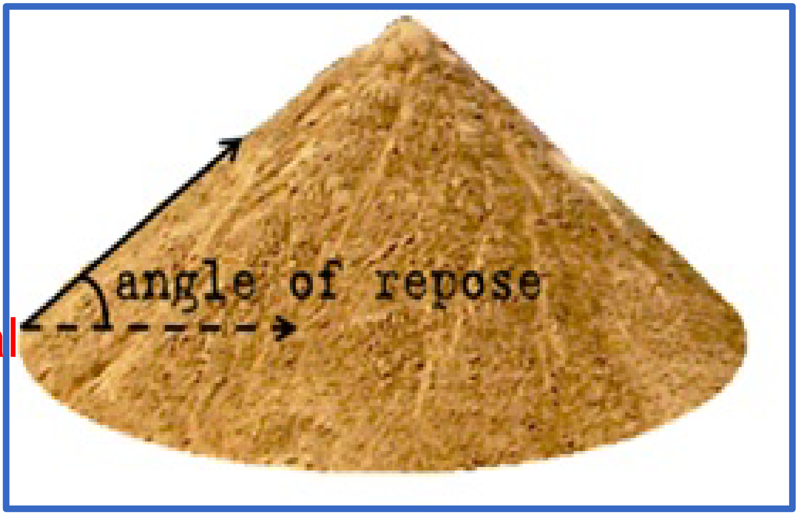
$V_{avg} = (V_{in} + V_{out})/2\ m^3$/kg dry air

- Droplet Diameter assumed to be 100 microns.

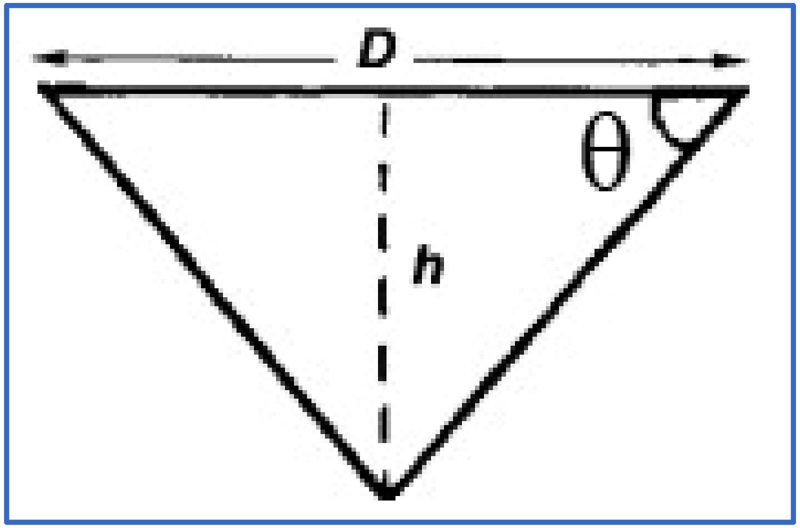
Angle of repose (θ) is the maximum possible angle between the surface of pile of powder and the horizontal plane, this angle is used for conical part design

Angle of repose depends upon

- Density
- Surface area
- Shapes of particles
- The coefficient of friction of the material



$$\vartheta = tan^{-1}\left(\frac{2h}{D}\right)$$



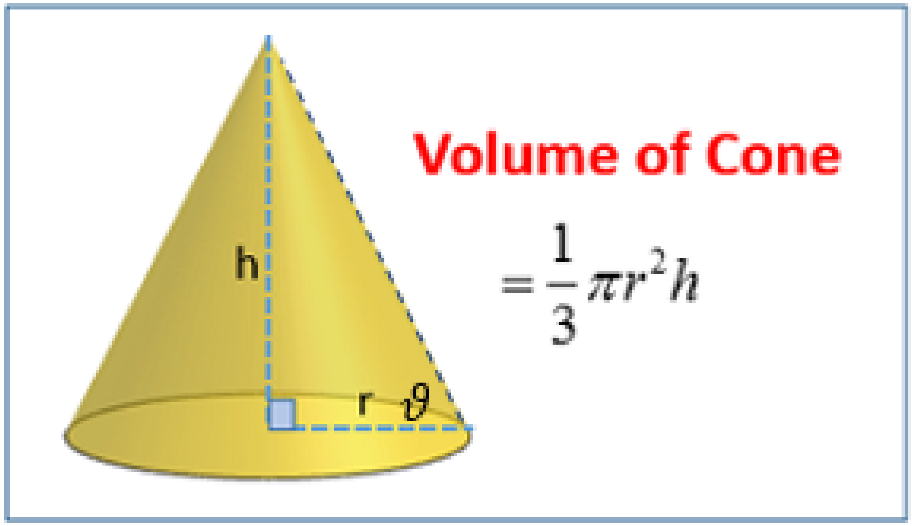
Powder density

The bulk density of a material is the **ratio of the mass to the volume** (including the inter-particle void volume) of an untapped powder sample. The tapped density of powders or granulates is an increased bulk density attained after mechanically tapping a cylinder containing the sample.

$$Hausner\ ratio = \left(\frac{\rho_{tapped}}{\rho_{bulk}}\right)$$

Hausner Ratio	Flow Character	Angle of repose
1.00 – 1.11	Excellent	25 -30
1.12 – 1.18	Good	31 – 35
1.19 – 1.25	Fair	36 – 40
1.26 – 1.34	Passable	41 – 45
1.35 – 1.45	Poor	46 - 55
1.46 – 1.59	Very poor	56 – 65
˃ 1.60	Very, Very poor	˃ 66

- Assume flow property is very poor, and let Cone angle $\vartheta = 60$ degree



$$\tan(\vartheta) = \frac{Conic\ height}{Radius\ of\ chamber} = \frac{2 \times h_{cone}}{D_c}$$

$$h_{cone} = \frac{D_c}{2} \times \tan(\vartheta)$$

$$V_{cone} = \frac{\pi \times D_c^2 \times h_{cone}}{3 \times 4}$$

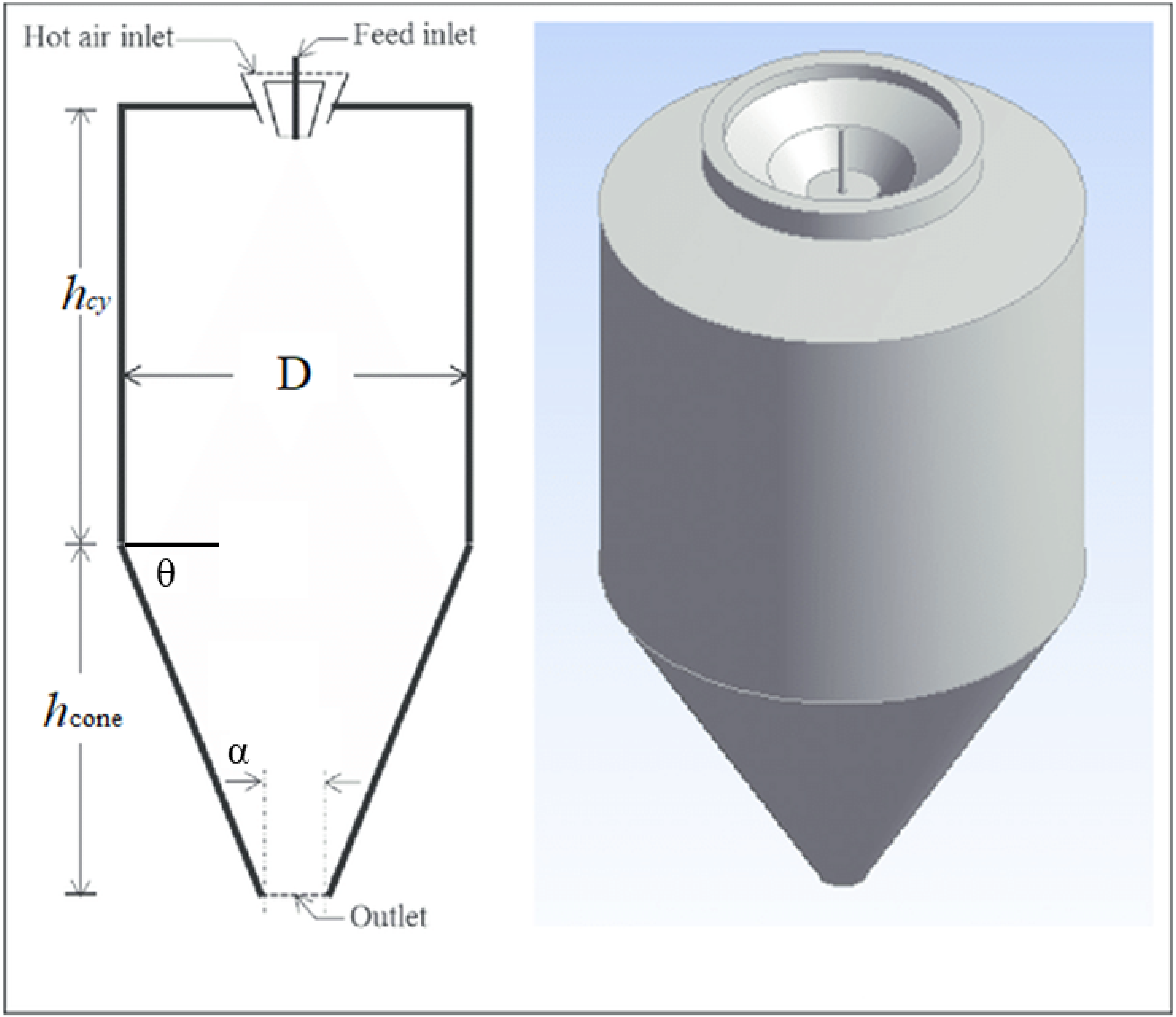
DIMENSION (SPRAY CHAMBER)

It is a cylindrical chamber with a conical bottom.

- Total Volume of chamber ($\mathbf{V_t}$) = $m_a^* V_{avg} t_d$
- Volume of the cylindrical chamber $V_{cy} = \frac{\pi D_c^2 h_{cy}}{4}$

$$V_t = V_{cone} + V_{cy}$$

$$V_{cy} = V_T - V_{cone}$$


Hot air inlet
Feed inlet
h_{cy}
D
θ
h_{cone}
α
Outlet


Thank you