SCALE UP DESIGN OF ROTOCONE VACUUM DRYER

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Abstract: Rotocone Vacuum Dryer (RVD) is a batch dryer, designed to reduce the moisture content of powdered heat sensitive materials. This paper deals with the scale up design study of a 4000 lit RVD from an existing 2000 lit RVD. Theoretical design calculations of 4000 lit RVD were carried out with respect to sizing, heating cycle, vacuum cycle and power requirement etc. The methodology followed was geometrical similarity with the existing 2000 lit RVD. In order to validate the theoretical design, experimental trials were carried out with chalk powder having initial moisture content of 1%. The reduction of moisture content of chalk powder was carried out 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 obtained sizing details of 4000 lit RVD are a) Diameter 2100 mm b) cylinder height 650 mm c) cone height 750 mm. The experimental results are in good agreement with the theoretical calculated values.

Keywords: Dryer, Moisture content, RVD

INTRODUCTION

Rotocone Vacuum Dryers are indirect drying dryers used for drying all solids from catalyst, polymers to pharmaceuticals and food ingredients. Raw material charged is heated indirectly and at the same time undergoes rotation on horizontal axis. Heat required to rise the temperature of solids is provided by circulation of hot liquid through jacket provided to the RVD. The conical shape of the dryer ensures the hot liquid is efficiently circulated. Once the required temperature is attained, drying of water or any volatile solvent from the solids is achieved by application of vacuum in the RVD. The drying operation here is built on the principle that water or other volatile product moves from a region of low pressure. After the completion of operation, vacuum is withdrawn and purged with inert gas or nitrogen gas. The dried solids are discharged through the discharge valve provided at the bottom of the cone.

These dryers are 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. Because Rotocone 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. They are closed environments and can be sealed and automated for Loading and discharging operations. It is cost effective, high energy efficient and environment friendly.

In this paper a scale up design of a 2000 litre to cone dryer is considered which can only dry 600 kg of chalk powder in a single batch. Due to increased demand, there is a need to enhance the production rate from existing 600kg/batch to 1200kg/batch. Therefore, it is required to scale up the RVD from existing 2000 lit capacity to a techno-economically feasible capacity. After a series of theoretical calculations, the optimum volume of RVD was finalized as 4000 lit.

Equipment &Materials

The typical arrangement of a RVD with its components is given in the figure. Chalk powder from M/s Surabhi Industries was used for validating the theoretical calculations. Initially, theoretical calculations were performed to arrive at the equipment size and operating conditions. Then the obtained results were validated with an experimental trial

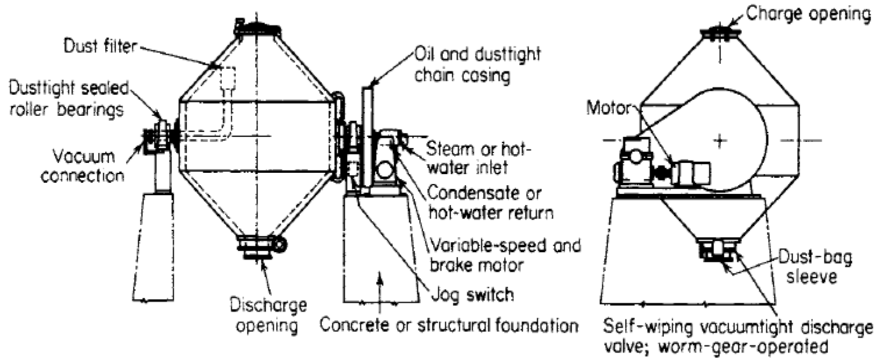

Fig 1. Pictorial representation of Rotocone Vacuum Dryer

Design Methodology

Sizing

The sizing of 4000 lit RVD 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 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

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 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

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, $\dot{m}$- 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 3.Power requirement (chalk powder) of 2000 lit and 4000 lit RVD

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

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 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

Process 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.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 Theory	2000 lit	4000 lit Theory

1.	Chalk powder	1% to 0.1%	105	105	60	66

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.

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

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 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	

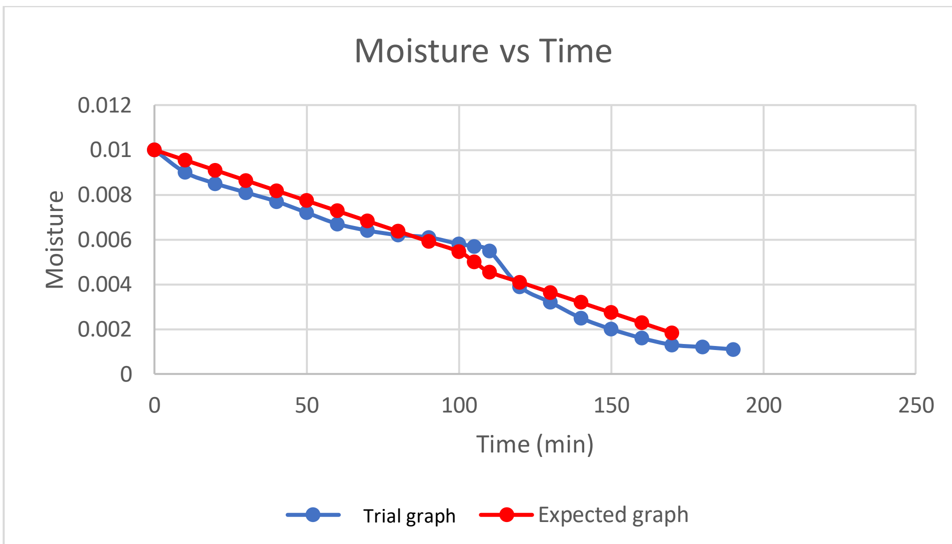

Fig 2. Graph showing variation of moisture with time

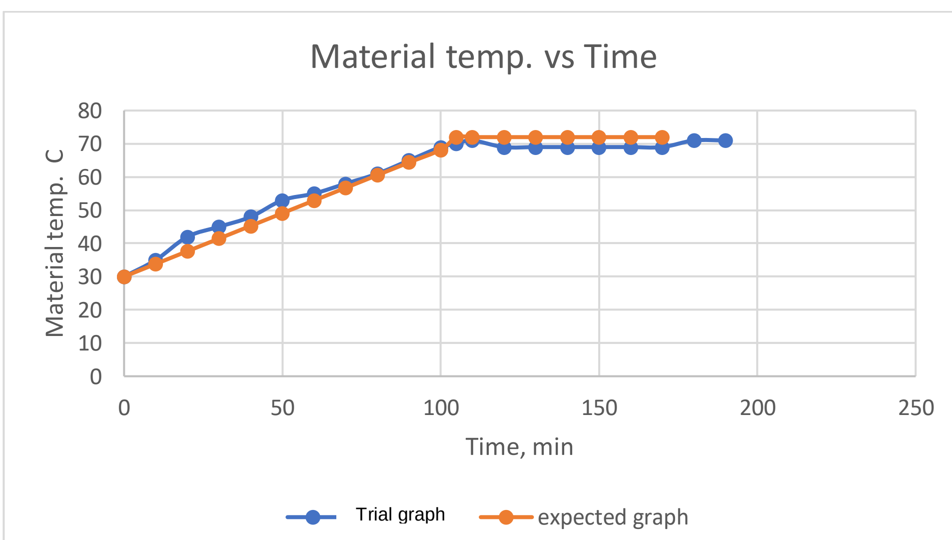

Fig 3. Graph showing variation of material temperature with time

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 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

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.

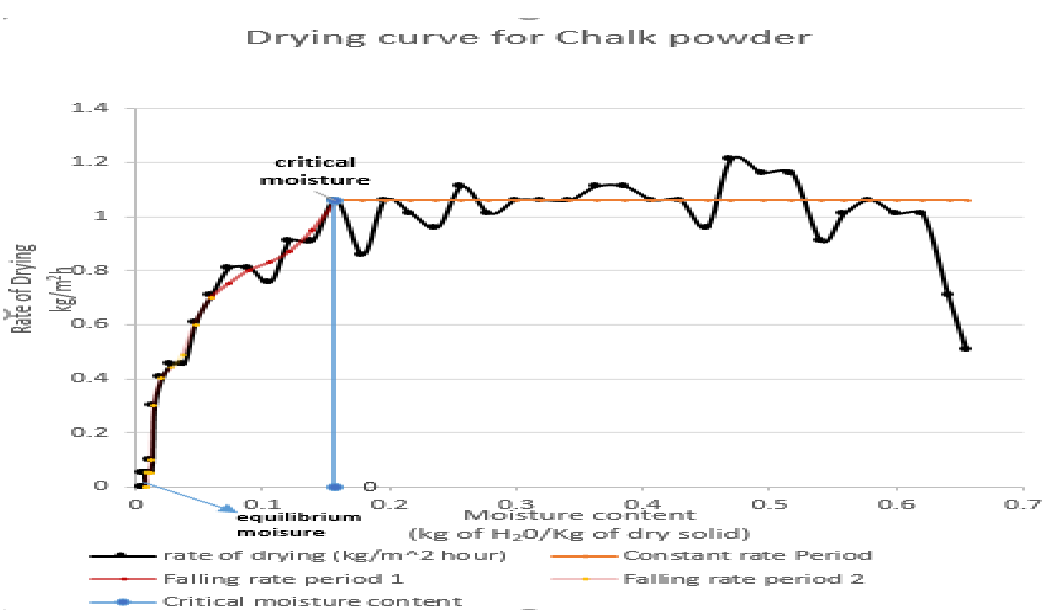

Fig 4. Characteristic Drying curve for chalk powder

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.

CONCLUSION

The scale up design of 4000 lit 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%.

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