SCALE UP DESIGN OF ROTOCONE VACUUM DRYER

Submitted in partial fulfillment of the requirements of the award of Bachelor of Technology degree in CHEMICAL ENGINEERING

by

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Mr. ANKIREDDY GIRIDHAR (39690001)** AND **R. SUDHAGAR (39690019)**, Who carried out the project entitled **"SCALE UP DESIGN OF ROTO CONE VACUUM DRYER"** under our supervision from July, 2022 to October, 2022.

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Date:

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ABSTRACT

Roto cone Vacuum Dryer is a Batch dryer, designed to reduce the moisture content of Powdered heat sensitive materials. Roto Cone tumble dryers are closed environments and are ideal for active pharmaceuticals, heat sensitive materials and toxic chemicals. They are very efficient in removal of fine moisture in batch operations. They can be sealed and automated for Loading and discharging operations.

This report deals with the scale up design study of 4000 lit RVD. To facilitate doubled production capacity there is a need to increase the dimensions (scale-up) of RVD capacity from 2000 to 4000 lit. Theoretical design calculations of 4000 lit RVD was carried out with respect to mechanical, heating cycle, vacuum cycle and power requirement etc. In order to validate the theoretical design, experimental trials were carried out with chalk powder having initial moisture content of 1% with the available RVD. The study emphasis on reduction of moisture content of chalk powder from 1% to 0.1 %, at 72 °C with vacuum pressure, 550 mm of Hg and 3 hour drying time by capacity of 1200 kg/process. The design aims to scale up, calculation of time, power requirement and to validate the designed values. The methodology was used to redesign the RVD scale up, manufacture component, process parameters, and test performance. The main advantage of scale up is to increase production rate by reducing the number of batches and time for drying a particular quantity. The sizing results on 4000 lit RVD shows following dimensions as a) Diameter 2100 mm b) cylinder height 650 mm c) two cones height 750 mm. The performance test results before and after the RVD scale-up were a) capacity of 4000 l, b) Power requirement 14 Kw, c) RVD rotation speed 7 rpm, d) Time: theoretical- 171 min, Experimental- 195 min**.** The experimental results were matched with theoretical calculated values.

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LIST OF SYMBOLS

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Symbol	Description
Φ	Characteristic moisture content
F	Relative drying rate
N	Drying rate
N_m	Constant-rate period
X	Volume-averaged moisture content
Xcr	Moisture content at the critical point
Xe (X^*)	Moisture content at equilibrium
K	External mass-transfer coefficient
Φm	Humidity potential coefficient
Y_W	Humidity above a fully wetted surface
Y_G	Bulk-gas humidity
X_I	Inlet moisture content
X_O	Outlet moisture
I	*E*nthalpy of the solids or gas plus their associated moisture
G	Gas mass flow rate
A_s	Area of the heat-transfer surface
ΔT_{WS}	Temperature driving force of wall to solid
h_{WS}	Wall-to-solids heat-transfer coefficient
X_1	Initial moisture content
X_2	Final moisture content
t_{CR}	Constant rate of drying time

t_{FR}	Constant rate of drying time
V	Volume
L	Length
D	diameter
Π	Pi
T	Temperature
H	Height
R	Radius
R	Radius
X_{metal}	Thickness of metal
K	Thermal conductivity
H	Heat transfer coefficient
U	Overall heat transfer coefficient
ΔTlm	Logarithmic Mean Temperature difference
A	Area
C_p	Specific heat
Q	Heat
M	Mass
T	Time
Λ	Latent heat
X_C	Critical moisture content
Q	Heat transfer rate
$\dot{m}$	Mass flow rate

LIST OF ABBREVATIONS

ASME	The American Society of Mechanical Engineers
CIP	Clean-In-Place
DVD	Double Cone Vacuum Dryer
EMI	Electromagnetic interference
GAD	General Arrangement Drawing
GMP	Good Manufacturing Practice
HMI	Human Machine Interface
IR	Infrared Radiation
LMTD	Logarithmic Mean Temperature Difference
MOC	Material of Construction
PLC	Program logic Controller
PTFE	Poly Tetra Fluro Ethylene (Teflon)
RCVD	Roto Cone Vacuum Dryer
RHS	Rectangular Hollow Sections
RF	Radio Frequency
RPM	Rotations per Minute
RVD	Rotary Vacuum Dryer
SHS	Square Hollow Sections
SCADA	Supervisory Control and Data Acquisition
VFD	Variable Frequency Drive

Chapter 1

INTRODUCTION

In Chemical engineering Drying is the oldest, most diverse and most common of unit operations. Drying is a mass transfer process of evaporating water or any another volatile solvent from a solid, semi-solid or liquid. In production, before selling or packaging of products, drying is often used as a final step. Here we are interested in one such operation carried out in ROTO CONE VACUUM DRYER.

Roto Cone Vacuum Dryers are indirect drying dryers used for drying all solids from catalyst, polymers to pharmaceuticals and food ingredients. It is cost effective, high energy efficient and environment friendly.

The Roto cone vacuum dryer is a batch operation under vacuum used for Drying of solids or powder. In the batch operation, raw material charged is heated indirectly and simultaneously undergoes rotary motion of the cone assembly. The dryer conical shape ensures the heat media, hot liquid, circulation efficiently. Drying of water or any other volatile liquid takes place when heat transferred from outer cone through jacket, and vacuum is applied in the inner cone. The drying operation is built on the principle that water or other volatile product moves from a region of low pressure. The vapor pressure is achieved by heating the product to drying temperature of the absorbed or free liquid is sucked by vacuum or purging with Nitrogen. Hence, the necessary conditions for effective drying are attained by uniform heat transfer throughout the batch and quick removal of the vapor. The applied vacuum control throttling was achieved through PLC.

These dryer is used for drying of products that are damaged especially by high temperatures and materials having special features such as simply oxidized, volatile compounds, toxic dust and strong irritants.

The low rotational speed of the dryer makes them ideal for friable and delicate solids such as macromolecules, crystals, or solids that are agglomerated. The cone shaped vessel has simplified the complete discharge of friable materials.

Because Roto Cone tumble dryers have no agitator or shaft seals and only one seal on the vacuum line, cross-contamination is minimized and inspection and cleaning are simplified. It is very economical by total solvent recovery.

Roto Cone tumble dryers are closed environments and are ideal for active pharmaceuticals and toxic chemicals. They can be sealed and automated for Loading and discharging operations.

Chapter 2

DRYING

Drying is the process of yielding solid product by evaporating volatile materials, normally water. Drying is considered as mass transfer and heat transfer process. Heat is consumed to evaporate water in drying. The drying process consumes significant amount of heat energy which is generally equal to latent heat of vaporization of water, 2500 J/g. Simultaneously, the material will evaporate and leave the system either by diffusion and/or convection.

While designing and operating a dryer there are other concerns besides Heat transfer and mass transfer. The quality of product such as color, particle density, hardness, texture, flavor, etc. is also very strongly influenced by the drying conditions and the physical and chemical transformations occurring in the dryer. The measurement and/or calculation for designing and understanding the drying process involves the following:

1. Mass and energy balances
2. Thermodynamics
3. Mass- and heat-transfer rates
4. Product quality considerations

The below section describes how these aspects are calculated and measured and how the info is used in engineering application.

2.1 MOISTURE TRANSPORT MECHANISMS WITHIN SOLIDS

Different Mechanisms by which moisture moves to the surface of material in drying are

- *Diffusion of moisture through solids*:. Diffusion is a molecular process, brought about by random wanderings of individual molecules. If all the water molecules in a material are free to migrate, they tend to diffuse from a region of high moisture concentration to one of lower moisture concentration, thereby reducing the moisture gradient and equalizing the concentration of moisture.
- *Convection of moisture within a liquid or slurry*:. Drying of a flowable solution into a solid makes liquid motion within the material brings wetter material to the surface.
- *Evaporation of moisture within a solid and gas transport out of the solid by diffusion and/or convection:* Within a solid if it is boiling or porous evaporation can occur. Subsequently vapor from the sample must move out.
- *Capillary flow of moisture in porous media*: The flow of liquid in porous media by capillary action is due to the reduction of liquid pressure within small pores due to surface tension forces.

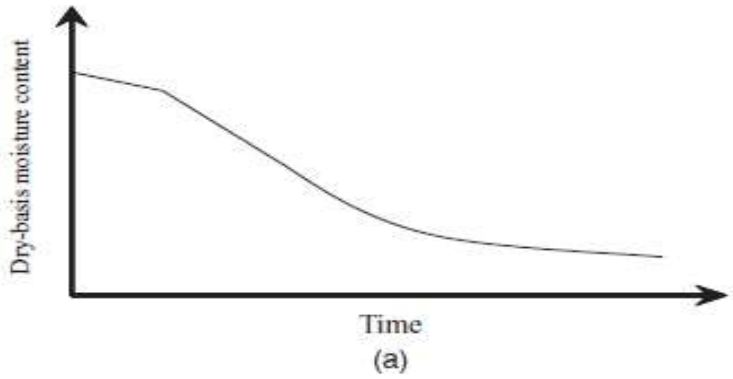
2.2 KINETICS OF DRYING

The rate of drying of drying is discussed in this section. The drying kinetics commands the size of drying equipment, which straightly affects the operating and capital costs of a process involving drying. The drying rate can also impact the dried product quality as other phenomena can occur simultaneous, such as shrinkage due to moisture loss and heat transfer.

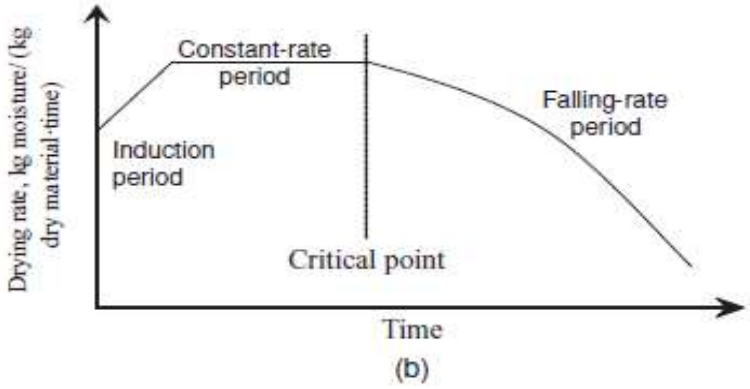
2.2.1 Drying Curves and Periods of Drying The Drying curve provides most basic and vital kinetic data on drying. A drying curve defines the drying kinetics and how they vary during drying. The drying curve is affected by the size or thickness of the drying material, material properties and drying conditions. This section describes, the drying curves general characteristics and its uses. To obtain drying curves using experimental techniques are disclosed in the “Experimental Methods” section and

drying curves uses for scale-up are discussed in “Dryer Modeling Design and Scale-up.”

Several representations of a typical drying curve are shown in Fig. 2-1. The plot in Fig. 2.1*a,* is the moisture content (on dry basis) vs time. The plot in Fig. 2.1*b,* is rate of drying as a function of time, the derivative of fig. 2.1a plot. The plot in



(a)



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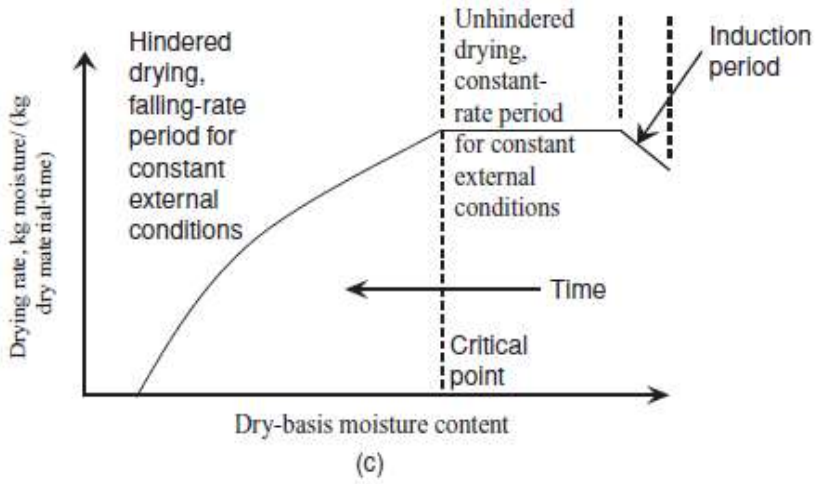


Fig. 2.1 Several common representations of a typical drying curve

Fig. 2.1*c,* is rate of drying as affected by the drying material average moisture content. As time passes the material loses moisture, the movement of time in the plot Fig. 2.1c is from right to left.

The different periods of drying show some salient features of the drying curve show. These periods in the drying curve are common, but not all periods occur in every drying process. The first period of drying where material is being heated early in drying is called the induction period. The constant rate period or second period of drying is where the surface remains sufficiently wet to keep the vapor pressure of water on the surface. When the surface dries sufficiently, the rate of drying decreases and the falling-rate period happens. This period can also be stated as *hindered drying.*

Figure 2-1 describes the critical point as the changeover between constant-rate and falling rate periods of drying. At this changeover the *critical point* refers to the average moisture content of a material. The drying curves examples are shown in sections below and the phenomena that give rise to common shapes.

2.2.2. Characteristic Drying Rate Curve concept: During the falling rate period, the rate of drying curves, often show the same shape for a specific material. (Figs. 2.2 and 2.3), to facilitate drawing of a single characteristic drying rate curve for the material being dried. Strictly speaking, the concept should

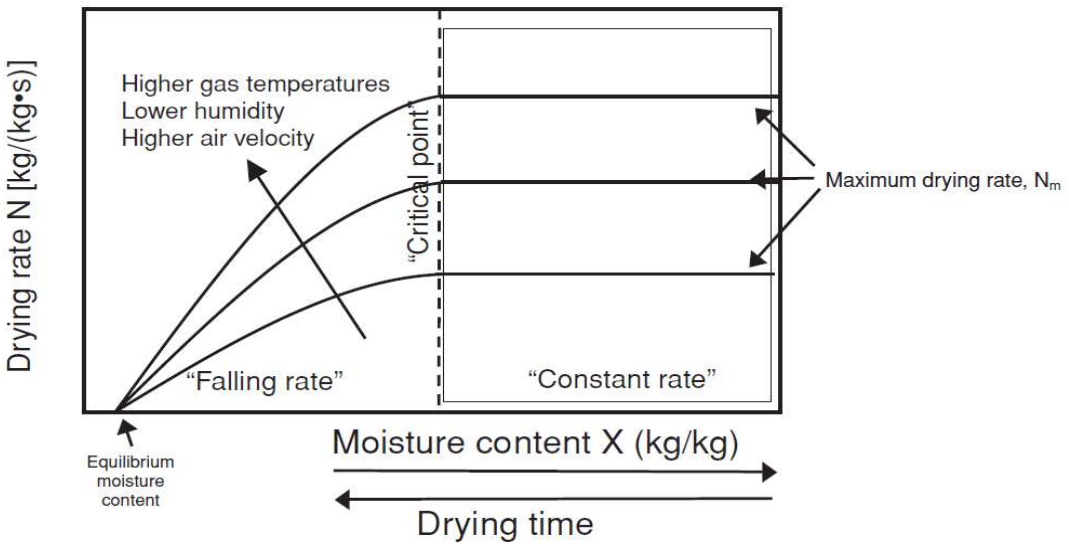


Fig. 2.2 Drying curves for a given material at different constant external conditions.

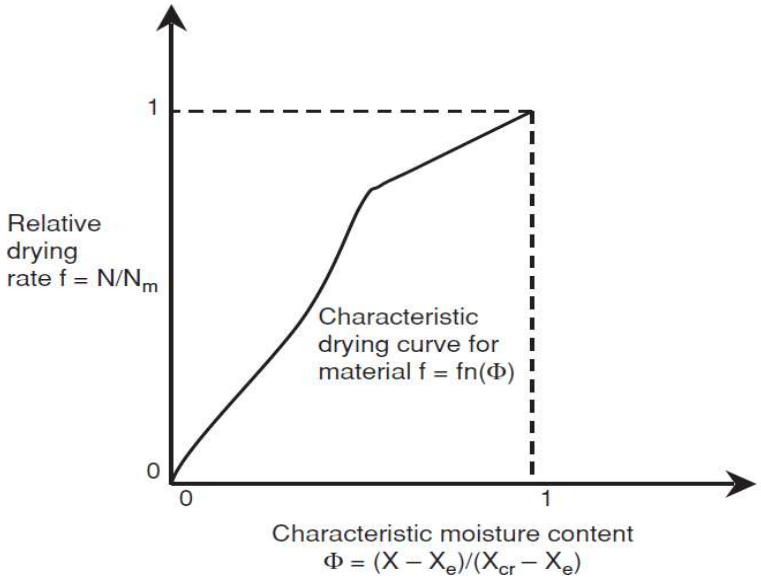


Fig.2.3 Characteristic drying curve.

only apply to materials of the same specific size (surface area to material ratio) and thickness, but some evidence shows that concept can applied for rather wider range with reasonable accuracy. A linear falling rate curve is a often a good reasonable approximation for the form of the characteristic function, in the absence of experimental data/ (good approximation for fair for ion-exchange resin, silica gel, milk powder). At the first drying period the each volume averaged , free moisture

content, is assumed that there is a corresponding specific rate of drying to the un-hindered drying rate is independent of the external drying conditions. *Volume-averaged* is not just rather the distance but averaging over the volume (distance cubed for a sphere). The relative drying rate is defined as

$$f = N/N_m \qquad (2\text{-}1)$$

where N - drying rate, N_m - rate in the constant rate period, and the characteristic moisture content becomes

$$\Phi = \frac{X - Xe}{Xcr -} \qquad (2\text{-}2)$$

Where, X - volume averaged moisture content, Xcr - moisture content at the critical point, and Xe - at equilibrium. Thus, the drying curve is normalized to pass through the points(1,1), and (0,0) i.e. critical point of transition in drying behavior and at equilibrium respectively.

This representation for the drying rate in falling rate period leads to a simple lumped-parameter expression, namely,

$$N = f\,N_m = f\,[k\,\varphi_m(Y_W - Y_G)] \qquad (2\text{-}3)$$

Here k - external mass-transfer coefficient, φm - humidity potential coefficient (corrects for the humidity not being a strictly true representation of the driving force; close to unity most of the time), Y_W -humidity above a fully wetted surface, and Y_G - bulk-gas humidity. For understanding the performance of industrial drying plants due to its simplicity and the separation of the parameters that effect the drying process, basis equation (2-3) is widely used. The material itself *f,* the process conditions $\varphi_m(Y_W - Y_G)f$ *and* the design of the dryer k.

However, the characteristic drying curve, is obviously a gross approximation. A common drying curve will be found only if the volume-averaged moisture content imitates the moistness of the surface in some fixed way.

2.3 EXPERIMENTAL METHOD

In drying research, Lab-scale, pilot-scale, and plant-scale experiments all play important roles. For studying product characteristics and physical properties, Lab-scale experiments are often necessary; In proof-of-concept process tests and to

generate larger quantities of sample material, pilot-scale experiments are often used; and to analyze processing problems and to start or change a full scale process. plant-scale experiments are often needed.

2.3.1. Drying Curves Measurement: It is difficult to use experimentally measured drying curves. Naturally, this is a 3-step process. The first step is sample collection at different time intervals of drying, the second step is sample analyzation of all samples for moisture, and the third step is data interpretation to make process conclusions.

Based on the type of dryer, solid sample collection techniques rest on. Since the curve for drying is the moisture content vs time, it must be likely to attain material before the completion of drying process. When sampling drying curve for a material, the several important considerations are:

1. The sampling process desires to be fast comparative to the drying process. Drying taking place after or during sampling can yield misleading results. Samples must be closed prior to analysis. Plastic bags don't afford sufficient seal.
2. In heterogeneous samples, to represent the compositon of the mixyture accurately the sample must be large enough.

Table 2.1 outlines some sampling techniques for various dryer types.

Dryer type	Sampling method
Fluid bed dryer	Sampling cup
Sheet dryer	Collect at end of dryer. Increase speed of change the drying time.
Tray dryer	Record initial moisture and mass of try with time.
Indirect dryer	Decrease residence time with higher flow rate and sample at exit.
Spray dryer	Residence time of product is difficult to determine and change. Special probes have been developed to sample partially dried powder in different places within the dryer (Ref. Langrish)

For the collection and interpretation of drying data, moisture measurement techniques are critical. The crucial message of this section is that the value of moisture obtained almost definitely depends on the technique of measurement and that when measuring moisture, it is important to have a *consistent technique*. Table 2-2 contrasts and compare some different techniques for measurement of moisture.

The most shared method is gravimetric, loss-on-drying. A sample taken in pan or tray is weighed and placed into an heater or oven at approximately high temperature for a given length of time. After drying sample is weighed again. The weight difference obtained is assumed to be owing to the evaporation of water completely from the sample. The drying time, sample size and temperature, and are all important factors. In the given time, a very thick or large sample may not dry fully; a little sample may not correctly represent the composition of a mixed sample. The temperature too effect the performance of drying as low temperature can lead to incomplete drying of sample, but high temperatures can burn the sample, causing an affectedly high loss of mass.

Generally, samples(solid) are collected as described, nevertheless in some experiments, it is more appropriate to measure the humidity change of the air owing to drying. This technique is more common in lab scale equipment than pilot scale or plant scale equipment and requires a decent mass balance of the system.

Table 2.2. Moisture Determination Techniques

S.No	Method	Principle	Advantages	Disadvantages
1.	Gravimetric (loss on drying)	Water evaporates when sample is held at a high temperature. Difference in mass is recorded	Simple technique. No extensive calibration methods are needed. Lab equipment's is commonly available.	Method is slow. Measurement time is several minutes to overnight (depending on material and accuracy). Generally, not suitable for process

				control. Doesn't differentiate between water and other volatile substances.
2.	IR/NIR	Absorption of infrared radiation by water is measured.	Fast method. Suitable for very thin layer or small particles.	Only surface moisture is detected. Extensive calibration is needed.
3.	RF/Microwave	Absorption of RF or microwave energy is measured.	Fast method. Suitable for large particles.	Extensive calibration is needed.
4.	Equilibrium relative humidity (ERH)	The equilibrium relative humidity headspace above sample in a closed chamber is measured. Sorption isotherm is used to determine moisture.	Relatively quick method. Useful particularly if a final moisture specification is in terms of water activity (to retard microorganism growth)	May give misleading results since the surface of the material will equilibrium with the air. Large particles with moisture gradients can give falsely low readings. Measurement of relative humidity can be imprecise.
5.	Karl Fischer titration	Chemical titration that is water specific. Material can be either added	Specific to water only and very precise. Units can be	Equipment is expensive and requires solvents. Minimal calibration

		directly to a solvent or heated in an oven, with the headspace purged and bubbled through solvent.	purchased with an autosampler. Measurement takes only a few minutes.	required. Sample size is small, which may pose a problem for heterogeneous mixtures.

2.3.2. Performing a Mass and Energy Balance on a Large Industrial Dryer: To evaluate the system operating condition and for knowing additional capacity available it is often necessary to understand the measuring of mass and energy balance on a large dryer. This evaluation can also be used to debug and detect gross problems, such as product buildup and leaks. In this process the several steps are

1. Draw a rough diagram of the overall process with all the flows of mass out and into of the system. Check the system for the places where air leaks out or in. Physically walking around the equipment is the best way to get this information.
2. Decide on the envelope for the mass and energy balance. Some dryer systems have steam heating systems or combustion and/or hot-air recycle loops. To understand the dryer operation these may not be necessary to include.
3. Decide on places to measure temperatures and airflows and to take product and feed samples. Such measurements are often not equipped for drying systems and other process equipment; the system may require slight modification, for instance humidity tubes or ports installed into pipes for pitot tubes. The probe must not leak when ports are placed.
4. Take the proper measurements and compute the mass and energy balances.

The measurements are outlet and inlet temperatures, humidity's, and flow rates of the air outlets and inlets as well as the temperature and moisture of the dry and feed solids. The following measurement methods for each are

- *Airflow Rate:* Measurement of this is often the most difficult. For blowers though the fan curves are available but they are not constantly reliable. For measurement of local velocity a small pitot tube is used. Pitot tube's best location to use is in a straight section of pipe. It is advisable to measure the cross section of the pipe or duct at multiple positions, particularly near elbows or in laminar flow and other flow disruptions.
- *Air Temperature:* In most cases a simple thermocouple is used, but special care must be taken for wet or sticky material in some cases, as it may build up on the thermocouple. Low temperature will yield by a wet thermocouple due to evaporative cooling.
- *Air* Humidity: Calibration of humidity probes is needed before use, and the absolute humidity or both the relative temperature and humidity needs to be logged. If the temperature of probe is lower the dew point of the air in the process, then on the probe condensation will occur until the probe heats.
- *Feed and Exit Solids Rate:* Particularly for a unit in production, they are generally known. By using a bucket and stopwatch Liquids can be measured. Solids can be measured in a variety of ways.
- *Feed and Exit Solids Moisture Content:* As described above, using appropriate technique these are measured. For both the exit and feed solids the same method is used. For feed moisture data do not rely on formula sheets

2.4 CLASSIFICATION OF DRYERS

There is several ways for classification of Drying equipment. For selection of the most suitable dryer for the task and in understanding the important principles on which it operates an effective classification is vital. The main types are as follows:

1. Form of feed and product—particulate (solid or liquid feed), sheet, slab
2. Mode of operation—batch or continuous

3. Mode of heat transfer—convective (direct), conductive (indirect), radiative, or dielectric
4. Condition of solids—static bed, moving bed, fluidized or dispersed
5. Gas-solids contacting—parallel flow, perpendicular flow, or through-circulation
6. Gas flow pattern—cross flow, co-current, or counter-current

The drying system other important features are use of gas or solids recycle, the type of carrier gas (air, inert gas, or superheated steam/solvent), operating pressure (atmospheric or vacuum) and type of heating (indirect or direct-fired). Though, these are primarily linked to the choice of the operating conditions and overall system, not to the individual dryer used. The different categories relative importance depends on the purpose of the classification. Dryer design, construction, and operation, are differentiated in categories 2 and 3 are particularly useful. In Figs. 2.4 and 2.5, Basic diagrams for batch and continuous dryers are revealed respectively. Though, in the selection of a set of dryers for preliminary attention in a given drying problem, the most key factor is frequently category 1, the form, physical properties and handling characteristics of the wet material.

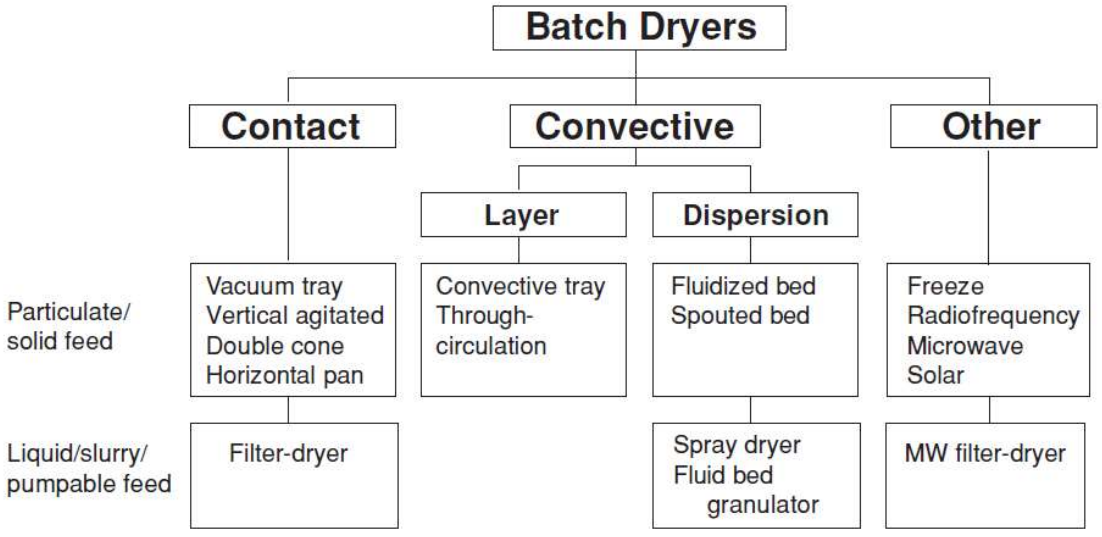


Fig.2.4 Batch dryers classification

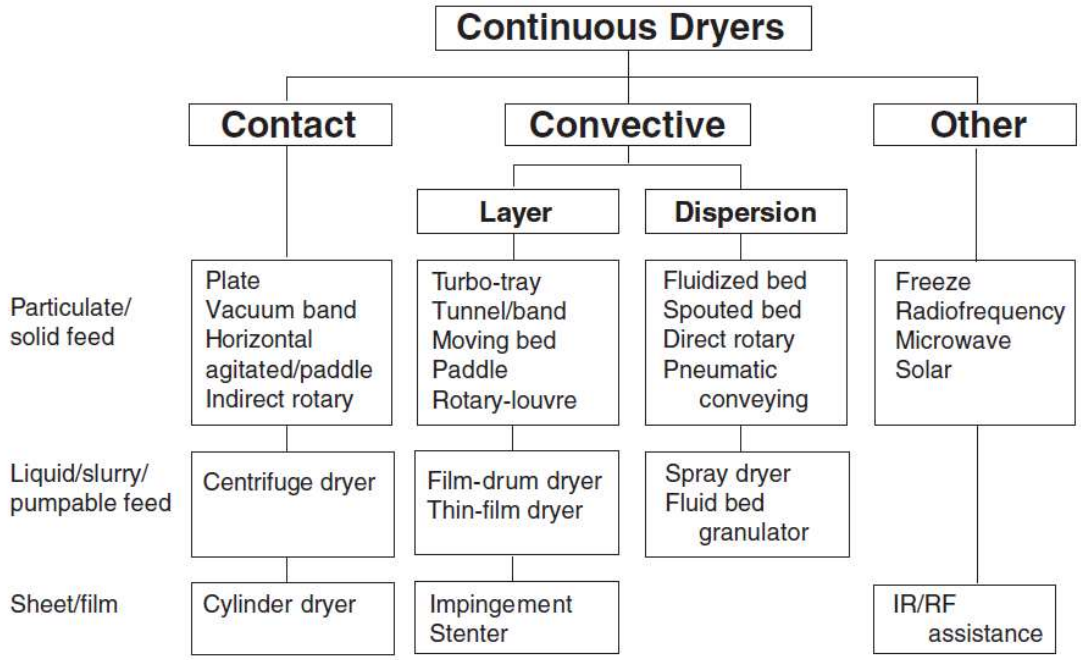


Fig. 2.5 Continuous dryers classification

The feed category is a very primary description; *particulate* can also contain powders, pellets, pastes, granules, performs, etc.; slurry/liquid also includes sludges and solutions.

2.5 SELECTION OF DRYING EQUIPMENT

Dryer Selection Considerations: It is a challenging task and rarely clear-cut for selection of dryer. There may be several different dryer types for 500-μm particles, which are possible to handle the task well, at parallel cost. There may be no dryers for 5-μm particles, that are fully appropriate, and the duty is to find the “least bad”!

The board choices of suitable equipment can be revealed with the help of dryer classification. For instance:

- Batch dryers are nearly invariably used for mean quantities below 50 kg/h and continuous dryers above 1 ton/h; in the intervening range, any may be suitable.
- Slurry or liquid feeds, continuous sheets and films, or large artifacts need completely diverse equipment to particulate feeds.

- Powders and particles below 1 mm are successfully dried in contact or dispersion dryers, but maximum through-circulation units are inappropriate. On the other hand, for particles of several millimeters or above, rotary dryers, spouted beds and through circulation dryers are very appropriate.
- Dispersion convective dryers (including fluidized-bed, rotary, and pneumatic types) and Through-circulation dryers, and rotary or agitated contact dryers, normally give healthy drying rates than contact tray dryers or non-agitated cross-circulated.
- For fragile particles where it is wanted to avoid attrition, non-agitated dryers (including through-circulation) may be desirable.
- For solids, or organic solvents which are toxic, highly flammable, or decompose easily, contact dryers are frequently desirable to convective, as it is easy to control environmental emissions and the containment is better. A closed-cycle system using an inert carrier gas (e.g., nitrogen) is often needed, if a convective dryer is used,
- For heat-sensitive materials, vacuum, Cocurrent, and freeze dryers can be particularly appropriate.

The procedure given here in a simple step- by- step.

1. *Initial selection of dryers: F*or handling the wet material and the dry product choice those dryers which is best suited and fit into the continuity of the process as well as producing a product of the desired physical properties. This initial selection can be made based on the materials handled by the various types of dryers.
2. *Initial comparison of dryers:* Selected dryers should be evaluated nearly from performance data and available cost. From this assessment, those dryers which appear to be inappropriate or inefficient from the standpoint of performance should be rejected from further consideration.
3. *Drying tests:* Drying tests should be carried out in those dryers still under thought. The optimum operating conditions and the product characteristics will be determined by these tests and based on these results a firm quotations are formed for equipment vendors.

4. *Final selection of dryer:*. Based on the outputs of the quotations and drying tests, the final choice of the most appropriate dryer can be made. In the preliminary selection of a dryer the following the important features are considered:
    - Properties of the material being handled
        a. Physical characteristics when dry
        b. Physical characteristics when wet (adhesiveness, stickiness, flowability, cohesiveness)
        c. Flammability
        d. Corrosiveness
        e. Abrasiveness
        f. Particle size
        g. Toxicity
    - Drying characteristics of the material
        a. Moisture type (unbound, bound, or both)
        b. Moisture content intially(maximum and range)
        c. Moisture content finally (maximum and range)
        d. Allowable drying temperature
        e. Feasible drying time for different dryers
        f. Non-water volatiles level
    - Flow of material to and from the dryer
        a. Batch or Continuous operation
        b. Quantity to be handled per hour (or batch size and frequency)
        c. Process subsequent to drying
        d. Process prior to drying
    - Product quality
        a. Contamination
        b. Shrinkage
        c. Over drying
        d. State of subdivision
        e. Uniformity of final moisture content
        f. Decomposition of product

g. Bulk density

h. Temperature of product

- Recovery problems
  - *a.* Recovery of Dust
  - *b.* Recovery of solvent
- Facilities available at site of proposed installation
  - *a.* Humidity, Temperature, and cleanliness of air
  - *b.* Space
  - *c.* Available electric power
  - *d.* Available fuels
  - *e.* Exhaust-gas outlets
  - *f.* Vibration, Permissible noise, dust, or heat losses
  - *g.* Source of wet feed

The nature of material handled is the basic property for choice of the dryer. For example a slurried material may opt for different dryer than that of a wet coarse solid, which in turn has different dryer for sheet material.

Following primary choice of choosing appropriate dryers, a approximate estimation of the cost and size has to be determined to eliminate the inefficient one. When sufficient data is not available, the user can approach the equipment manufacturer for primary cost and performance data. While comparing the performance of a dryer, the features in the list above should be properly studied so that the dryer performance is not affected. The steps in the process for simplifying or eliminating should not affect the operations that follow drying, such as filtration, grinding etc.

2.6 DRYER MODELING, DESIGN, AND SCALE-UP

General Principles Models and calculations on dryers can be categorized in terms of (1) the level of complexity used and (2) the purpose or type of calculation (design, performance rating, or scaleup).

Levels of Dryer Modeling can be carried out at four different levels, depending on the amount of data available and the level of detail and precision required in the answer.

Level 1. *Heat and mass balances*: These balances give information on the material and energy flows to and from the dryer but say nothing about the required equipment size or the performance which a given dryer is capable of.

Level 2. *Scoping:* Approximate or scoping calculations give rough sizes and throughputs (mass flow rates) for dryers, using simple data and making some simplifying assumptions. Either heat transfer control or first-order drying kinetics is assumed.

Level 3. *Scaling:* Scaling calculations give overall dimensions and performance figures for dryers by scaling up drying curves from small-scale or pilot-plant experiments.

Level 4. *Detailed:* Rigorous or detailed methods aim to track the temperature and drying history of the solids and find local conditions inside the dryer. Naturally, these methods use more complex modeling techniques with many more parameters and require many more input data.

***Types of Dryer Calculations*:** There are three types of computation methods for designing a new dryer or improving the efficiency of an existing one.

- New dryer design performance cycle data and processed using the process flowsheet and physical properties data sheet.
- For new set of process conditions the Performance of the present dryer is calculated.
- Scale-up from laboratory-scale or pilot-plant experiments to a full-scale dryer

A dependable model for drying of solids in the falling rate period which actually determines the total drying time is difficult. The kinetics of the said period mainly depends upon movement of internal moisture within a solid. This is highly dependent on the internal structure, which in turn varies with the upstream process, the solids formation step, and often between individual batches. The key parameters of solids drying will not able to derive from theory alone or using any physical properties data. Therefore, experimental data is required. It also helps to design and scale up of a dryer exactly and more dependable than the design based

on thermodynamic data. The experiments are very useful in certifying the theoretical model and also provide necessary data for calculating the non measureable parameters. It is also helps in designing models more accurately.

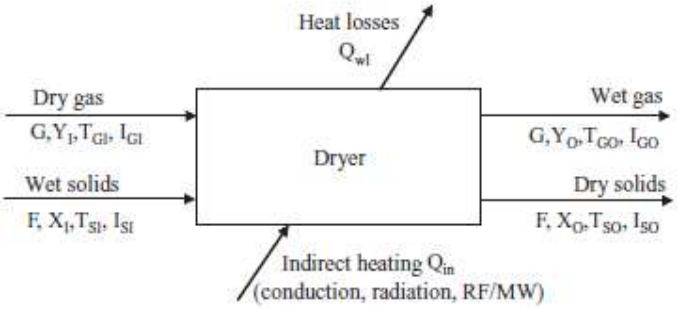


Fig. 2.6. Heat and material flows around a continuous dryer.

Heat and Mass Balance: Fig.2.6 represents the mass and heat balance process diagram of continuous dryer with parameters on dry basis.

Mass Balance: The mass balance generally done on the main solvent. The rate of evaporation is given as E(kg/s). the evaporation rate of vacuum or contact dryer is nearly equal to the vapor flow at exhaust, expect for any non-condensable gas. Where as for contact dryers it is equal to increased humidity at exhaust. At steady state rate of evaporation expression for continuous dryer is given as

$$E = F\,(X_I - X_O) = G\,(Y_O - Y_I) \qquad (2.4)$$

Assuming that flows of dry gas(G) and dry solids(F) doesn't vary between the dryer input and output. Sometimes the mass balance is also carried out on solids and gas. These allows us to check for any gas leaks during process or any entrainment of solids to the exhaust in the process.

During the scale-up or design calculations, flow rate of solids, inlet moisture contentand outlet moisture content(X_I) is required. The rate of evaporation and outlet gas are computed. During the performance, the process is reverse i.e. evaporation rate is calculated for existing conditions and thereafter solids quantity and final moisture of solids are back computed.

The instantaneous rate of drying at any point during drying in batch dryer with m as mass of dry solids is given as

$$E = m\left(\frac{-dX}{dt}\right) = G\,(Y_O - Y_I) \qquad (2.5)$$

Heat balance: for continuous dryer the expression in the form

$$GI_{GI} + FI_{SI} + Q_{in} = GI_{GO} + FI_{SO} + Q_{wl} \qquad (2.6)$$

Where, I - enthalpy (kJ/kg dry material) (solids, moisture present in solids and gas). Enthalpy of the gas includes the latent heat term for the vapor. Expanding the enthalpy terms gives

$$G(C_{sI}T_{GI} + \lambda_{YI}) + F(C_{PS} + X_I C_{PL})T_{SI} + Q_{in} = G(C_{SO}T_{GO} + \lambda_{YO}) + F(C_{PS} + X_O C_{PL})T_{SO} + Q_{wl} \qquad (2.7)$$

Here C_s is the humid heat $C_{PG} + YC_{PY}$. The equation of batch dryer given as

$$GI_{GI} + Q_{in} = GI_{GO} + m\frac{d\mathrm{ls}}{dt} + Q_{wl} \qquad (2.8).$$

Scoping Design Calculations Without any experimental data or drying curve, the sizing of dryer and time for drying can be found using scoping computing based on mass and heat balance. These calculations allows to determine almost accurately the surface area required for convective dryers and Volume for batch dryers, but the not exact for determining other data.

Continuous Convective Dryers during designing, the essential solids quantity F and with known initial and final moisture X_I and X_O respectively, as is the ambient humidity Y_I. The conditions of oulet gas (temp. T_{GO} and hum. Y_O) is found either by calculating with the chosen inlet gas temp. or with the help of Psychometric chart. 10% to 20% enthalpy reduced will be there due to heat losses and sensible heat absorbed by solids and some heat also lost during breaking the bonds for removal of bound moisture. Now that the gas mass flow, G, can be calculated using mass balance equation [Eq. (2.5)]. A typical gas velocity U_G along the dryer is now chosen, for example, 20 m/s for a flash dryer, 0.5 m/s for a fluidized bed, and 3 m/s for a co-current rotary dryer. Cross-sectional area A for through-circulation and dispersion dryers, is

$$A = \frac{G}{\rho_{\mathrm{GI}} U_G} = \frac{F(X_1 - X_0)}{G_I U_G (Y_0 - Y_1)} \qquad (2.9)$$

The calculated area, A, provides the platform of determining the diameter of dryer , or rectangular bed linear sizing. The outcome accuracy may be approximately equal to 10% can then be calculated and can be improved further by good approximations of heat losses and velocity. During the performance, gas flow rate is found by reversing the equation, $G = \rho_{Gl} U_G A$.

The above procedure doesn't provide any data about dryer dimensions or drying time of solids. Calculating the minimum time for drying is calculated for maximum drying rate, *Ncr with assumption* of gas phase heat transfer control and guessing appropriate heat transfer co-efficient for gas to solid. The t_{min} equation given as

$$t_{min} = \frac{X_1 - X_0}{N_{cr}} \tag{2.10}$$

Alternative assumption is that the whole process of drying time can be calculated using Eq. (2.13) for first order falling rate. It is recommended to measure the drying time experimentally.

Continuous Contact Dryers The controlling factor is surface area available for heat transfer. The design equation is found using

$$A_S = \frac{Q}{h_{WS}\,\Delta T_{WS}} = \frac{E\lambda_{ev}}{h_{WS}\,\Delta T_{WS}} = \frac{F(X_I - X_O)\lambda_{ev}}{h_{WS}\,\Delta\, T_{WS}} \tag{2.11}$$

Where, *Q- heat transfer rate between wall and solids*

ΔT_{WS} – temperature difference between outside the wall and solids inside dryer or driving force

λ_{ev} – latent heat of evaporation of volatile liquid, solids and vapor to required temperature.

h_{WS} - heat transfer co-efficient between the solid and wall

Here, the controlling factor is again the rate of heat transfer.

If the falling rate period of drying is dominating factor, then the kinetics used to calculate the residence time of solids in dryer for the given surface area, A_s, is not sufficient to get the required moisture content. Once more it is suggested for experimental drying curve.

Batch Dryers: By fixing the batch size, the dryer dimensions and volume of the dyer that contains the solid material for drying can be calculated. The residence time for drying the solids is calculated using the formula

$$t_{CR} = \frac{m_s(X_I - X_O)\lambda_{ev}}{h_{WS}\Delta T_{WS}A_S} \tag{2.12}$$

The following are assumed, controlled rate of heat transfer and rate of constant drying. Drying calculation for falling rate will be wrong unless proper scaling was not developed using the drying curve. we can compare the surface area to volume ratios of various dryers and can derive the data to compare the drying times with each other.

Falling-Rate Kinetics: In the hindered drying, the constant rate time (t_{CR}) for drying is corrected to the first order kinetics of falling rate using the following equation,

$$\frac{t_{FR}}{t_{CR}} = \frac{X_1 - X_E}{X_1 - X_2} \ln\left(\frac{X_1 - X_E}{X_2 - X_E}\right) \tag{2.13}$$

Where X_1, X_2 and X_E are intial, final and equilibrium moisture content respectively. Falling rate time is always greater or equal to constant rate time $t_{FR} \geq t_{CR}$. The equation for combining both constant rate period, ending at X_{cr} and falling rate period with first order kinetics, starting at X_{cr} and ending at X_E is

$$\frac{t_{2S}}{t_{CR}} = \frac{X_1 - X_{cr}}{X_1 - X_2} + \frac{X_{cr} - X_E}{X_1 - X_2} \ln\left(\frac{X_{cr} - X_E}{X_2 - X_E}\right) \tag{2.14}$$

Where, X_{cr} is critical moisture content.

Scale-up Effects: If the scale up the dryer volume increases, which is either controlled by constant rate drying heat transfer or following the proportionality of first order kinetics of falling rate from the characteristic drying curve then then the drying rate *N* (kg/kg/s) and drying time *t* will be proportional to the ratio between the area over which heat enters and the mass or volume of solids.

For Dryers of all types the specific drying rate is constant for the set of conditions which is nothing mass flux or evaporation rate per unit area. Thus the convective dryers, fluidized bed dryers and contacts dryers drying time remains same as long as the depth of layer solids remain constant i.e. with increase in volume doesn't effect the drying time. But for rotary or agitated(mechanical) dryers the surface area of heat transfer increases the square of dryer diameter and volume as cube. Therefore, time for drying increases by cube root of batch.

$$\frac{t_2}{t_1} = \left(\frac{m_2}{m_1}\right)^{1/3} \tag{2.15}$$

Taking into considerations of above points Roto cone Vacuum dryer (RVD or RCVD) has been chosen for drying of materials which cannot resist high temperature, material which are easily oxidized, volatile materials which should be retrieved, materials strong irritant and poisonous in nature

Chapter 3

ROTO CONE VACUUM DRYER

Roto cone vacuum dryer drying operation is a batch type. Here, the batch raw material charged is indirectly heated while undergoing simultaneous rotary motion of the cone assembly. The conical shape of the dryer confirms efficient circulation of hot liquid heating media. Drying takes place when heat is transferred from outer cone jacket to inner cone and vacuum application to the inner cone. The principle of drying operation is based on that, the water or other volatile material moves from a zone of low pressure. The product to be dried in warmed to raise the vapor pressure of the free liquid or absorbed by vacuum or by sweeping it with Nitrogen. Hence the necessary conditions for actual drying are attained by uniform heat transfer throughout the batch and rapid removal of the vapor. The applied vacuum is controlled with PLC by throttling valve.

Roto cone vacuum dryer is appropriate for drying of materials which cannot with stand high temperature or heat sensitive materials such as materials that are easily oxidized, poisonous in nature, volatile materials which should be retrieved and materials strong irritant. The roto cone dryer with advanced technology combines during operation under vacuum. The roto cone vacuum dryer enables improved drying efficiency, low temperature operation and economize the process by total solvent recovery. IcGMP based working helps in achieving optimum dust control, while offering advantages of efficient charging and discharging of materials of RVD. The drying unit initially breaks large lumps using equipped lump breakers and subsequently powders them. The reduced drying time and a lump free product is obtained with rotary action of dryer together with mechanical action of the breakers.

3.1 MATERIAL OF CONSTRUCTION:

All Contact Parts are usually SS316 Or Higher Grade, and Non Contact Parts are SS304 (Or Mild Steel in case of Non-GMP set up). Incase of Highly Corrosive chemicals, the Contact Parts are recommended to be Hastelloy (C22 Or C276), Or Halar PU Coated SS304 or Coated SS304.

Fig. 3.1 Photograph of Roto cone Vacuum Dryer.

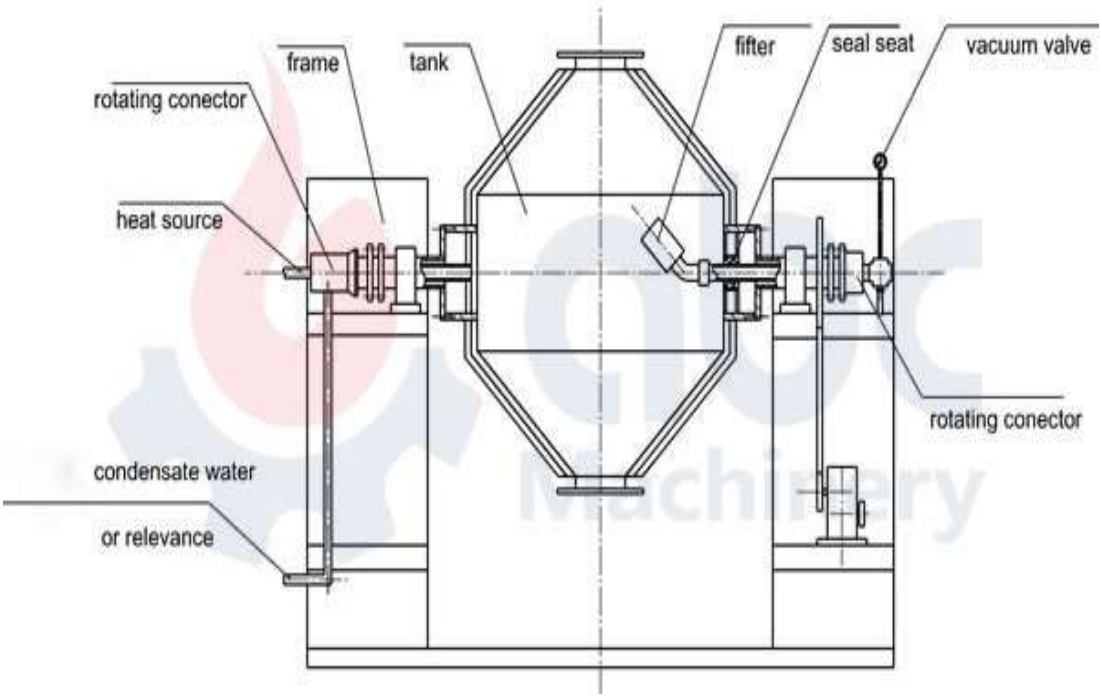


Fig. 3.2 Roto cone vacuum dryer

3.2 SURFACE FINISH

The contact surface of product needs to be very smooth as per GMP (Good Manufacturing Practice) guidelines. This also helps in avoids formation of electrolytic cell formation owing to the surface corrosion. Thus, Mirror Finish of minimum 240 grit for product contact surface generally, and 180 grit matt finish for non-contact surface. For cases of a Non-GMP set up, the surface is either epoxy coated or painted with protective layer,if Mild Steel is used (for Product Non-Contact in some cases).

3.3 OPERATION PRINCIPLE

During the roto cone vacuum dryer operation product is dried by creation of a vacuum. Thus the pressure decreases around the product to below the water vapor pressure thereby resulting in reducing product water boiling point. The product water evaporates and enhances rate of drying of the product. The process is also carried out under low relative humidity for improved drying.

3.4 MAJOR COMPONENTS OF AN RCVD:

The components can be listed as under:

1. RCVD Bowl: A central cylindrical shaped vessel with top and bottom cones usually angled at 45 degree.

2. RCVD Jacket: A metal jacket for Heating and Cooling the external surface of the bowl. Jacket includes central circular cylindrical portion, top and bottom cone.

3.**Charging Hole Or Manhole with Openable or Hinged Door**: A manhole and a closing lid is provided for both charging the wet material and maintenance purpose. Usually manhole is big enough for either accessing the interiors by hand Or for manual entry of a person inside the bowl.

4. Bottom Discharge Valve (usually butterfly valve): A suitable diameter of discharge valve is provided for unloading the dry mass at the end of the operations.

5. Vacuum Pipe with Vacuum Bulb: The horizontal hollow pipe (either of heavy schedule or bored out of a solid rod) is provided for extraction of vapors generated

through the filter on the vacuum bulb (either a normal cloth filter Or sintered mesh filter).

6. Mechanical Seal between Vacuum Pipe and RCVD Bowl interface: Because the RCVD bowl rotates, while, the vacuum pipe is stationary, and, at the same time, vacuum pipe protrudes through the bowl horizontally, a mechanical seal is needed which allows smooth rotation of the bowl without vacuum or material leakage. In some arrangements, the seal sits exactly between the gap Or machined steps created between the vacuum pipe and the bowl. However, in some designs, before the mechanical seal, a PTFE (also known as Teflon) bush is fixed at the interface and further (after the PTFE bush) the mechanical seal is fixed.

7. Hot Fluid Or Steam Connection to RCVD Jacket: A horizontal pipe is provided (which is usually provided on the drive end) for supplying the hot fluid (usually Hot Water Or Steam Or extremely rarely Other Hot Fluid). Usually the piping is done such that the hot fluid travels through the core pipe and gets distributed in the RCVD jacket through the channeling effect. The same fluid when exchanges heat with the surface looses its temperature and returns back to the same pipe, however, now through the annular space created by other bigger pipe that parallelly covers the core pipe. It means Pipe In Pipe arrangement, where, the inner pipe carries supply fluid and outer pipe carries the returning fluid going back to the heating source.

8. Support Structure with base frame Or base plate: A support structure of hollow metal shapes viz. SS304 Or Mild Steel RHS Or SHS (Rectangular Hollow Sections Or Square Hollow Sections) are used to support the RCVD from both the sides i.e. Drive Side, as well as, Vacuum Side. Either a base frame of structural steel is provided Or simply base plates are provided at the bottom of the legs to grout it on the floor Or anchor it on the pedestal.

9. AC Motor: AC motor of 415 Volts, 1440 rpm, 50 to 60 Hz and of adequate power (considering a suitable starting torque at full load condition) is chosen. Voltage and Frequency can vary depending on the country of usage. Some countries use either 110 Or 220 Volts only, whereas, other countries use Voltage ranging from 415 to 450 Volts. Frequency varies too from country to country.

10. Drive and/or Gearbox: A suitable drive is chosen that is suitable to the motor, as well as, keeping in mind the reduction ratio. In some case, the gearbox is provided with Spur Wheel and Pinion Wheel arrangement (usually for higher capacity RCVDs) for the limitations of the gearbox size and reduction ratios. Whereas, in some cases, directly the gearbox is provided with motor for directly reducing the RPM from 1440 to 10-12. The selection of gearbox depends on RPM (rotations per minute) and client's need. Both Helical Bevel, as well as, Worm Reduction gearboxes are popular.

11. Couplings, Bearings and Plummer blocks: Suitable couplings are used between drive and motor. In many of the designs, the drive end shaft enters into the hollow gearbox, which is directly coupled with a motor. Bearings and Plummer blocks are provided on both the sides (i.e. drive and non-drive) to support the RCVD bowl, as well as, to allow it to rotate freely.

12. Electromechanical Brake Or Pneumatic Brake: It becomes essential to break the speed of the RCVD at times, hence, electromechanical brake (works on the principle of EMI) Or pneumatic brake is provided that ensures the RCVD rotational motion is broken and it comes to a halt immediately. These kinds of brakes are especially needed for a Helical Bevel Gearboxes, which does not lock the shaft from reverse rotation.

13. Variable Frequency Drive (VFD): AC Frequency Drive is provided to control Or vary the speed of rotation between 6 to 12 rpm usually.

14. Safety Railing: An openable safety railing is provided with a limits switch Or proxy sensor, which ensures that RCVD rotates only when the railing is closed. If someone accidently Or purposefully opens the railing to go near the RCVD, the motor stops immediately, hence, mitigates the possibility of any accident.

15. Instruments viz:

a) **Product Temperature Sensor**: A horizontal RTD sensor passing through central vacuum pipe, with probe open to the vapors and/or the powder mass inside the RCVD bowl.

b) **Vacuum Guage Or Compound Guage on the RCVD Manhole**: A dial type guage is provided to note the vacuum as well as pressure inside the RCVD bowl.
c) **Pressure Guage on the RCVD jacket**: Ideally the jacket pressure should not exceed 3bar (as a practice). More pressure may cause damage to the RCVD bowl surface.
d) **Temperate Sensor on Condenser**
e) **Pressure and Vacuum Guage for Receiver and Its Jacket respectively.**

3.5 OTHER PARTS OF THE RCVD SYSTEM:

1. Condenser: The vapors coming out of the RCVD is generally condensed by using a Shell and Tube Type Heat Exchanger. In the heat exchanger utility fluid(mostly chilled water Or cooling water) is circulated on shell side and on the tube side process side fluid (vapors) are passed. Though, it can be the other way around too (based on the heat load calculations). To avoid heat losses to ambient Condenser can be insulated and cladded.

2. Receiver: At the bottom of the Shell and Tube Heat exchanger a condenser solvent recovery receiver is provided. Receiver can be Horizontal cylindrical with saddle support or a vertical cylindrical with legs support. A arrangement for vacuum breaking is provided with a control/ On-Off valve on the receiver.

3. Vacuum Pump: To enable the extraction of vapors to complement the condensation process a right capacity Vacuum Pump is connected to the system (mostly to the receiver), which generates vacuum inside the RCVD bowl.

4. Water Heating system Or Low Pressure Steam (for heating RCVD surface): A dedicated skid mounted vertical cylindrical vessel with external heating i.e either with steam (LPS) or with Electrical Heaters is provided for hot water system. The pump circulates the hot water from hot water generation tank into the RCVD jacket and the return water is sent back to the hot water tank. To ensure water doesn't spill over a level guage/switch is provided and, valves gets ON when level goes down to make up water. The inlet water temperature control is ensured by placing temperature sensor on the Hot Waters Tank and RCVD jacket inlet which together

controls the flow of Steam (through PID control valve) Or the Electrical Heater. For direct steam heating, uniform temperature is maintained in the jacket by the PID control valve for throttling the steam.

5. Nitrogen Purging system: To clean the vacuum bulb filter and pushing the vapors out towards the condenser by intermediate or perioding gushing or N2 gas a small nitrogen container is provided with control valves. The purging of N2 is done through the same vacuum pipe, therefore, it is required to stop temporarily while purging.

3.6 WORKING

Rotary Vacuum Drier (RVD) is loaded with fine powder and heated using hot water circulation inside the RVD jacket to the required temperature (70 ± 5 ^{0}C). The hot water from hot water tank is pumped to RVD jacket by using the pump. The hot water temperature in tank is maintained at 70 ± 5 ^{0}C. The temperature controller is used to control and monitor the temperature of hot water inside the tank. The above cycle of rising temperature and maintaining required temperature is called heat cycle. After completion of heat cycle, vacuum is applied, with heating cycle continuing, is called vacuum cycle. 200-300 mm Hg of Vacuum is maintained in RVD by using the appropriate controls at vacuum pump and same is monitored. After completion of both cycles, RVD is purged with Nitrogen (N2) gas to break the vacuum. After purging with nitrogen, a sample is collected from RVD and sent to lab for moisture analysis. After the completion of operation, the material is unloaded from RVD and packed in batch containers. The discharge valve is operated remotely. The whole operation is remotely operated from control room with the PLC controls and SCADA.

3.7 THE FACTORS THAT MAKES RCVD or RCVD or DVD SO POPULAR AND A PREFFERED CHOICE ARE AS UNDER:

1. Vacuum Drying under Moderate or Low Temperature: RCVD bowl is provided with a metal jacket (usually SS304 grade in Pharma API) which allows the Hot Water or Low Pressure Steam (at usually 3 to 3.5 bar, Non IBR) to heat the surface and inturn heat the mass to be dried by conduction and convection. Because of the application of the vacuum inside the closed bowl, the vapor pressure inside the bowl

drops and hence the boiling point of the liquid to be evaporated (viz. Water or Solvent) too drops and hence boiling takes place at lower temperature and vapor generation (and subsequently extraction of vapors) happens faster as compared to any other traditional drying method.

2. Material Shuffling for achieving Uniform Heat Transfer: RCVD is provided with a rotary mechanism, wherein, the bowl rotates along a horizontal axis (it is supported over A or C shaped strong metal structures with bearings) at a low rpm (rotations per minute). Here the layer by layer shuffling of the mass inside the RCVD bowl takes place, resulting into uniform heat transfer amongst the wet powder particles. Most importantly, the powder mass shuffling takes place with minimum contact with any mechanical moving parts inside the RCVD bowl. All other vacuumized dryers works on either a complete static bed Or wet powder being shuffled by some mechanical agitator type structure. However, such structures needs to be cleaned thoroughly as per pharmaceutical standards and hence RCVD is preferred over other vacuumized dryers.

3. Vacuum Application, Inert Gas Purging and Temperature sensing through a smallest possible protrusion: RCVD has a unique design in which a horizontal hollow pipe (which acts as a vacuum Or suction pipe) protrudes inside the RCVD bowl through a central smallest possible opening. The same pipe acts as a inert gas (usually nitrogen) purging nozzle (used to push the vapors). Further, a temperature sensing element is passed through this horizontal pipe, which, further tries to sense the temperature of the inside mass And/ Or vapors. In any other type of a vacuum dryer, managing all these things is too difficult as there is a risk of vacuum leakage.

4. Possibility of fully automatic loading and unloading of the mass: It is one of the biggest concern of the Pharma, as well as, other industries today, to handle hazardous and polluting drugs Or chemicals, while ensuring Or following the safety standards. RCVD comes with a charging manhole, discharge butterfly valve and optional sampling valve, as well as, spray ball for cleaning in place (CIP/ WIP). The Charging and Discharging operation can be made completely automated.

Besides above Some of the other benefits of Vacuum Dryer are:

1. **Predictable and Repeatable outputs.**

2. **Drying of Temperature Sensitive Products -** At reduced pressures all liquids vaporize at lower temperature at ,so, it is possible to vaporize the liquids at very low temperatures.
3. **Reduced Energy –** The temperature differential is increased without raising the temperature by evaporating the liquid under vacuum at low temperature.
4. **Safe for Friable Products –** Because of the low speed of tumble dryer operation, making roto dryers ideal for delicate and friable solids such as macromolecules, crystals or agglomerated solids.
5. **More Complete Discharge –** There is no trap of product as in agitated dryers, due to Rota-Cone Dryers have very little surface area and no agitator. The cone angle of 45 degree allows all products to freely discharge.
6. **Low Cross Contamination –** There is less number of moving parts in the tumble dryer(one moving part) which is an inherently simple and clean design. So, the yield will be improved and reduces the cross contamination.
7. **Easily Cleaned –** With a standard single spray nozzle the whole RVD internals can be cleaned.
8. **Easily Inspected Interior –** From on vantage point – loading hatch, all surfaces of the Rota Cone Vacuum Dryer can be inspected.
9. **Single Enclosed Environment –** As the loading and discharging operations are sealed, automated and purged, active pharmaceutical ingredients, drugs and toxic chemicals can be dried safely. The isolated system also guarantees the maximum collection of solvents, with operator and the environment protection.
10. **Avoid Oxidation –** The Rota-Cone Vacuum Dryer aids in avoiding oxidation of chemical and with an inert gas purge by maintaining an oxygen free environment.

3.8 Advantages

- Drying time is reduced.
- Dust control by total contained process.
- Charging and Discharge is very efficient
- Lump free product due to Choppers(Lump breaker).
- Charging ports are easily openable
- Re-drying of lumps are eliminated.

- Final product Handling and exposure is avoided.
- Dried product is of uniform size.
- Crystalline or amorphous powders can be processed as they are prone for lumps.
- Internal surface cleaning is easy, which ensures high quality product..
- Maintenance of Optimum and Continuous vacuum in the process.
- Shuffling material uniformly over the heated surface of the cone.

3.9 Design Options:

- Agitator for lump breaking
- Addition of liquid
- Sampler for solids
- Drum Loading and Unloading System automation
- Polished Contact Surface
- CIP - Clean-In-Place Spray Nozzles
- Stamp of ASME code
- XP Electrics
- Vacuum System
- Recovery system for solvent
- Control systems for Hot Water or Hot Oil Temperature
- Complete Controls

3.10 CARE TO BE TAKEN WHILE DESIGNING AN RCVD:

1. Material of Construction: The correct choice of MOC will choose the adherence to the quality and process parameters, as well as, durability of the RCVD.

2. Level of Automation: Based on the production deparment requirement and budget allocation, the level of automation can be planned. Example, the external Powder Transfer System can be combined along with the RVD and the bottom discharge valve can be pneumatically stimulated. if product charging or discharging is the prime need.

3. Statutory and Safety compliance: Special features are united such as Touch Screen HMI (Human Machine Interface) with PLC (Programmable Logic Control)based on the company policy and FDA mandate,. Any other sophistication such as 21 CFR Chapter 11 compliance by adopting special Data Security measures, in which activity of each user recorded can be maintained by individualistic password protected logins. while designing an RCVD, overall Safety, GMP guidelines along with respective FDA mandates has to be followed.

4. Batch Size Calculations: Basic Thermodynamics Or Heat Load calculations helps in determining the optimum batch size, in addition to, the time cycle, hence monthly Or timely production quantity.

5. Available Floor Space, Availability of the Utilities and Floor Layout/ Elevation: The area and space available will be over looked by project team and the decision as RVD doesn't fit in that size is regretted later. Similarly, if not planned properly the utility equipment's such as Vacuum Pump, Hot Water Tank, Steam, Chilled Or Cooling Water, Nitrogen and Electrical Panel etc can cause a more trouble such as financial loss due to structural rearrangement work, major construction work and sometimes production time loss too. During the design stage, RCVD GAD (General Arrangement Drawing) is superimposed on Auto cad Layout Drawing to see the possibility of installation.

6. Thorough attention to the minute design aspects: Designing aspects such as Positioning of the Mechanical Seal, Spur-Pinion Geared Drive versus Direct Gearbox Drive system, Usual Vacuum Bulb with PP cloth bag versus Sintered Mesh Filterbag, CIP system (cleaning in place) by Spray Ball, In-Process Sampling, Nitrogen Purging, External Choppers/ Lump Breakers, Cantilevers Shaft versus Both side Supported Structure etc has to be given extremely detailed attention.

7. Product Specific Operational Challenges (based on the previous experience Or Studies): The Engineering and Maintenance of plant specific needs from production team has to given importance in the capital purchase. The Safety and Statutory department also helps in ensuring the smooth production.

8. Mechanical and Process Design, as well as, Sizing of the Equipments: With varying parameters such as temperature, pressure and vacuum Stress analysis/ calculations has to be carried out. Similarly, based on the the static and dynamic

loads the thickness calculations must be done. As per the Industry Standards, the important bought out items such as Motor, Gearbox, Seal, Valves etc should be designed.

The above knowledge let us now move to Generally design parameters or Scale up parameters of dryers followed by Rotocone Vacuum Dryer (RVD).

Chapter 4

SCALE UP DEISGN OF 4000 lit ROTO CONE VACUUM DRYER

These are rotating batch vacuum dryers, as shown in Fig. 4-1. Some types are an offset cylinder, but a double-cone shape is more common. They are very common in the pharmaceutical and fine chemicals industries.

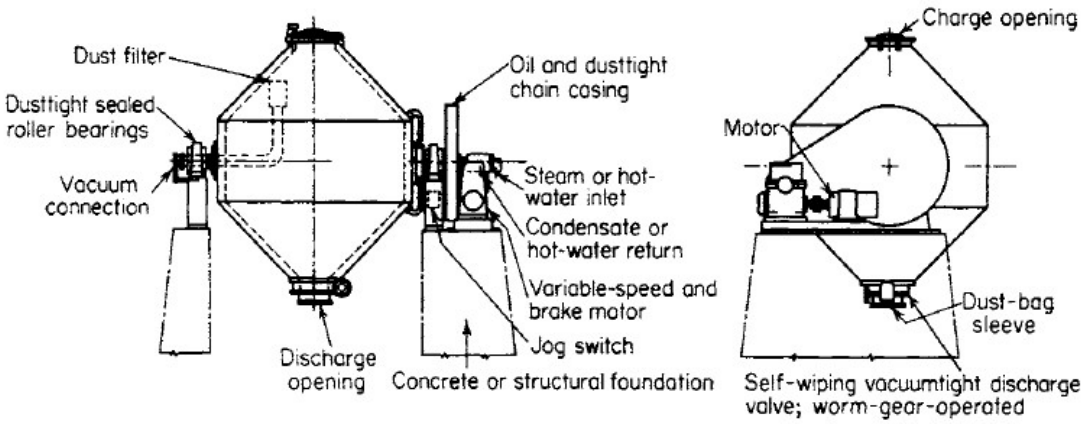


Fig. 4.1 Rotating (double-cone) vacuum dryer.

4.1 AIM

To scale up Roto cone vacuum dryer in order to facilitate the increased production rate for drying heat sensitive products by doubling the drying capacity of RCVD or RVD, i.e. from 2000 Lts to 4000 Lts. The design aims for arriving the RVD dimensions, heat load calculations w.r.t heating time and vacuum time and power required for 4000 Lts.

4.2 SCOPE

The scope of design is to scale up or sizing the RVD to 4000 lit and there by calculating the theoretical time requirement for reducing moisture content of product from 1 % to 0.1 %. The time or total time required for drying is the sum of runtime of heat cycle and vacuum cycle. Design also realizes the power requirement or power consumed during the drying process. Experimental trials will be done on the

4000 lit RVD and the results of these trials, will be compared with theoretical values obtained from the design calculation.

4.3 MATERIALS AND METHODS

1.Materials and tools: The tools employed for experimental studies were: Ovens, Non-contact thermometers, weigh balance, scooping spoon and petri dish. Besides above tools following materials are used in process: cyclone separator, water pump, pressure gauge, temperature sensors, BOT trolleys, condenser, operation control unit, chalk powder (Size – 300 µm, Mohs hardness -3, material composition – $CaCO_3$, Thermal conductivity – 0.09 W/m-K, Bulk density -0.6 g/cc, specific heat – 0.9 kJ/kg-K), gunny bags and batch containers

2.Methodology: The study was carried by sizing or scale up of RVD and test performance of RVD. The sizing or scale up of RVD is based on volume requirement. The sizing dimensions was theoretically calculated and compared with available RVD's in the market for choosing a RVD nearer to our requirement.

The design parameters, time requirement and power requirement of the chosen RVD are estimated theoretically. For this study, material chosen was chalk powder of average particle size 300 µm.

The performance test of RVD using chalk powder was carried out with measurement of initial moisture content. Then, powder weighing 50% volume of RVD was charged into the RVD and drying process is carried out to reduce the moisture content from 1 to 0.1 %. During the drying process, the temperature and vacuum of RVD was recorded against time. Test time was compared with theoretical time.

4.4. SIZING

The sizing of RVD design starts by choosing the capacity required. Here we require to design 4000 lit RVD. The basic point to be considered in design or scale up is L/D ratio. The L/D ratio of RVD is generally taken as 1.5 (see fig 4-2).

The first step in sizing is calculation of Diameter (D) of RVD based on the Standard formulas issued in table.

$$V = \frac{\pi D^2}{12}\left(\frac{L}{D}\right)$$

Where, V= Capacity or Volume of RVD

L= length of RVD

D= dimeter of RVD

Table 4.1. Calculation of Key Dimensions for Various Batch Contact Dryers (Fig. 4-2 Shows the Geometries)

Dryer type	Volume as $f(D)$	Typical L/D	Diameter as $f(V)$	Surface area as $f(D)$	Ratio A/V
Tumbler/double-cone	$V=\frac{\pi D^3}{12}\left(\frac{L}{D}\right)$	1.5	$D=\left[\frac{12V}{\pi(L/D)}\right]^{1/3}$	$A=\frac{\pi D^2}{2}\left[\left(\frac{L}{D}\right)^2+1\right]^{1/2}$	$\frac{A}{V}=\frac{6}{D}\left[1+\left(\frac{D}{L}\right)^2\right]^{1/2}$
Vertical pan	$V=\frac{\pi D^3}{4}\left(\frac{L}{D}\right)$	0.5	$D=\left[\frac{4V}{\pi(L/D)}\right]^{1/3}$	$A=\pi D^2\left(\frac{L}{D}+\frac{1}{4}\right)$	$\frac{A}{V}=\frac{4}{D}\left(1+\frac{D}{4L}\right)$
Spherical	$V=\frac{\pi D^3}{6}\left(\frac{L}{D}\right)$	1	$D=\left[\frac{6V}{\pi(L/D)}\right]^{1/3}$	$A=\pi D^2\left(\frac{L}{D}\right)$	$\frac{A}{V}=\frac{6}{D}$
Filter dryer	$V=\frac{\pi D^3}{4}\left(\frac{L}{D}\right)$	0.5	$D=\left[\frac{4V}{\pi(L/D)}\right]^{1/3}$	$A=\pi D^2\left(\frac{L}{D}\right)$	$\frac{A}{V}=\frac{4}{D}$
Conical agitated	$V=\frac{\pi D^3}{12}\left(\frac{L}{D}\right)$	1.5	$D=\left[\frac{12V}{\pi(L/D)}\right]^{1/3}$	$A=\frac{\pi D^2}{2}\left[\left(\frac{L}{D}\right)^2+\frac{1}{4}\right]^{1/2}$	$\frac{A}{V}=\frac{6}{D}\left[1+\frac{1}{4}\left(\frac{D}{L}\right)^2\right]^{1/2}$
Paddle (horizontal agitated)	$V=\frac{\pi D^3}{4}\left(\frac{L}{D}\right)$	5	$D=\left[\frac{4V}{\pi(L/D)}\right]^{1/3}$	$A=\pi D^2\left(\frac{L}{D}\right)$	$\frac{A}{V}=\frac{4}{D}$
Paddle, heated agitator	$V=\frac{\pi D^3}{4}\left(\frac{L}{D}\right)$	5	$D=\left[\frac{4V}{\pi(L/D)}\right]^{1/3}$	$A=\pi D^2\left(\frac{L}{D}\right)(1+R)$	$\frac{A}{V}=\frac{4}{D}(1+R)$

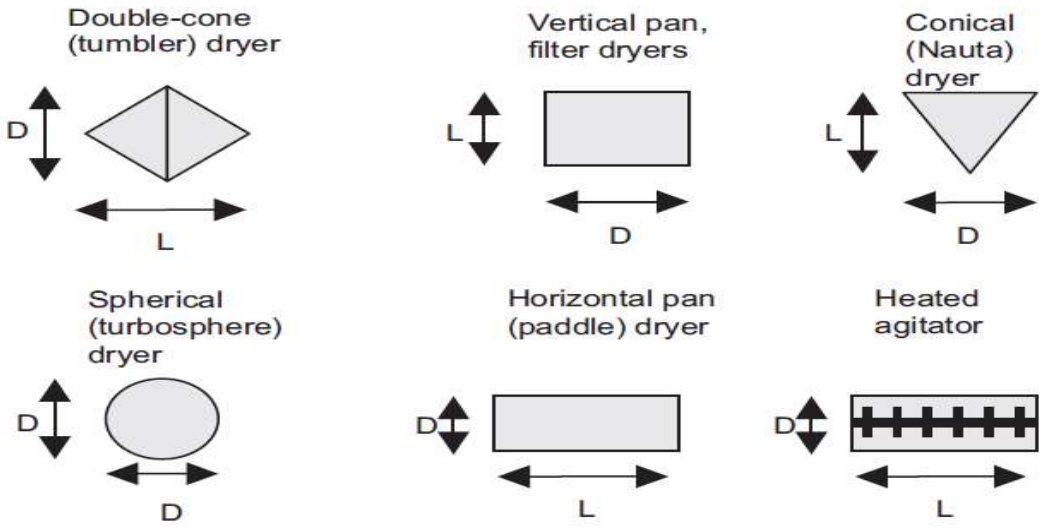


Fig. 4.2 Basic geometries for batch dryer calculations

4.4.1. Calculation of Diameter of RVD

$$V = (\pi D^2/12)(L/D)$$

$$4 = (3.14 * D^2/12)(1.5)$$

$$D^2 = 48/(1.5*3/14)$$

$$= 2.168 \text{ m}$$

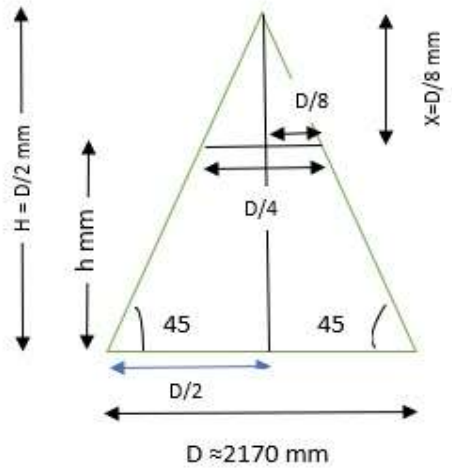


Fig. 4-3 Cone sizing dimensions

4.4.2. Calculation of Volume of truncated cones

From above fig.4-3, h = H-X mm

= 1085-275 mm

= 810 mm

Volume of truncated cone, V_{c1}

$$V_{c1} = (1/3)* \pi*h*(R^2 + r^2 + R*r)$$

$$= (1/3)*3.14*810*(1085^2 + 275^2 + 1085*275)$$

$$= 1.315\ m^3$$

For two cones, $V_c = 2* V_{c1}$

$= 2*1.315$

$= 2.63\ m^3$

4.4.3. Calculation of Remaining volume for RVD

Total volume of RVD = 4000 lit = 4 m^3

Volume of two cones = 2630 lit = 2.63 m^3

Shortage of Volume = 4 – 2.63 = 1.37 m^3

The Shortage of Volume in RVD is compensated or offset by a cylinder in between the two cones. Hence the volume of cylinder, V_{cyl}= 1.37 m^3

4.4.4. Calculation of Height of Cylinder

Volume of cylinder, $V_{cyl} = \pi* R^2*h_{cyl}$

$$1.37 = 3.14 * 1085^2 * h_{cyl}$$

Height of cylinder, $h_{cyl} \approx 370$ mm

4.4.5. Theoretical Sizing representation

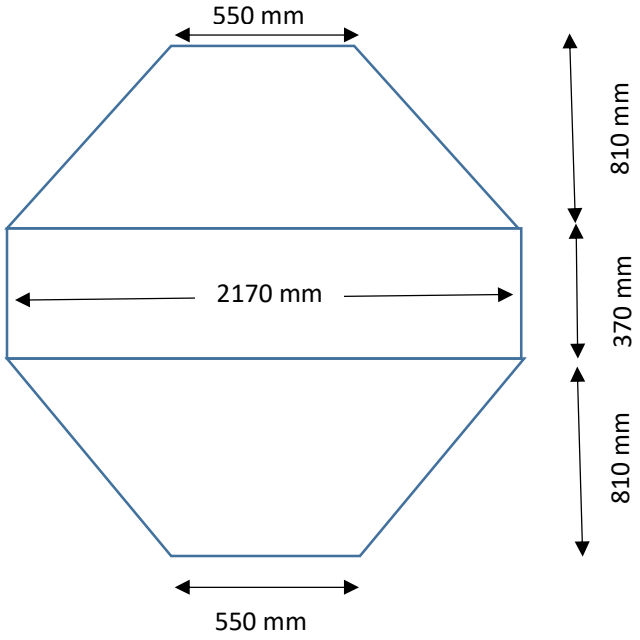


Fig. 4-4 RVD sizing based on Theoretical calculations

4.4.6. Actual RVD sizing representation

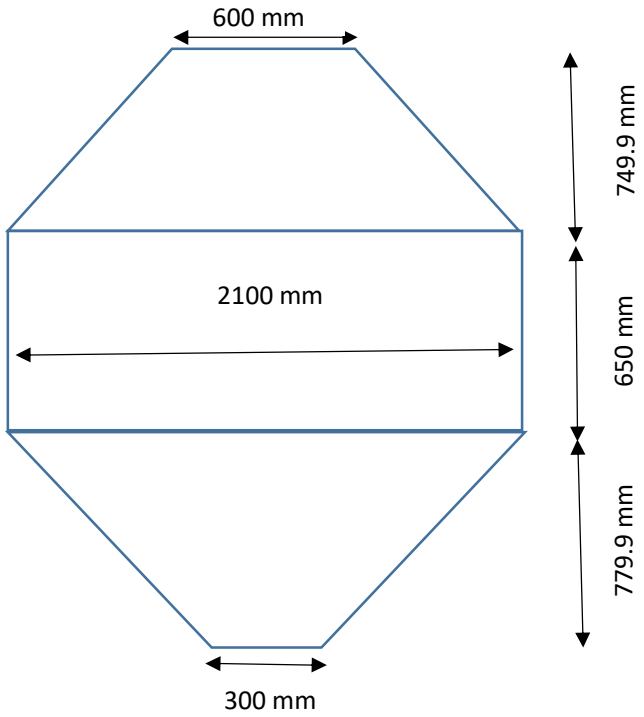


Fig. 4.5 Actual RVD sizing, obtained from market

4.5. DESIGN OF ACTUAL RVD

(Calculations of 4000 lit RVD Based on Standard Dimensions)

4.5.1. Calculation of Volume of RVD

V_{tot} = $V_{top\ cone}$ + $V_{cylinder}$ + $V_{bottom\ cone}$

$V_{cylinder}$ = $(\pi D^2 h)/4$ = 2.25 m^3 = 2250 lit

$V_{top\ cone}$ = $(\pi\, h(D^2 + d^2 + Dd))/12$ =1.178 m^3 = 1178 lit

$V_{bottom\ cone}$ = $(\pi h(D^2 + d^2 + Dd))/12$ =1.044 m^3 = 1044 lit

V_{tot} = 2250 + 1178 + 1044 = **4472** lit

4.5.2. Calculation of Curved surface area or Drying surface area

$A_{tot} = A_{Cylinder} + A_{top\ cone} + A_{bottom\ cone}$

$L = \text{sqrt}(h^2 + (R-r)^2)$

Where, h= height of cone

L = Slant height of cone

$A_{Cylinder}$ = $\pi D h_{cyl}$ = 3.14*2.1*0.65 = 4.286 m^2

$A_{top\ cone}$ = $\pi L(R-r)$ = 3.14*1.06*(1.5/2) = 2.49 m^2

$A_{bottom\ cone}$ = $\pi L(R-r)$ = 3.14*1.2 *(1.8/2) = 3.36 m^2

Atot = 4.286 + 2.49 + 3.36 = **10.136 m^2**

4.5.3. Calculation of Overall Heat transfer co-efficient for material heat transfer

$1/U = (x_{metal} / k_{metal}) + (1/ h_{water}) + (x_{material} / k_{material})$

Where,

x_{metal} = thickness of metal = 16 mm

k_{metal}= Thermal conductivity of Metal (SS316) = 16.3 W/m.K

h_{water} = Heat transfer co-efficient of water in forced circulation

=3000 W/ m^2.K

$x_{material}$= Thickness of material (chalk powder) in the form of

scale = 1 mm

k_{metal} = Thermal conductivity of material (Chalk Powder)

= 0.09 W/m.K

1/U = 0.016/16.3 + 1/3000 + 0.001/0.09

1/U = 0.000982 + 0.000333+0.0111

U = 80.55 W/m^2 K

4.5.4. Calculation of Overall Heat transfer co-efficient for heat transfer of inside air

$1/U = (x_{metal} / k_{metal}) + (1/h_{water}) + (1/h_{air})$

Where,

h_{air} = Heat transfer co-efficient of air inside the RVD = 50 W/ m^2.K

1/U = 0.016/16.3 + 1/3000 + 1/50

1/U = 0.000982 + 0.000333+0.02

U = 46.92 W/m^2 K

4.5.5. Calculation of Overall Heat transfer co-efficient that is lost to surroundings through insulation packing (glass wool)

$1/U = (x_{metal} / k_{metal}) + (1/h_{water}) + (x_{glass\ wool}/k_{glass\ wool})$

Where,

$x_{glass\ wool}$ = thickness of glass wool = 20 mm

$k_{glass\ wool}$ = Thermal conductivity of glass wool = 0.03 W/m.K

1/U = 0.016/16.3 + 1/3000 + 0.02/0.03

1/U = 0.000982 + 0.000333+0.666

U = 1.49 W/m^2 K

4.5.6. Calculation of Logarithmic Mean Temp. difference (LMTD) (for heat transfer between Jacketed water to material inside)

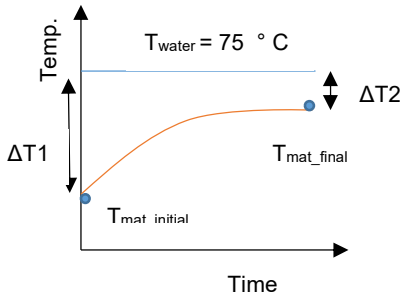
$\Delta T1 = T_{water} - T_{mat\_initial} = 75 - 30 = 45\ ^\circ C$

$\Delta T2 = T_{water} - T_{mat\_final} = 75 - 72 = 3\ ^\circ C$

$\Delta T_{lm} = (\Delta T1 - \Delta T2)/(\ln(\Delta T1/\Delta T2)$

$= 45 - 3/\ln(15)$

$\Delta T_{lm} = 15.5\ ^\circ C = 15.5\ ^\circ K$



4.5.7. Calculation of Logarithmic Mean Temp. difference (LMTD) (for heat transfer between Jacketed water to surroundings)

$\Delta T1 = T_{water} - T_{metal\ OD\_initial} = 75 - 35 = 40^\circ C$

$\Delta T2 = T_{water} - T_{metal\ OD\_final} = 75 - 40 = 35^\circ C$

$\Delta Tlm = (\Delta T1 - \Delta T2)/(\ln(\Delta T1/\Delta T2)$

$= 5/\ln(1.142)$

$\Delta Tlm = 37.44\ ^\circ C = 37.44\ ^\circ K$

4.5.8. Calculation of Heat transfer to the Material

(*Only Half area will be in contact with material, as material taken is 50% of the volume of RVD)*

$q_{material} = U\ A\ \Delta Tlm$

$= 80.55 * (10.136/2) * 15.5$

$q_{material} = 6347.9$ J/s

4.5.9. Calculation of Heat transfer to the inside air

(The other Half area is occupied with air)

$q_{air} = U\ A\ \Delta Tlm$

$= 46.92 * (10.136/2) * 15.5$

$q_{air} = 3685.7$ J/s

4.5.10. Calculation of Heat transfer to the surroundings

$q_{surroundings}$ = U A ΔT_{lm}

= 1.49*(10.136)*37.43

$q_{surroundings}$ = 565.29 J/s

4.5.11. Total Heat transferred to RVD

Total heat transferred = Heat transferred to inside of RVD (material + air) + Heat lost to surroundings

q_{tot} = $q_{material}$ + q_{air} + $q_{surroundings}$

= 6347.9 + 3685.7 + 565.29

q_{tot} = 10,598. 89 J/s

Heat losses through pipeline, valves and pump is assumed to be 10%

Therefore, total heat required,

q_{tot} = 10,598.89 + 10,598.89 * 0.1

= 10598.89 + 1059.88

q_{tot} = 11658.68 J/s

4.5.12. Calculation of Mass flow rate requirement

$q_{tot} = \dot{m} c_p \Delta T$

Where,

$\Delta T = T_{Initial} - T_{final}$ = 75-72 = 3 °C

$C_{P\ water}$, Specific Heat of water = 4182 J/kg. K

$\dot{m} = q_{tot}/(c_p \Delta T)$

$\dot{m}$ = 11658.68/(4182*3)

$\dot{m}$= 0.92 kg/s ≈ 1 kg/s = 1 lit/s

4.6. POWER REQUIREMENT

For 1 kg/s of water heat required to raise the temperature from 72°C to 75°C

$$r_{required} = \dot{m} c_p \Delta T$$

Where,

$\dot{m}$ = 1 kg/s = 1 lit/s

$\Delta T = T_{Initial} - T_{final} = 72-75 = -3$ °C

$C_{P\ water}$, Specific Heat of water = 4182 J/kg. K

$$q_{required} = \dot{m} c_p \Delta T$$
$$= 1*4182*-3$$

$q_{required}$ = -12546 J/s *(-ve indicates heat to be supplied)*

Heat loss During heating the water through walls and heater scaling is assumed to be 10%

Therefore, the Net Heat required is, q_{net}

$$q_{net} = q_{required} + q_{required}*0.1$$
$$= 12546 + 1254.6$$

q_{net} = 13800.6 J/s ≈ 14 kW

The power required for Maintain the RVD jacketed water Temp. = **14 kW**

4.7. RVD ROTATION

The RPM of RVD is calculated using the critical Speed of Ball mill

$$Nc = (1/2\pi)(\text{sqrt}(g/R)$$
$$= 0.498\ \text{sqrt}(1/R)$$
$$= 0.498\ \text{sqrt}(2/2.1)$$

Nc = 0.4859 rps = 29.1 rpm

For RVD speed is 25% of critical speed

RVD Rotation = 29.1 * 0.25 = 7.28 ≈ 7 rpm

4.8. HEAT CYCLE

Calculation of Heat required to raise the Temperature of material to 72 °C.

Heat required to raise the temperature of solids and liquids present.

$$\mathbf{Q_{hc} = m_{mat}\ [\ c_{ps}(\ T_{fmat} - T_{imat}\ )\ + X_a\ c_{pl}\ (T_v - T_{imat})}$$

Where.

m_{mat}= mass of material taken in RVD = 1200 kg

c_{ps} = specific heat of solid material = 750 J/kg °C

T_{imat} = Initial temperature of material(solids)= 30 °C

T_{fmat}= final temperature of material(solids) = 72 °C

T_v = vaporization temperature of liquid(water) = 72 °C

c_p = specific heat of liquid(water) = 4182 J/kg °C

X_a = amount of water in kg / dry solids in kg

Q_{hc}= 1200* [750*(72-30) + 0.01*4182*(72-30)]

= 1200 [31500 + 1756.44]

Q_{hc} = 39907728.0 J

Time required to raise the feed temperature to 72 °C, t_{hc}

t_{hc} = Q_{hc} / $q_{material}$

= 39907728 / 6347.9

= 6286. 76 s

t_{hc} = 6286.76 s = 104.7 min ≈ 105 min

4.9. VACUUM CYCLE

Calculation of Heat required to raise the Temperature of material to 72 °C

Heat required to raise the vaporize liquids(water) present.

$$Q_{vc} = m_{mat} [\lambda (X_i - X_f)]$$

Where,

m_{mat}= mass of material taken in RVD = 1200 kg

λ = latent heat of liquid (Water) = 2333 kJ/kg °C

X_i = Initial amount of water in kg/ wt. of dry solids in kg

X_f = final amount of water in kg/ wt. of dry solids in kg

Q_{vc}= 1200 [2333 (0.01 – 0.001)]

= 1200*[20.997]

Q_{vc} = 25196.4 kJ = 25196400 J

Time required to raise the feed temperature to 72 °C, t_{vc}

$t_{vc} = Q_{vc} / q_{material}$

= 25196400 / 6347.9

t_{vc} = 3969.25 s

t_{vc} = 3969.25 s = 66.15 min ≈ 66 min

4.10. TOTAL TIME OF PROCESS

Total time = Heat cycle time + Vacuum cycle time

$$t_{tot} = t_{hc} + t_{vc}$$

t_{tot} = 105 + 66 = 171 min

4.11. EXPERIMENTAL DETERMINATION OF CHARACTERISTIC DRYING CURVE FOR CHALK POWDER

Experiment is carried out by taking small amount of material in Petri dish and heated in oven. The temperature of oven kept at 72 °C and pressure at 1 atm. The weight of sample with Petri dish is taken in regular time interval (5 min) . The process was continued till no change in weight is observed.

Calculations:

Weight of dish	=	53.79 gm
Weight of dish +material	=	63.79 gm
Weight of material	=	10.00 gm
Total weight of material on dry basis	=	9.85 gm

Initial moisture content	=	0.01 kg of water/ kg of dry solid
Total amount of water added	=	6.5 gm
Final moisture content	=	0.65 kg of water/ kg of dry solid
Final weight of dish +water +material	=	70.2 gm
Time period taken	=	300 s
Area of dish	=	23.7675 cm^2

Table 4.2. Measured values of a sample heated in atmospheric oven at 72 °C over a period of time

S. No.	Time (min)	Temp. ◦C	Weight of solid + dish (gm)	Weight of solid with moisture (gm)	Moisture removed (gm)	Moisture content $\left(\frac{kg\ of\ H2O}{kg\ of\ dry\ sol}\right.$	Rate of drying $\frac{gm}{cm^2\ s}$	Rate of drying $\frac{Kg}{m^2\ hr}$
1	0	31	70.2	16.41	0	0.6660	0.0000	0.0000
2	5	45	70.1	16.31	0.1	0.6558	1.40E-05	0.5049
3	10	46	69.96	16.17	0.14	0.6416	1.96E-05	0.7068
4	15	47	69.76	15.97	0.2	0.6213	2.80E-05	1.0098
5	20	46	69.56	15.77	0.2	0.6010	2.80E-05	1.0098
6	25	46	69.35	15.56	0.21	0.5797	2.95E-05	1.0603
7	30	46	69.15	15.36	0.2	0.5594	2.80E-05	1.0098
8	35	47	68.97	15.18	0.18	0.5411	2.52E-05	0.9088
9	40	46	68.74	14.95	0.23	0.5178	3.23E-05	1.1612
10	45	46	68.51	14.72	0.23	0.4944	3.23E-05	1.1612
11	50	46	68.27	14.48	0.24	0.4701	3.37E-05	1.2117
12	55	46	68.08	14.29	0.19	0.4508	2.66E-05	0.9593
13	60	47	67.87	14.08	0.21	0.4294	2.95E-05	1.0603
14	65	46	67.66	13.87	0.21	0.4081	2.95E-05	1.0603
15	70	46	67.44	13.65	0.22	0.3858	3.09E-05	1.1108
16	75	46	67.22	13.43	0.22	0.3635	3.09E-05	1.1108
17	80	46	67.01	13.22	0.21	0.3421	2.95E-05	1.0603
18	85	46	66.8	13.01	0.21	0.3208	2.95E-05	1.0603
19	90	46	66.59	12.8	0.21	0.2995	2.95E-05	1.0603
20	95	47	66.38	12.6	0.2	0.2792	2.80E-05	1.0098
21	100	47	66.17	12.38	0.22	0.2569	3.09E-05	1.1108
22	105	47	65.98	12.19	0.19	0.2376	2.66E-05	0.9593
23	110	47	65.78	11.99	0.2	0.2173	2.80E-05	1.0098
24	115	47	65.57	11.78	0.21	0.1959	2.95E-05	1.0603
25	120	46	65.40	11.61	0.17	0.1787	2.38E-05	0.8583

26	125	47	65.19	11.4	0.21	0.1574	2.95E-05	1.0603
27	130	47	65.01	11.22	0.18	0.1391	2.52E-05	0.9088
28	135	47	64.83	11.04	0.18	0.1208	2.52E-05	0.9088
29	140	47	64.68	10.89	0.15	0.1056	2.10E-05	0.7573
30	145	46	64.52	10.73	0.16	0.0893	2.24E-05	0.8078
31	150	45	64.36	10.57	0.16	0.0731	2.24E-05	0.8078
32	155	46	64.22	10.43	0.14	0.0589	1.96E-05	0.7068
33	160	47	64.10	10.31	0.12	0.0467	1.68E-05	0.6059
34	165	49	64.01	10.22	0.09	0.0376	1.26E-05	0.4544
35	170	50	63.92	10.13	0.09	0.0284	1.26E-05	0.4544
36	175	54	63.84	10.05	0.08	0.0203	1.12E-05	0.4039
37	180	52	63.78	9.99	0.06	0.0142	8.41E-06	0.3029
38	185	54	63.76	9.97	0.02	0.0122	2.80E-06	0.1010
39	190	52	63.75	9.96	0.01	0.0112	1.40E-06	0.0505
40	195	54	63.74	9.95	0.01	0.0102	1.40E-06	0.0505
41	200	53	63.73	9.94	0.01	0.0091	1.40E-06	0.0505
42	205	53	63.72	9.93	0.01	0.0081	1.40E-06	0.0505
43	210	56	63.71	9.92	0.01	0.0071	1.40E-06	0.0505
44	215	56	63.7	9.91	0.01	0.0061	1.40E-06	0.0505
45	220	55	63.7	9.91	0	0.0061	0.00E+00	0.0000
46	225	56	63.7	9.91	0	0.0061	0.00E+00	0.0000

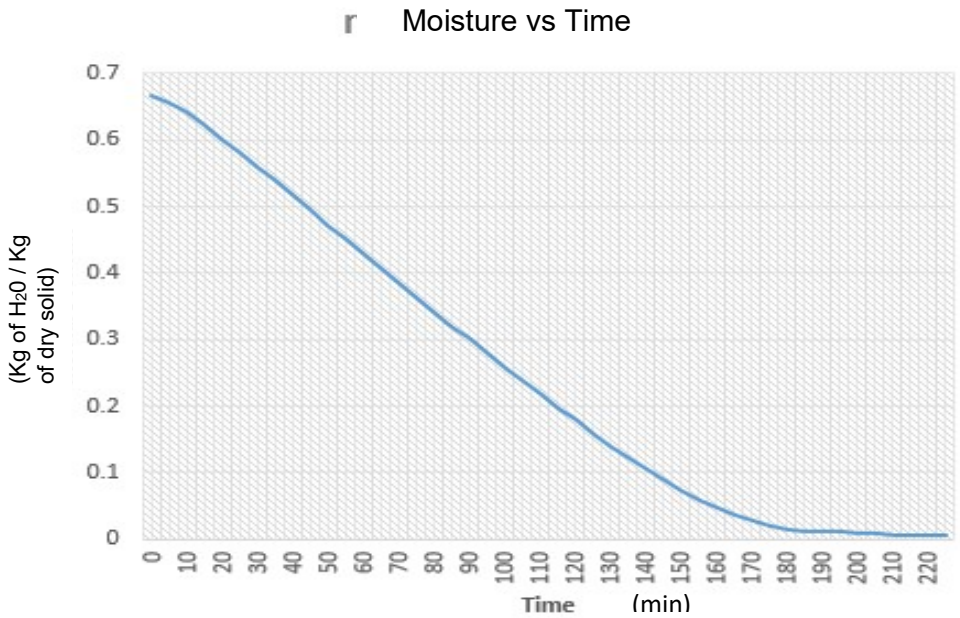


Fig. 4.6 Moisture vs time graph of chalk powder

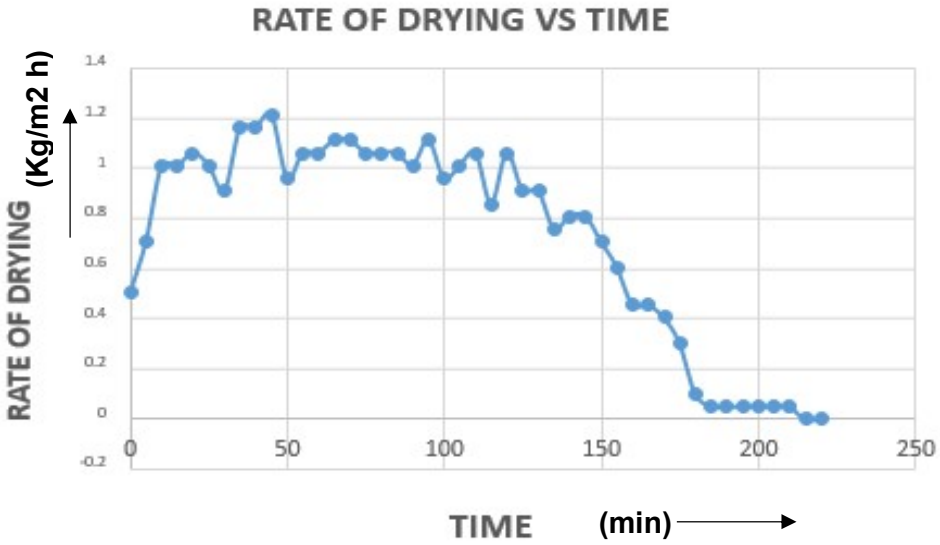


Fig. 4.7 Rating of drying vs Time graph of chalk powder

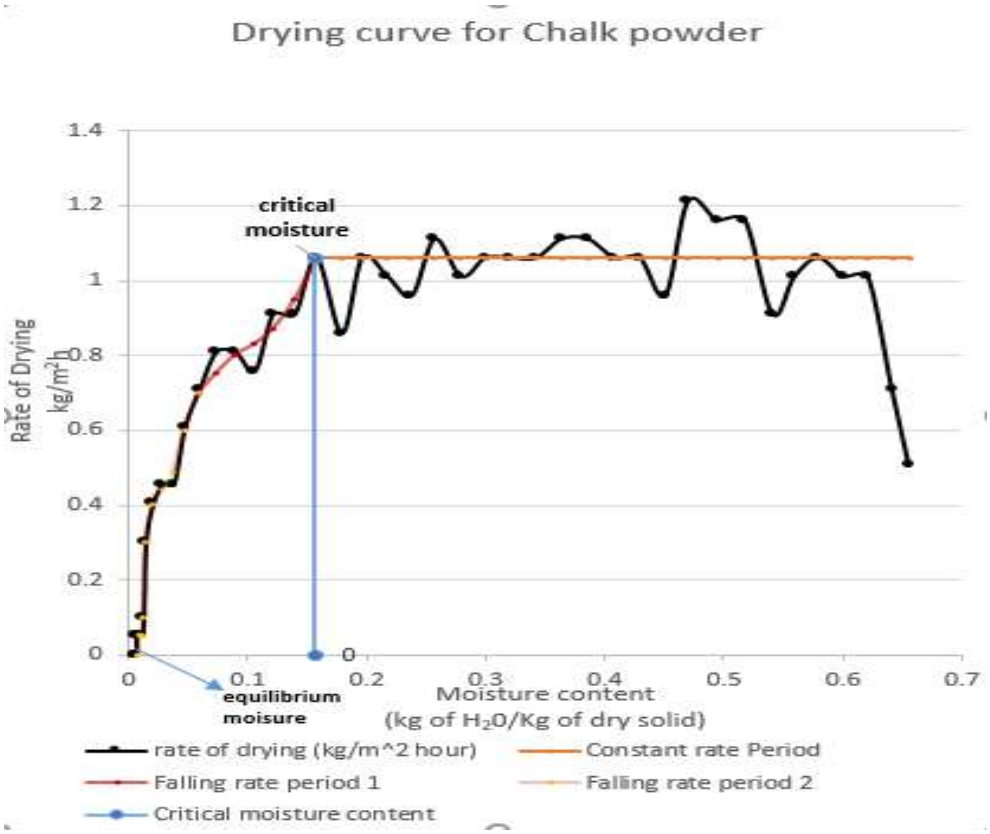


Fig. 4.8 Characteristic Drying curve for chalk powder

From the above Graph,

Critical moisture content, $\mathbf{X_c = 0.15}$

Equilibrium Moisture content, $\mathbf{X^* = 0.006}$, for calculation purpose it can be approximated to zero.

Chapter 5
RESULTS AND DISCUSSION

The Scale up design of 4000 lit RVD was discussed in this section w.r.t Sizing, Optimization of Speed, Power requirement, heat load calculations and time. An experimental trial with chalk powder was done in order to compare the theoretical data. The results of trial were discussed below.

5.1. SIZING

The sizing of 4000 lit was done based on linear dimensions for scale up. The main parameters governing the design is length to Diameter ratio, i.e L/D ratio, which is generally taken as 1.5, and Diameter of RVD. Diameter is determined using the formula

$$V = \frac{\pi D^2}{12}\left(\frac{L}{D}\right)$$

Where, V is required volume of RVD.

The theoretical arrived dimensions to actual dimensions available at site are on slight variation due to process requirements. The variation lies at Height of cylinder and Bottom cone flange dimensions.

The variation in bottom cone flange dimensions is result of change in slant angle of bottom, which naturally is 45°. The slant angle is slightly increased in actual RVD, so as to empty the material completely in lesser time and also avoid accumulation of material on RVD surface. The variation in the height of cylinder is due to preference for 10% higher volume, for accommodating higher density material, than the required volume or offset adjustment done on cylinder volume after volume calculations of two cones.

The loading volume of the material to be dried is 50% of the total volume of RVD

Table 5.1. Sizing comparison between theoretical derived and actual 4000 lit RVD

S.No.	Geometrical parameter	2000 lit RVD	4000 lit RVD	
			Theoretical	Actual
1.	Diameter	1533 mm	2170 mm	2100 mm
2.	Height of top cone	455 mm	810 mm	749.9 mm
3.	Height of bottom cone	465 mm	810 mm	779.9 mm
4.	Height of cylinder	870 mm	370 mm	650 mm
5.	Flange dia. of top cone	450 mm	550 mm	600 mm
6.	Flange dia. of bottom cone	310 mm	550 mm	300 mm
7.	Total Volume of RVD	2183.7 lit	4000 lit	4472 lit

5.2 ROTATIONAL SPEED

The rotational speed of RVD is calculated based on the critical speed double cone blenders. The critical speed is the speed at which material moves along with circumference of rotating object. At this speed, centrifugal force and centripetal force acting on material are equal. By equating both the equations, we obtain critical speed, N_c. This is given by,

$$N_c = \frac{1}{2\pi}\sqrt{\frac{g}{R-r}}$$

Where, R, radius of rotating object and r, radius of material. In RVD, the radius of material is very small compared to Radius of RVD. So, the radius of material is neglected for calculation. The same critical speed formula is for Double cone blending, which is 60-80 % of critical speed, N_c. But in RVD that speeds can damage size of friable materials and crystal structure of some materials due to attrition. So RVD will generally runs on lower speed, near to 25% of critical speed.

The observed result and calculated result nearly match. Therefore, the speed of RVD is can be taken as 25% of critical speed of RVD.

Table 5-2. Rotational speed of 2000 lit and 4000 lit RVD.

RVD	Theoretical speed (rpm)	Original RVD speed (rpm)
2000 lit	8	7
4000 lit	7	6

5.3 POWER REQUIREMENT

The power requirement is calculated for chalk powder, which turns out to be 14 kW. As the above calculation is especially for chalk powder, the power requirement supplied is generally above than the calculated. As, there are two to three types of products dried in the same RVD, power requirement varies with type of material used for drying. The material with highest power requirement will be selected. The power requirement is given by q(J/s)

$$q = \dot{m} C_p \Delta T$$

where, ṁ- mass flow rate, C_p – Specific heat of hot circulating fluid and ΔT-temperature drop during circulation. To maintain or to use only required power, a thyristor, i.e., a variable voltage drive to regulate the voltage, is used to control the power requirement. Thus, conserving the power usage.

Table 5-3. Power requirement (chalk powder) of 2000 lit and 4000 lit RVD

RVD	POWER, (kW)	
	CALCULATED	SUPPLIED
2000 lit	-	15
4000 lit	14	20

5.4 HEAT LOAD CALCULATIONS

Heat load is amount of heat required by the RVD to heat the materials to the required boiling temperature and then reducing the moisture content of material to specified moisture content, which includes heat lost to surroundings and losses through pipes, valves etc.. The heat required for heating the material was supplied by circulating hot water from hot water sump/tank around the RVD jacket.

The following assumptions was considered in heat calculations of RVD

1. There is no heat transfer between the material and air inside (occupying other 50% volume of RVD). Assuming both material and air are in thermal equilibrium at any time.
2. Expect for the water flowing in the jacketed area, assuming all the heat transfers are based on conduction with no radiation.
3. The thickness of material scale up around the RVD was assumed to be 1 mm.

Total heat load on the RVD for reducing moisture content of chalk powder from 1% to 0.1% was calculated, which is around 10.5 kW. The heat requirement done on chalk powder is not same for other material. As the heat required varies inversely with thermal conductivity of material and directly with the amount of moisture to be dried. So, the same heat requirement cannot be used for different material or with different amount of moisture. The variation of heat requirement during the drying process are controlled by regulating the mass flow rate of hot water.

The calculated Mass flow rate of jacketed water for the chalk powder drying i.e from 1% to 0.1% is 1 kg/s, whereas for other materials it varies. It is given by, ṁ (kg/s)

$$\dot{m} = \frac{q}{C_p \Delta T}$$

where, q- total heat required per second, C_p- Specific heat of water and ΔT – the change in temperature of water at inlet minus outlet of RVD jacket. To accommodate higher temperatures or different material drying, the Mass flow rate of water will be given higher with variable flow control meter, which regulates the Mass flow based on the requirement.

Table 5.4. Mass flow rate (chalk powder) of 2000 lit and 4000 lit RVD

RVD	**Mass Flow rate, (lit / s)**	
	CALCULATED	**SUPPLIED**
2000 lit	-	10
4000 lit	1	20

5.5 TIME

The time required for the material to rise temperature to near drying conditions and moisture removal is based on the heat supplied and amount of moisture present in material. It is generally given by, t (s), heat required to heat transferred per second.

$$t = \frac{Q}{q}$$

where, Q- total amount of heat required and q – Total heat transferred per second or heat transfer rate. The calculated time for heat cycle and vacuum cycle was 105 min and 66 min respectively.

The time varies inversely with type of material (thermal conductivity) to be dried and directly with amount of moisture present in the material. This implies that higher the thermal conductivity of the material, the more is heat transferred resulting in lesser time and vice versa. Similarly, more the moisture content, more amount of water to be evaporated resulting in more time for drying.

Table 5.5. Time required for drying in 2000 lit and 4000 lit RVD

S. No.	Material	Moisture percentage	Heat cycle time (min)			Vacuum cycle time (min)		
			2000 lit	4000 lit		2000 lit	4000 lit	
				Theory	actual		Theory	actual
1. #	Ammonium perchlorate	0.11% to 0.01%	40	40	45	15	18	25
2.	Chalk powder	1% to 0.1%	105	105	110	60	66	85

Data obtained from the previous records.

5.6 EXPERIMENTAL TRIAL

An experimental trial was done on 4000 lit RVD with chalk powder as feed material. 1200 kg (equal to 50% volume of RVD) of chalk powder having bulk density 0.6 g/cc and 1% initial moisture content was charged in the RVD. The charged material was heated using jacketed hot water of temperature 75 °C. The material has undergone a thermal change from ambient to 72 °C in 110 min, normally called as heat cycle. Then temperature of 72 °C is maintained for 85 min with vacuum of 560mm, called as vacuum cycle.

During the trial, moisture values and material temperature are measured and recorded for every 10 min. The recorded data was plotted on graph, Moisture vs time and Material temp. vs time.

Table 5.6. Data recorded for Chalk powder trial on 4000 lit RVD

Sl. No.	Time(min)	Moisture (kg of water/ kg of dry solids)	Material temp. (°C)	Cycle
1	0	0.01	30	HEAT CYCLE
2	10	0.009	35	
3	20	0.0085	42	
4	30	0.0081	45	
5	40	0.0077	48	
6	50	0.0072	53	
7	60	0.0067	55	
8	70	0.0064	58	
9	80	0.0062	61	
10	90	0.0061	65	
11	100	0.0058	69	
12	110	0.0055	71	

13	120	0.0039	69	VACUUM CYCLE
14	130	0.0032	69	
15	140	0.0025	69	
16	150	0.002	69	
18	160	0.0016	69	
19	170	0.0013	69	
20	180	0.0012	71	
21	190	0.0011	71	
22	195	0.001	71	

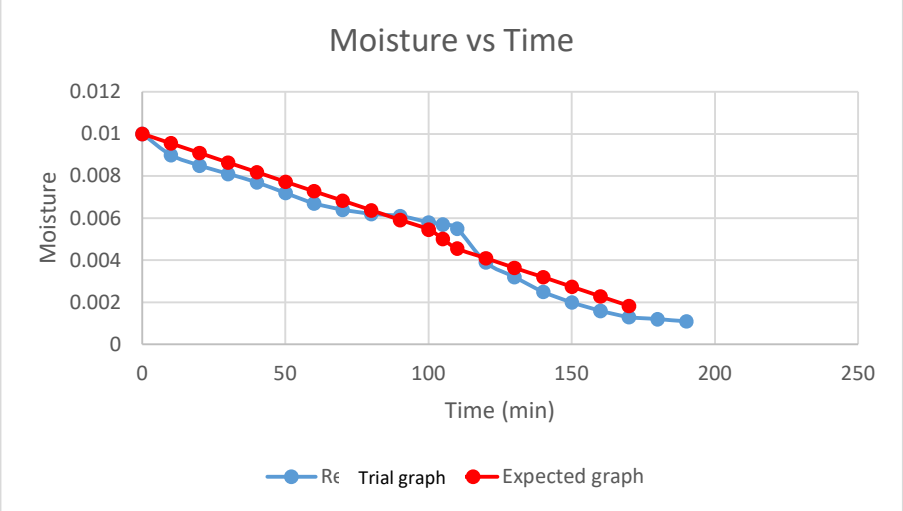


Fig. 5.1 Graph showing variation of moisture with time

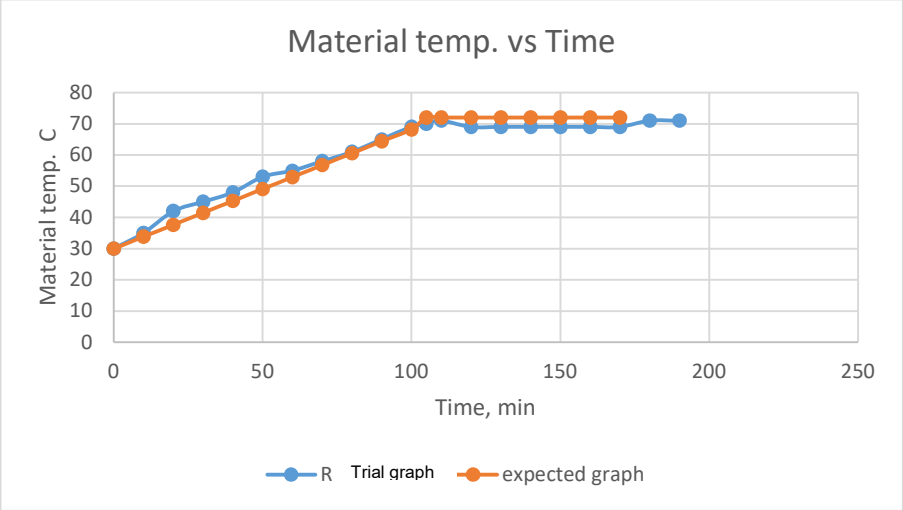


Fig. 5.2 Graph showing variation of material temperature with time

The graph indicates very minimal variation between theoretical to experimental studies. The actual results of drying time for both studies are tabulated below. This variation in theoretical to experimental always exist all type of studies. The variation may be due to approximations in design formulas, assumptions towards calculations or practical constraints in process. So, the results established proves scale up design of 4000 lit RVD is appropriate.

Table 5-7. Comparison of theoretical and experimental time for drying in 4000 lit RVD

Sl. No.	**Type of cycle**	**Theoretical time (min)**	**Experimental time (min)**
1.	Heat cycle	105 min	110 min
2.	Vacuum cycle	66 min	85 min

5.7 CHARACTERISTIC DRYING CURVE

The characteristic drying curve was plotted against rate of drying vs moisture content at conditions, temperature – 72 °C and pressure 1 atm. The results obtained are critical moisture content X_c = 0.15 kg of H_2o/kg of dry solids and equilibrium moisture content X^*= 0.006 kg of H_2o/kg of dry solids.

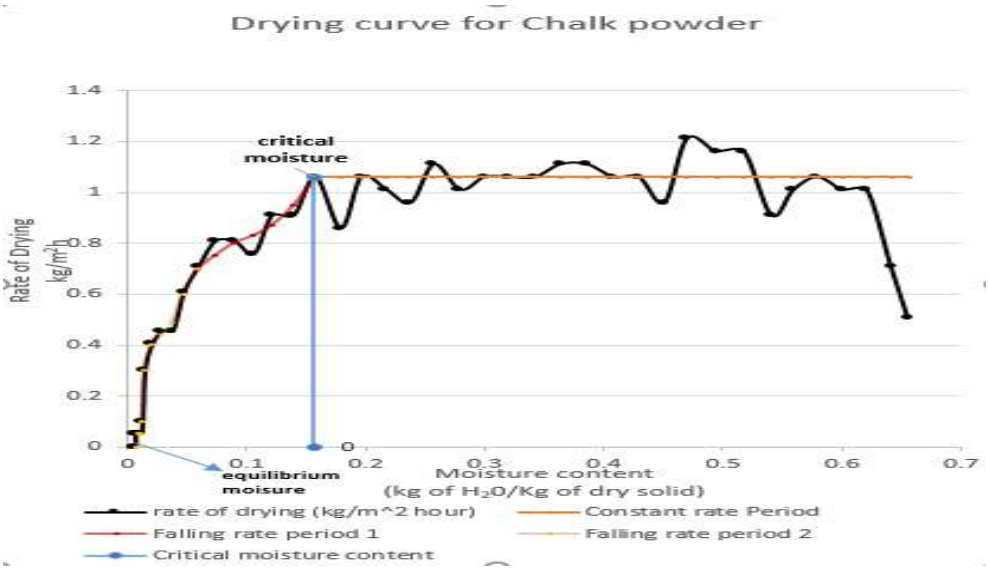


Fig. 5.3 Characteristic Drying curve for chalk powder

In the graph, the moisture content of chalk falls on the falling rate period 2. So RVD is chosen as drying equipment to reduce the moisture content. RVD's are generally designed to remove fine moisture content of heat sensitive materials in very efficient way. The chalk powder, though not heat sensitive, was chosen for experimental trial to verify design scale up.

Chapter 6
CONCLUSION

The scale up design of 4000 Lt RVD with L/D ration equal to 1.5 and diameter, 2.16 m was achieved. The design parameters are matched with the available RVD, and the parameter are given in results and discussion chapter. The heating and vacuum cycles were calculated for the given materials loading and the experimental results were matched. The test with increased (doubled) volume and doubled capacity of loading, which generally equals 50% volume of RVD has been carried out. The RVD initially in Heat Cycle, where material (Chalk powder) temperature is raised and controlled at 72±2 °C, has consumed time of 110 ± 5 min against theoretical value of 105 min. Upon reaching temperature of 72 °C, vacuum Cycle was initiated, to evacuate RVD to 560 ± 50 mm of Hg vacuum, has last for time interval of 75 ± 5 min against theoretical value of 66 min. RVD with total time of two cycles, i.e., around 190 ± 5 °C, has reduced the moisture content of material (chalk powder; initial moisture content of 1%) from 1% to 0.1%.

The heat associated for rising and maintenance of material (chalk powder) temperature during the two cycles was provided by Hot water. This hot water was pumped from the hot water sump with controllable discharge flow rate of maximum, 10 kg/s or 10 lit/s against theoretical value of 1 LPS, is circulated through the jacket of RVD. The power required to rise or maintain hot water in sump was done using thyristor controllable current heaters of 20 kW against 14kW

Table 6-1. The parameters after scale up from 2000 Lt to 4000Lt RVD

S.NO.	**PARAMETER**		**RVD**	
			2000 Lt	**4000 Lt**
1.	Time	Heat cycle	105 ± 5 min	110 ± 5 min
		Vacuum cycle	60 ± 5 min	75 ± 5 min
2.	Power		15 kW	20 kW

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