# Process Equipment Design of Rotary Vacuum Dryer

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*Abstract*— Process equipment design of well-known equipment rotary vacuum dryer in an innovative way in order to meet economic considerations, Time constraint, Resources, Safety regulations, and Method of fabrication. For the same equipment, deductive failure analysis of an undesired state of the system is analyzed.

***Key words:*** Drying Curve, Rotary Vacuum Dryer

## I. INTRODUCTION

Drying is perhaps the oldest, most common and most diverse of chemical engineering unit operations. For each and every product, there is a representative curve called the Drying Curve that describes the drying characteristics for that product at specific temperature, velocity and pressure conditions. It is the moisture content that allows control of the drying process such that drying is carried out until a specific level of moisture content is achieved rather than for a fixed time period. The methods used to measure the moisture content are: Electrical resistance type meters operate on the principle of electrical resistance, which varies minutely in accordance with the moisture content of the item measured. Most of these types of instruments are suitable for measuring moisture content in grain, wood, food, textiles, pulp, paper, chemicals, mortar, soil, coffee etc. Dielectric moisture meters rely on surface contact with a flat plate electrode that does not penetrate the wood. Modern portable moisture balances are available with built in infrared heaters, which directly measures the moisture content of the product and gives a profile of moisture content variations with time. For measuring moisture content in paper rolls or stacks of paper, advanced methods include the use of Radio Frequency Capacitance method.

The rate of drying is determined for a sample of substance by suspending it in a cabinet or duct, in a stream of air from a balance. The weight of the drying sample can then be measured as a function of time from wet product to bone dry product. The curve of moisture content as a function of time, can be plotted. While different solids and different conditions of drying often give rise to curves of very different shapes in the falling rate period.

The drying in a rotary vacuum dryer is a batch operation under vacuum. While the system is rotating hence exposing more area of the material to be drier thoroughly, the jacketed vessel around it expends heat to the material further speeding up the drying process. The vacuum generated through the attached shafts on the sides creates a lift that makes the system give out moisture quickly. It is possible to dry heat sensitive materials at well below boiling points of water and solvents. Drying time depends on material being dried, amount of solvent or water to be removed, desired final moisture content, permissible jacket temperature etc.

Rotary vacuum dryer is suitable 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. The rotary vacuum dryer with improved technology integrates during operation under vacuum. It facilitates enhanced drying efficiency, low temperature operation and economy of process by total solvent recovery.

## II. ADVANTAGES

1) Reduces drying time
2) Handling and exposure of final product is avoided
3) Gives uniformity size dry product
4) System can process crystalline or amorphous powders which are prone for lumps
5) Easy to clean internal surface, thus ensuring purity of product
6) Optimum and continuous vacuum maintenance during process
7) Uniform material shuffling over the heated contact surface of the cone.

## III. DISADVANTAGES

1) The discharge cake contains residual moisture.
2) High energy consumption by vacuum pump
3) Rotary vacuum dryer requires high investment costs, high operating costs; low efficiency of equipment, production.

A study was conducted in an industry which utilizes a rotary vacuum drier in order to obtain its final product X.

Further the data taken is, with respect to the industrial requirements, the values can be changed as per requirements.

## IV. CALCULATIONS FOR ROTARY VACUUM DRIER

### A. *Input*

| | |
|---|---|
| D (external diameter of the vessel) | 1600mm |
| Volume of the vessel | 500 litres |
| Working volume of the vessel | 60% of the volume = 300 litres |
| Discharge opening | 175mm |

Table 1: Input

We are taking it as a class 1 vessel, as the vessel will contain lethal or toxic substances for which weld joint efficiency J= 0.9-1

As per Indian standards code IS: 1570-1961( 05 Cr 18 Ni 11 Mo), it has been observed that **stainless steel 320** is appropriate for the lethal or extreme conditions. As per the material of construction we obtain that

Tensile stress = $5.40 \times 10^8$ N/m$^2$

Yield stress = $2.75 \times 10^8$ N/m$^2$

Allowable stress(s) = $1.10 \times 10^8$ N/$m^2$

As per observed codes for highly toxic materials in an external pressure vessel minimum temperature should be 250°C, the highest temperature of inside material plus minimum of 50°C.

So the resulting temperature = 300°C

Pressure should be (1-P) and it has been seen that P= 80% of the maximum pressure that is 80% of 760mm of Hg, so P= 150mm of Hg or 19998.35 N/$m^2$

Now, calculating the thickness of the vessel

$$t = \frac{PD}{2fJ+P} \quad (1)$$

$$\frac{19998.35\times1600}{2\times1.10\times10^8\times0.9+19998.3548} = 0.161mm$$

Adding the corrosion allowance =
0.161 + 3= 3.161mm
Standard thickness becomes 4mm

*1) Jacket over the Rotary Vacuum Drier*

$t_{rc}$ = required minimum thickness of jacket
$t_{rj}$ = required minimum thickness of outer jacket
P = design pressure
j = jacket space
E = weld efficiency to the jacket

$t_{rc}=2\times t_{rj}$……………………………(2)

the jacket we are designing is of type 1 , $t_{rc}$ for type 1 jackets is 16mm

$t_{rj}$ = 16/2 = 8mm

$t_{rc} = 0.707 j\sqrt{\frac{P}{S}} = 0.707 j\sqrt{\frac{19998.35}{110}}$ =16, getting j = 1.678mm ( s = allowable stress)

$$t_{rc} = \frac{Pr}{SE-0.6P} \text{……………………..(3)}$$

$$= \frac{19998.35\times1.6}{110\times E-0.6\times19998.35} = E = 127.262$$

Total thickness = 4+16 = 20mm

*2) Top and Bottom heads of the vessel*

It has been observed that the top head of a rotary vacuum drier is a torispherical head as torispherical head provides a large opening for inlet , while the bottom is the conical head because sharper the edge easier it would be to obtain discharge.

a) Top head is in torispherical shape

While bottom outlet is in conical shape

Thickness of the head is determined by

$$t = \frac{PDc}{2\times f\times J} \quad (4)$$

C is the shape factor depending on the values of He/D and d/$\sqrt{t\times D}$ (d is the inlet diameter which is given).

For He/D, it is the value minimum of $\frac{D^2}{4R0}$ and $\sqrt{\frac{Dr}{2}}$

solution of the above equation will require iterations as 'c' is a function of 't'.

Taking first approximation be Ri = Ro= D

$$ho = Ro - [\sqrt{\left(Ro-\frac{D}{2}\right)\times\left(Ro+\frac{D}{2}-2ro\right)}] \quad (5)$$

Ro=D=1.6m; ro=0.06×1.6 = 0.096m;

Now calculating the values,

ho= 0.2709m = 270.9mm

$D^2/4Ro$ = 0.4m

$$\sqrt{\frac{Dr0}{2}} = 0.277m$$

He/D=0.2709/1.6 = .169 = 0.17

Now,

$$t/D = {}^{Pc}/_{2fJ} \quad (6)$$

=19998.35c/2× 11000000 × 0.9

= 1.0100× $10^{-4}$c

Observing the table in BC bhattacharya and calculating for different values,

Taking t/D = 0.035, we obtain c = 3.46, which on back substituting we get a different value of t/D, so we do another iteration and we finally obtain that at t/D = 0.002 we obtain the value of c as 3.59 and the values obtained are close enough so t/D=0.002

Now thickness of the head is t= 3.2mm ; as we want the heads to be of lesser thickness to make the vessel light weight and also so that heads can be easily removed for cleaning , so the corrosion allowance is 3 mm that gives the thickness to be 6mm

$$C = \frac{2fJt}{PD} \quad (7)$$

= 3.57

By next table, we obtain that $\frac{d}{\sqrt{tD}}$ = 4.5

d= 402mm

b) The Lower Conical Head

For the discharge[12],

$$\text{Volume} = 1/3\times\pi r^2\times h = 0.131\frac{D^3}{\tan\alpha} \quad (8)$$

For the maximum discharge volume = 300 litres;

h= 923.76mm

For maximum discharge the suitable apex angle should be maximum which is α = 60° (α is the half apex angle)

From the table for α= 60, Z value is 3.2

Thickness of the head at the junction where the outlet diameter would be present

$t = \frac{PDZ}{2fJ}$ = 5.17mm, adding corrosion allowance to it = 5.17 +3 = 8.17 = 9mm

Thickness away from the junction

$$t = \frac{PDk}{(2fJ-P)\cos\alpha} \quad (9)$$

$$Dk = 0.5\times\sqrt{\frac{Dt}{\cos\alpha}} = \quad (10)$$

=80mm

*3) Height of the vessel from tensile stress*

Stress = force/ area =5.40× $10^8$= P$\frac{D^2}{lD}$ =592.533mm

Total height of the vessel = 592.533 + 923.76 + 270.9=1787.19mm

Now for the external pressure vessels we use stiffeners to prevent failure of the vessel

*4) Stiffeners Design*

a) Critical length

$$Lc = 1.11\, Do\sqrt{\frac{Do}{t}} \quad (11)$$

$L_c$ = 35.52mm Lc = critical length

Out of roundness U = 1.5% for newly made vessels

E (Modulus of elasticity for the given material as referred from the table is) = 1.16× $10^{11}$ N/$m^2$

b) Corroded shell thickness

Required for elastic stability

$$P = KE\left(\frac{t}{D}\right)^m \quad (12)$$

Where K and m are variable values obtained from the table using D/L ratio

For D/L =0.889 K = 0.7476 and m= 2.484.

199983= 0.7476×1.16× $10^5$ × $(t/1.6)^{2.484}$;

t = 8.6mm t= 10mm

c) For plastic deformation

f=allowable tensile stress = 540MN/$m^2$

 

$$P = 2f(t/D)\frac{1}{1+\frac{1.5U(1-0.2\frac{D}{L})}{100(\frac{t}{D})}} \text{.....................}(13)$$

D/L =1.08

Putting the value of D/L back into the equation we obtain P = 0.276 which is greater than 0.19998 so it is safe

If stiffeners are used then effective length becomes 1m

D/L =1.6 again using the table and the values of K = 4.737 and m= 2.67

$.19998 = 4.737\times 116000 \times (\frac{t}{1.6})^{2.67}$ ; t= 6.2mm

Adding the corrosion allowance to the thickness = 6.2 +3= 9.2 = 10mm

For stiffening rings we require ,

$$I = \frac{D^2L\left(t+\frac{As}{L}\right)f}{12\,E} \quad (14)$$

Trying different beams: I beam or channel beam or equal angle beam or tee bar

Using the data according to thickness:

| Different beams used | A($cm^2$) | Calculated I($cm^2$) | Given I($cm^2$) |
|---|---|---|---|
| I Beam (ISLB 325) | 54.9 | 213.6 | 9874.6 & 510.8 |
| Channel beam ( ISJC 100) | 7.41 | 33.69 | 123.8 & 14.9 |
| Equal angle beam | 5.07 (45×45) | 24.82 | 9.2&9.2 |
| Tee bar (ISNT 20) | 1.13 | 9.89 | 0.2 & 0.4 |

Table 2: Beam Used

Given I > Calculated I (so looking at the data we obtain that I beam is the most suitable one)

*B. Output*

| | |
|---|---|
| working volume | 300 litres |
| Tensile stress | $5.40\times10^8 N/m^2$ |
| Allowable stress | $1.10\times10^8 N/m^2$ |
| Yield stress | $2.70\times10^8 N/m^2$ |
| Temperature | 300°C |
| Pressure | $19998.35 N/m^2$ |
| Thickness of vessel | 4mm |
| Jacket thickness | 20mm |
| Torispherical head thickness | 6mm |
| Conical head thickness | 9mm |
| Conical head Dk | 80mm |
| Height of vessel | 1787.19mm |
| Corroded shell thickness for elastic stability | 10mm |
| Plastic deformation (thickness obtained) | 10mm |
| Beam used | I beams |

Table 3: Output

## Reference

[1] Coulson and Richardson's Chemical Engineering, Volume 2, 5th, edition, J.M. Coulson and J.F. Richardson, Butterworth-Heinemann (2002)
[2] Introduction to chemical equipment design, mechanical aspects BC Bhattacharya
[3] ASME VIII DI Appendix 9

 