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New approach for obtaining uniform- sized granules by prilling process

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ABSTRACT

Granule size is used as a parameter and as a quality specification by manufacturers while designing a cost- effective prilling tower for obtaining a standard granule size.

In this study, we obtained a standard 2 mm diameter granule using an alternate prilling method other than those available in the industry.

Introduction

Prilling and physical description of prilling devices

The height of a prilling tower, and the velocity at which granules are made to drop inside the tower.(e.g., ammonium nitrate granules: 3 m/s) limit the size of the particles formed in the prilling tower(Andreas, 1974).

A product should have sufficient time to crystallize and cool in the prilling tower. The greatest falling distance (distance a particle has to travel from the top to the bottom of the prilling tower) that can be achieved in a prilling tower having 1 diameter of 15 m is 60 m. In 1961, Grassmann and Reinhart reported that particles having a perfect spherical shape cannot be realized for large prill droplets; these droplets form a flat shape when Reynolds > 10-3. For Reynolds > 10-3, the particles diameter is approximately 3 mm (Andreas, 1974).

Prior to the prilling process, the solution is mixed in a reactor at a temperature that is 10-20 oC higher than the melting point. Low temperature causes plugging in the prilling tower due to crystallization of the solution, whereas high temperature causes a decrease in the cooling, which in turn causes a decrease in the yield. The solution is moved to the top of tower with the help of a pump; subsequently, droplets are sprayed from the top of the tower (Kjaergaard, 2000).

The superficial gas velocity of the particles under ambient cooling conditions is between 0.5 and 2 m/s. An increase in the temperature by 20^{o}C was observed for some examples. Broken particles, which are formed because of the particles crushing against the tower wall, cause impurities to build up; these impurities plug the drainage valve for the cooling air on the tower-floor (ground). Spray crystallization or prilling can be carried out in two different configurations: one where the solution and air conditioner are next to each other and the other where the solution and air conditioner are apart from each other.

The advantage of the first configuration is that the solution will come into direct contact with the cooling air, and the crystallization process will not generate noise. On the other hand, in the second configuration, an increase in the retention time of particles is observed. The floor (ground) of a prilling tower is either flat or conical. The conical tower, by virtue of having an additional conical base, differs in height from the flat tower. Although the flat tower does not possess additional height, it shows some degradation on the prill surface (Kjaergaard, 2000).

The product is dried by crystallization and cooling.

A short retention time, makes it impossible for the product to be dried completely. Therefore, it requires a secondary phase of cooling. Further, even after exiting the tower, the product has to be frequently cooled by a secondary cooler.

There may also be a need for extra cooling even after the second stage of cooling (Sabatini, 2004).

After leaving the prilling bucket (figure 1), the solution is cooled and forms small and big droplets.

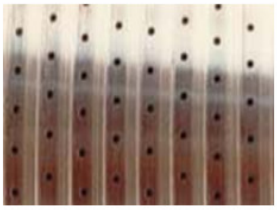

Figure 1. Prilling bucket available in industry

Powdered, digested solid materials are added to the solution in the prilling tower for diluting the main solution (Sabatini, 2004).

Formation of prill droplets

Generally, dispersion of a liquid to a gas is realized using two devices: a pressure nozzle or a rotating perforated bucket (Theoret, & Andorfy,1964).

Pressure nozzle

A pressure nozzle is used when the velocity of the particles is low. The nozzle helps in increasing the velocity of the particles and hence increasing the flow of particles.

When the particles are flowing at a low velocity, a pressure nozzle is used for increasing their rate of flow.

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High-speed jets from the nozzle push the through the perforated bucket. After reaching a certain distance from the nozzle, these high-speed jets convert the solution to small droplets.

If the properties of the solution remain unchanged, then the length of the stream of particles is a function of only the flow speed. The length of the stream attains its highest value at critical speed. Rayleigh presented qualitative graphics related to the analysis of dispersed jets.

Rayleigh explained the instability of jets by varying of the surface tension values.

The jet breakup that occurs because of surface tension happens at a speed lower than the critical speed. Von Ohnesorge, Duffie, and Marshall have taken photographs of jet breaks. Merrignton and Richardson confirmed that the droplet size is twice as large as the hole from where the droplets exit. The experiment was repeated 19 times. They inferred that the droplet's diameter is twice as large as the diameter of the nozzle (Theoret, & Andorfy, 1964).

Calculations for prill formation using a pressure nozzle

Weber mathematically analyzed the jet breakup as follows (Van Hijfte, 1982):

$\lambda/dh = \pi \times (2 \times (1+3 \times \mu 1 \ / (\rho \times \sigma \times dh \ )1/2 \ )) \ 1/2$

where

λ = wave length (m) (the maximum length of the stream of particles before leaves prilling bucket)

dh = hole diameter (mm)

$\mu 1$ = dynamic viscosity of the solution (Ns/m2): 2.5×10-3 kg/ms × 1000 g=2.5 g/ms

σ = surface tension of 97% ammonium nitrate(wt %=97)

= 99.225 dyn/cm : 99.225 (0.021020 g/1 dyne) = 208.57 g/m

$\rho 1$ = density of solution (kg/m3) =1.4 g/cm3=1.4 g/cm3 × 1000000 cm3/ = 1400000 g/m3

The spherical droplet's diameter is represented as follows:

$dp= 1.88 \times (1+ (3 \times \mu 1/(\rho \times \sigma \times dh \ )1/2 \ )1/6 \ \times dh$

where

dp = particle diameter (mm)

$(\rho \times \sigma \times dh \ )1/2 \ = (1400000 \text{ g/m3} \times 208.57 \text{ g/m} \times 0.7 \text{ mm} \times 1000 \text{ mm}))1/2 \ = 452.1$

$(3 \times \mu 1 \ / (\rho \times \sigma \times dh \ )1/2 \ )1/6 \ = (3 \times 2.5/452.1)1/6 = 0.504$

$1.88 \times (1+ (3 \times \mu 1 \ / (\rho \times \sigma \times dh \ )1/2 \ )1/6 \ \times dh = ((0.504 \times (0.7/1000))+1) \times 1.88=1.88 \text{ mm}$

The solution is sprayed using through a vertical nozzle having a diameter of 0.5 mm, and made to fall from a height of 40 m at 140 oC; the prill diameter is 1.1 m. The droplet's speed increases from 1.25 to 5 m/s and hence, the particle's diameter increases. As the velocity of the prill approaches 20 m/s, the prill's diameter becomes 1.6 mm.

Increasing the prill diameter with velocity causes fast crystallization of the product on the surface of the prill. If the crystallization is weak, the degradation of the product is great.

If the solution's viscosity is 10-3- 10 -1 Ns/m2 and the velocity is 1-10 m/s, then the diameter of the droplet emerging from the pressure nozzle will be twice the nozzle diameter.

Rotating perforated bucket

The method involving the use of a rotating nozzle at high capacity is carried out using a cylindrical or conical bucket with a hole. Liquid jets are formed by a centrifugal force. The mechanism for droplet formation is similar to the mechanism that uses a fixed nozzle. The solution is fed to the center of the rotating bucket. Under the influence of the centrifugal force, the liquid moves toward the perforated walls(Van Hijfte, 1982).

Calculations for prill formation using a rotating nozzle

The pressure difference at any hole in the prill bucket liquid layer, having a thickness δ, is represented by the following equation:

$\Delta P = \rho 1 \times (Vc2 /R) \times \delta$

It is assumed that the radial acceleration (Vc2 /R) influences the liquid column at thickness δ

where

ΔP = pressure difference (N/m2)

$\rho 1$ = density of solution (kg/m3)

Vc = ground speed (m/s)

R = ground diameter (m)

δ = liquid layer's thickness m, (amount of liquid that forms on the bucket's wall per second)

The pressure difference is constant, from the top to the bottom, of the bucket. We will verify this by studying the change in ground speed. The bulk's speed is least at the bottom of the bucket; using this knowledge, we will calculate the rotating speed of the bucket in terms of the mass flow. We attempt to determine the prilling speed(m/s) required to process 100 ton of product in 1 h.

R= 30 cm, H= 50 cm, and A= 2×3,14× (30/2) ×50= 4710 cm2

When liquid flows through a hole, the pressure head converts to kinetic energy.

$\Delta P= 1/(2c2) \ \rho 1 \times Vh2$

where

ΔP = pressure difference (N/m2)

$\rho 1$ = density of solution (1.4 g/cm3)

Vh = speed at the hole. (m/s) (Vh= Vc ((2×c2×δ)/R)1/2)

R= ground diameter (30 cm)

δ= thickness of liquid layer (15 cm)

c= hole coefficient.

If Vh = Vc

the value of " c" can be determined from the following formula:

$(2 \times c2 \times 15)/30$. "c" is found to be 1.

Then, $\Delta P= 1.4 \text{ g/cm3} \times 14 \text{ m/s} = 1.4 \text{ g/cm3} \times 1000000 \text{ cm3} \times 1 \text{ kg} \times 14 \text{ m/s}= 27\ 440 \text{ kg/m2.s}$

Speed and capacity are linearly dependent on ground speed. The capacity can be set by checking the ground speed.

Van Der Berg and Hallie reported that they obtained droplets having a smaller diameter when they used a rotating nozzle rather than a fixed nozzle at the same capacity. They prilled ammonium nitrate solution in a small prilling bucket at 140 oC (Van Hijfte, 1982).

It is shown that the average particle size is not dependent on the rotating speed (Van't Land, 2005).

$dp= 1.75 \times dh$

where

dp= particle diameter (mm)

dh= hole diameter (mm)

After calculating the pressure difference at different heights in the prilling bucket, we will calculate the particle's diameter. If we divide the bucket into 100 height intervals of 50 cm each, we should be able to determine the amount of solution in the bucket at each height interval and calculate the diameter of each hole through which the solution passes.

$100 \text{ ton/h} \times 3600 \text{ s} \times 1000 \text{ kg} = 28 \text{ kg/s}$

We divide the cylindrical bucket into 100 equal parts. The solution is prilled at a speed of 0.28 kg/s; 0.28 kg of solution is prilled per second. We can calculate this using solution's density (volume). We find that this value is 2.8 m3 . The volume of the

solution is 0.28 kg× 1000 g× 1cm3/1.4 g= 200 cm3. If there are 500 holes per part, each hole prills 0.4 cm3 of the solution in 1 s. We will now find r using the following surface area formula: 2×3.14×r2×h (r= dh)

where h is the bucket's diameter (15 cm). The aim of this calculation is to obtain a granule size that is comparable to the hole diameter.

It is assumed that the entire solution the bucket prill head immediately (Yeandle, 1950). The rotating speed of the bucket is 28 kg/s × 1000 g × (1cm3/1.4g) = 20000 cm3/s.

The cross-sectional area of the bucket covered by the solution flowing at ground speed is evaluated as follows:

=2×3.14×r2×h

=2×3.14×15×15=1413 cm2

Ground speed is calculated as 20000 cm3/ 1413 cm2/s= 14.15 cm/s ≈ 14 cm/s

0.40 cm3= 2×3.14×r2×15

Therefore, the hole's diameter is determined to be r = dh = 0.065 cm×10 mm= 0,7 mm

Wells and Kerns reported that urea solution prills in a rotating bucket. The speed of the rotating bucket used was 5 m/s, and its hole diameter was between 0.95 – 1.2 mm. The size of the particles obtained in this bucket was 1.55 mm (dp= 1.5 dh). From these results, it was deduced that the viscosity of the solution is between 10-3 and 10 – 1 Ns/m2 and, that the diameter of the droplet's having a speed of 1-10 m/s is 1.5-2 times the diameter of the hole(Williams, 1946).

The feed speed was adjusted by controlling the rotating speed of the bucket. It was proved that neither the particle speed nor the feed speed influences the size of the particles (Datin, 1942).

The distance that the prills can travel in the horizontal direction is a function of the initial speed of the droplets and their sizes.

The droplet speed is denoted as follows (Van' t Land, 2005):

(π/6) ×dp3 ×(ρs - ρg) ×g= cw× (π/4) dp 2×(1/2) ×ρg × Vp2

where

ρs = solid density (kg/m3)

ρg = gas density (kg/m3)

cw = falling particle's resistance coefficient

Vp = particle speed (m/s).

If Reynolds < 1,

cw = 24/Re and Vp = (ρs - ρg) g ×dp2 /(18 μg) (m/s) (Stokes' Law)

1<Reynolds <1000

The above condition is used for describing the speed of the particle.

If 10 3 <Reynolds <10 5

cw = 0.43 and Vp = 1.76 ((ρs - ρg)g× dp / ρg), (m/s)

Discussion

Obtaining uniform standard sizes of prills is an issue, in terms of quality, faced by the industry. Hence, manufacturers are searching for a cost-effective solution for producing prilling equipment.

For the industrial sectors that manufacture of prills, the maximum and minimum prill size is determine by the amount of packing required. For an average prill size of 2 mm, a packing of 50 kg is required; the weight packing of 50 kg is required; the weight of the packaging reduces as the prill size decreases. Dissolution speed of the solvent is one of the most important parameters in the manufacturing of prill; the shape of the prilling bucket is designed based on the dissolution speed. The shape of the prilling bucket is important as it determines the shape of the prill formed.

Prills are manufactured, according to the requirements of the industry in which they are going to be employed; prills are employed mainly in the fertilizer, pharmaceutical and food industries. The prilling bucket that is manufactured the most has a geometric shapes and an oval surface. It is determined that the oval surface alters the size of the prills. Under ideal production conditions, a conical bucket can produce prills having diameters between 0.5 and 2.5 mm, whereas a cylindrical bucket can produce prills having diameters between 1 and 2 mm. the size it is determined that prills diameters are between 0.5 mm- 2.5 mm ,as for cylindrical bucket, these are between 1 mm and 2 mm. The size difference between the prills produced by these two buckets arises because geometrical form of the buckets; the amount of solution prilled in the conical bucket, which is a rotating bucket, is more than the amount of solution prilled in the cylindrical bucket because of the pressure force, which decreases from the bottom of the bucket to the bucket to the top of the bucket. Moreover, a conical bucket moves more freely than a cylindrical bucket, and hence, the prills can be sprayed effectively and directly.

From the results of the experiment, it is inferred that the solution should be prilled using a cylindrical bucket (figure 2).

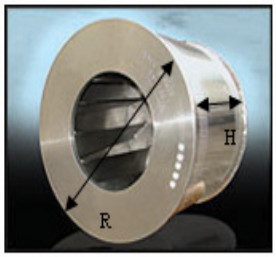

Figure 2. Side view of prilling bucket designed in this study. (R=30 cm, H= 50 cm)

Minimizing the pressure force at the bottom of the bucket, similar to the pressure force variation in a conical bucket, is the main aspect to be considered while designing a cylindrical bucket (figure 3).

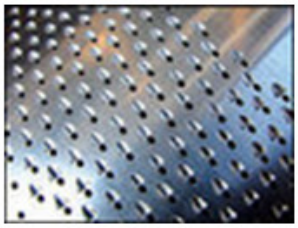

Figure 3. Prill bucket's holes (R=30 cm, H=50 cm)

Prills were manufactured in this study at a rate of 100 t per hour, which is similar to the operating speed used for manufacturing prills in factories. For the calculation of the pressure difference between prilling buckets, 97% ammonium nitrate was used. Using these results, we can design a prilling bucket that can be used in various industries.

Conclusion

In this study, a novel design of a prilling bucket for obtaining 2 mm diameter prills that can be used in the industry was realized. We manufactured prills at an average of 100 t per hour. A cylindrical bucket was designed with a 30 cm diameter, 50 cm height, and under these conditions, we obtained prills having a diameter of 1.75 – 2.25 mm (figure 4). These results

show that it is possible to obtain prills of similar size using the available prilling mechanisms.

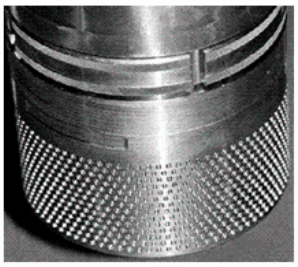

Figure 4. Front view of prilling bucket (R=30 cm, H= 50 cm)

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