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Assessment of Strength of Granules Prepared in Rotary Drum Granulator Based on their Residence Time

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Abstract : Various factors which affect the production and strength of granules prepared in Rotary drum granulator are particle size, residence time (Time of Rotation), Moisture and Binder. To get better production and strength of granules several experiments are carried out with varying time of rotation by keeping constant moisture and feed quantity. Less time of rotation leads to less formation of granules as nucleation plays an important role and more time of rotation leads to large size of granules, as in this case layering and coalescence plays major part. To determine the strength of granules a very important test i.e. Drop Test is done with repeated droppings and with varying height of dropping for different size of granules at wet and dried conditions. From the experiments and drop tests on different size of granules at different conditions, an optimum condition of time of rotation for feed is obtained which is responsible for more production and added strength of Granules.

Keywords: Strength of Granules, Time of Rotation, Moisture, Nucleation, Layering, Coalescence, Rotary drum granulator, Drop Test.

Introduction

Granules which are referred in this paper, prepared by wet granulation using an aqueous solution of corn starch as liquid binding agent to zirconium oxide powder and carbon are mixed in rotary drum granulator. When compared to briquettes, granules provide more surface area and porosity as feed for gas solid reaction which are mostly used in chemical industries.

Granulation[1] is a method to convert fine particles[2,3] into physically stronger and larger agglomerates[4] called as granules[5] with improved appearances, good flow property, better compression characteristics, mixing uniformity and reduce dustiness [6,7].

To perform particle size enlargement, a number of primary particles are to be bound to form agglomerate. This can be achieved using cohesive forces of the powder only (dry granulation)[8] or using capillary and viscous forces by addition of a binder liquid (wet granulation)[9].

Dry granulation

Dry granulation is a technique chosen, for instance, if the powder is sensitive to moisture. In dry granulation powder particles have to come in close contact with each other, to have the Vander Waals forces create the agglomerate. Slugging, which means the compression of a powder, is mostly used to obtain bonding. This can be performed in a roller compacter, in which powder particles are fed between two large rolls and thereby compacted. Sometimes even the presence of adsorbed layers of moisture is enough to bind particles.

Wet granulation[9]

In this process powder particles are mixed with liquid binders to produce granules. These granules are formed due the formation of inter-particle bonds between them. Liquid binder should be distributed through the powder by the help of mechanical agitation created by the granulator. A thorough mixing of binders and particles will develop liquid bridges among particles. As more liquid is added the tensile strength of these bonds will increase. These surface tension forces and capillary pressure among liquid particles (liquid bridges) are primarily responsible for initial granule formation and strength.

Granulation mechanism

Granules are formed due to formation of bonds between powder particles and these bonds must be strong enough to prevent breakdown of the final dried granules to powder in subsequent handling operations. There are five key mechanisms operating during the agglomeration process, but generally more than one will be applicable to any particular[10] system as shown in Figure 1.They are elaborated as follows:

Adhesion and cohesion forces

These forces help in formation of immobile liquid films that act like binder bridges.

Liquid bridges

The particle adhesion forces arise from surface tension of capillary pressure, from the liquid/ air system and the attraction between the surface of the solid substance and water.

Solid bridges

Solid bridges are bonds that are formed by the hardening of binder under high temperature. The force of the cohesion depends on a diameter of the contact area and strength of the bridge material.

Van der waals forces

These are attractive forces between solid particle surfaces. Decrease in size of solid particle stables agglomerates.

Form-closed bonds or interlocking bonds

Fiber and bulky particles are the examples of this case.

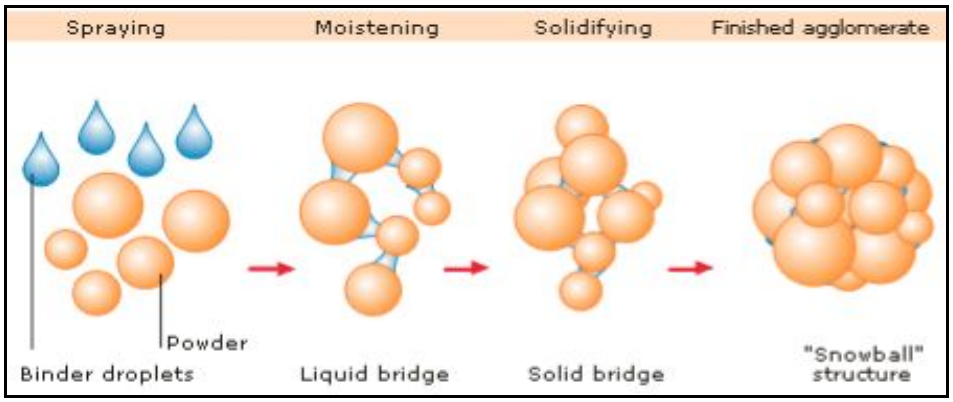

Figure 1.Process principle of Granulation

Three stages of wet granulation

The formation of granules in wet high shear granulators has been studied by several research groups. A thorough review has been presented by Iveson et al[11] and Summers et al [12], propose granulation to occur in three stages of nucleation, transition and ball growth.

Nucleation[13]

In this stage liquid bridges are formed between particles resulting in formation of a nucleus like structure. This nucleus structure is useful for successive enlargement of granules as shown in Figure 2.

Figure 2. Principle of Nucleation

Transition

Nuclei grow with two possible ways either by addition of single particle to the nuclei with the help of pendular bridges or by combination of two or more nuclei. These combined nuclei will be reshaped by the agitation process as shown in Figure 3.

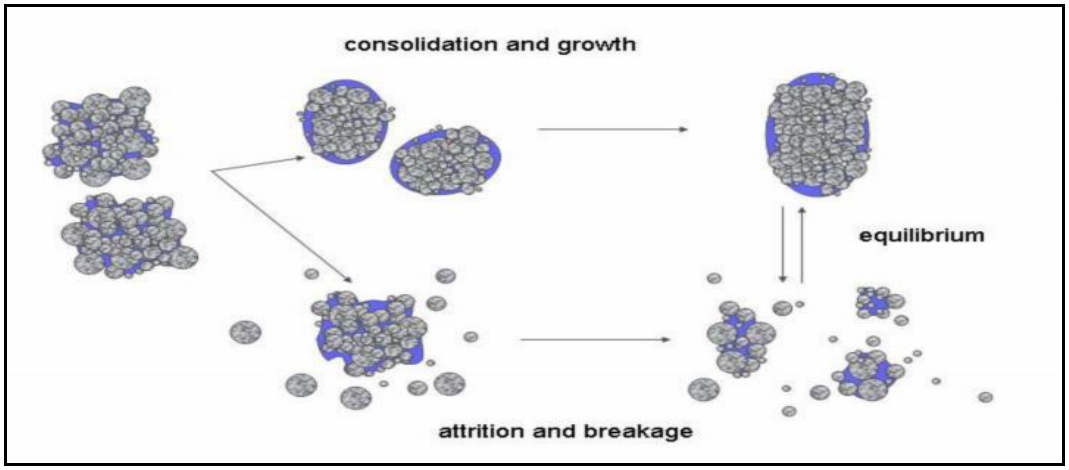

Figure 3.Principle of Transition

Ball growth

Further granule growth produces large, spherical granules and the mean particle size of the granulating system will increase with time[14].

There are four mechanisms involved for ball growth they are crushing and layering, coalescence, abrasion transfer and layering as shown in Figure 4[15].

a) Crushing and layering

In this process fragments of broken granules adhere to other granules and form a layer of material over the remaining granule.

b) coalescence[16]

Large granules are formed due to joining of two or more granules.

c) abrasion transfer

As a result of agitation in granulator there will be attrition of materials from granules. These abraded materials will adhere to other granules and increase in their size.

d) layering[17]

When the powder is added second time to granule bed it will adhere to the granules by forming a layer over the surface and results in increase of granule size.

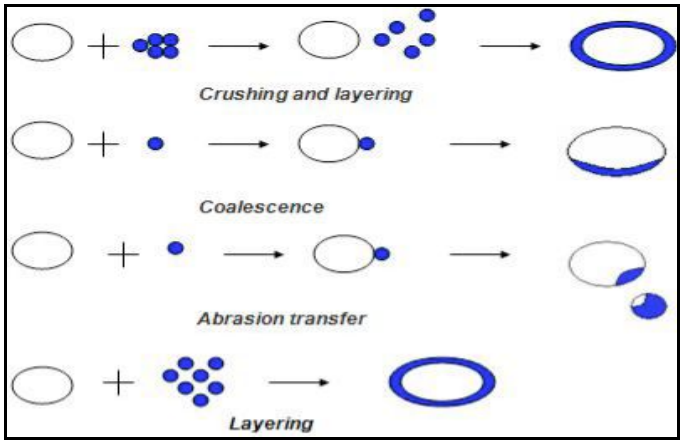

Figure 4. Ball growth Mechanisms

Granulation equipment

Granulation and agglomeration are the terms generally used to describe the process of particle formation or size enlargement. There are typically four main types of wet agitated granulating equipment based on the agitation process, they are drum granulators[18], pan granulators[19], fluidized bed granulators[20], mixed granulators (or high shear granulators)[21]. The agglomeration process in these granulators is dependent on material properties and process parameters[22] as shown in Figure 5.

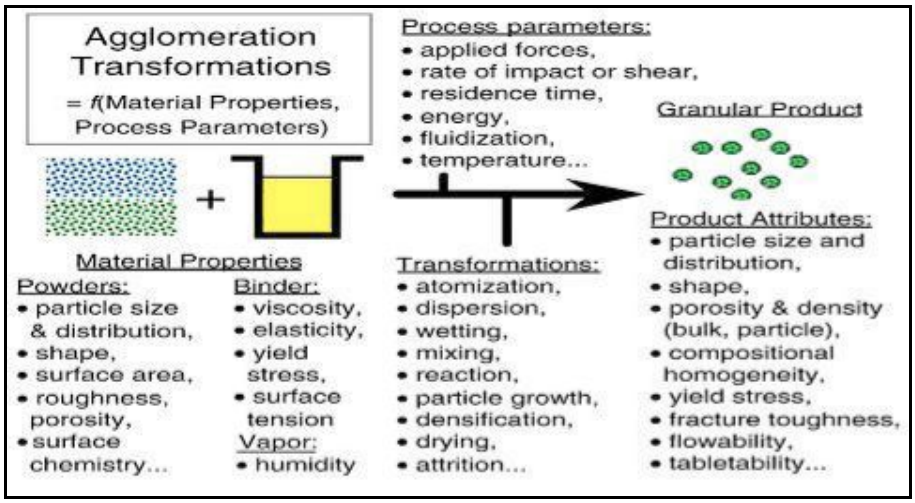

Figure 5. Agglomeration as a function of Material properties and Process parameters

Rotary drum granulator

Rotation drum granulators are mainly used for large capacities and heavy-duty materials where the binders are sprayed continuously over the rolled product during processing. The equipment is inclined at an angle up to 10° to help emptying the granules formed. The speed of rotation n is (0.30-0.55) nc, generally n is 8 to 20 rpm. The degree of filling is low (2-3%) and the length to diameter ratio (L/D) of drums is 2-5. The usage of maximum drum capacities can be noticed in chemical and metallurgy industries where drums with diameters up to 3m and length of 15 m are used to attain a capacity of 100 tons/h, capacity of the rotating drum depends on the properties of the product and agglomerates processed.

The key parameters that affect drum granulation process are moisture content, Initial size of feed particles, Rotational speed, Residence time, and Binder viscosity [23].

a) Moisture content

The moisture content should be at optimum levels depending on the material.

b) Rotational speed

The Rotational speed should be at optimum levels depending on the material. The optimal speed will allow particles to move in a cascading motion which increases the chance of coalescence and agglomeration.

c) Residence time

The residence time is proportional to particle growth, increasing residence time will ultimately increase growth and vice versa.

d) Binder viscosity

Binder viscosity also influences granulation i.e., more viscous binders cause granulation to occur to a higher degree.

The size enlargement process occurring in rotating drum is described as agglomeration process occuring on the bed of a rotating drum. Initially seed material is feed into the drum to which binding agent is later sprayed through a spraying system. Due to continuous rotation the material becomes uniformly moist and when further material is sprayed on to the bed, agglomerates are formed. Heat in the system can be controlled by the help of air fans as shown in Figure 6. After achieving the desired size, the granules are deposited on a vibratory screen separator where the granules are segregated into product and undersize granules. The product size granules are taken out of the processing area to storage. The undersize particles are directed to the granulating drum for further size enlargement.

The advantages and disadvantages of Rotating drum Granulator are given as follows

e) Advantages of rotating drum granulator are

1. Good construction and versatility
2. Large capacity and good control
3. Continuous or batch processing

f) Disadvantages of rotating drum granulator are

1. Relatively high energy is required
2. Large dimensions (space) and inefficient use of total volume
3. Non-uniformity of agglomerate size.

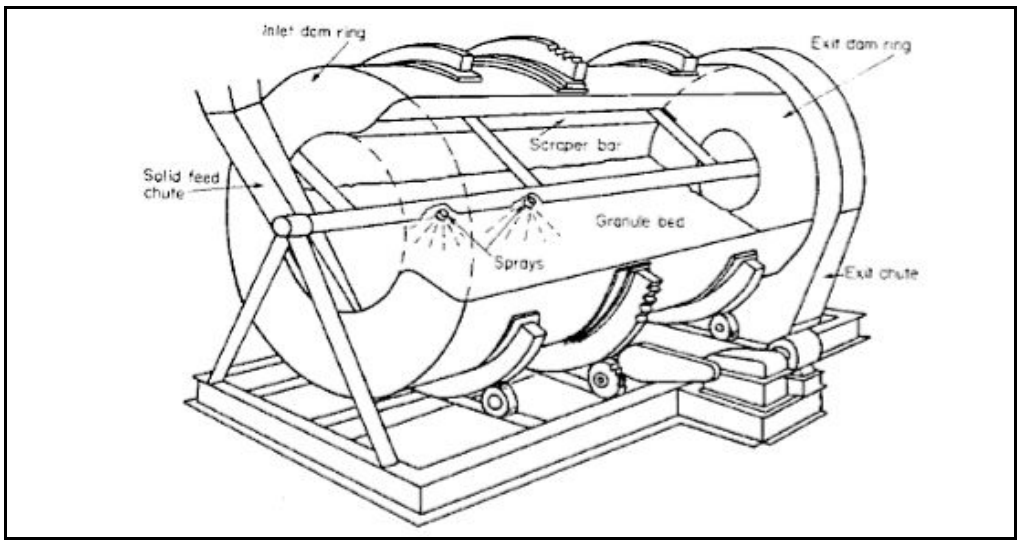

Figure 6. Drum Granulator

Quantifying pellet strength and durability

In the investigation of the characterization of a quality pellet, it was evident that a number of definitions exists regarding the strength and durability of pellets[24] which present clear definitions of each.

Strength

Strength refers to both the compressive and impact resistance of a pellet.

a) Compressive resistance

Compressive resistance testing simulates the loading due to self-weight in storage and the crushing of pellets in a screw conveyor. Compressive resistance, also referred to as hardness, is defined as the maximum compressive load that a pellet can incur before cracking. Compressive resistance is modeled using a diametrical compression test in which a single pellet is placed between two flat, parallel platens and an increasing load is applied at a constant rate until fracture. The load at fracture is read off of a recorded stress-strain curve and referred to as the compressive strength of the pellet.

b) Impact resistance

Impact resistance testing, models the impact forces induced on pellets during handling in the filling of silos, bins or storage bays when pellets are dropped either on a hard floor or onto one another.

Several methods have been used to establish the impact resistance of densified materials. All involve dropping a single particle several times from an established height and recording the mass or number of pieces retained above a specified particle size. ASTM method D440-86 (ASTM, 1998) of a drop-shatter test for coal was employed[25] for testing the durability of biomass logs. An impact resistance index (IRI)[26] was then calculated using an equation 1.

IRI=100(N/n) - ----equation 1.

Where, N = Number of drops, n = Total number of pieces after N drops

Since the standard number of drops employed by Li and Liu [25] was always two, the maximum value of IRI was 200.

Pellets were dropped from a height of 1.85 m onto a metal plate four times. Impact resistance was defined as the percentage of the initial weight retained after dropping.

Durability

Durability is defined by as the abrasive resistance of a densified product. Durability, as defined herein, is the most prevalent form of pellet quality analysis employed by pellet manufacturers and is used to adjust parameters during the pelleting process.

Hardness test

t is known that hardness reflects the resistance of material to its permanent deformation. Hardness of agricultural processed materials is measured based on crushing test. Kaliyan and Morey [24] investigated major factors that contribute to strength and durability of densified product, and they unveiled four major parameters: compression time, particle size distribution, moisture content, and compaction conditions.

A machine that is generally used for measuring the mechanical strength of materials (such as compressive strength and tensile strength) can also be used for determining the hardness of pellets. During the hardness test on pellets, the maximum load to break a pellet will be recorded. The Meyer hardness (MPa) is defined as the applied force (N, when the pellet is crushed) divided by the projected indentation area, knowing the indentation depth and the initial diameter of a pellet's cross section [27]. The maximum breaking force and the Meyer hardness of the pellets can be obtained from a typical force-displacement graph displayed during the test.

Drop test – theoretical development

Modes of pellet or granule breakage

Two major types of breakage are considered in pellets: volume breakage and surface breakage.

Volume breakage

In volume breakage the pellets are broken into smaller pieces including fine dust. This happens along the cracks, line of weakness when pellets experience impact force. After breakage the new fragments have smaller mean length than the pellet.

Dural[28,29] is an example of a device that imparts severe impact and shear on pellets to cause volume breakage

Surface breakage

For the case where the impact force is not large, enough surface breakage happens. In this case only abrasive forces cause chipping and removal of dust and fines from the surface of the pellets. For instance, vibration may cause surface breakage. The degree of dust generation in Surface breakage is less than that of volume breakage. Tumbler[30] is a good example of surface breakage. Pellets tested in tumbler remain in their original shape. Only small amount of dust is produced in Tumbler due to surface breakage. From our observation, these dusts and fines are mainly from the surface or corners of pellets.

In a drop test both kinds of breakages- volume and surface breakages happen depending on the impact force, which is affected by the mass of pellets and height from which pellets are dropped from.

Experimental drop tests

Drop tests with repeated droppings

A few samples of pellets are taken and repeated droppings are done until the surface and volume breakage of pellet is seen and Number of Drops are noted.

Drop tests with varying drop height

A few samples of pellets are taken and done repeated droppings with varying drop height from 45cm to 180cm and noted Number of Drops.

Drop tests with varying sample mass or size

A few samples of pellets are taken and repeated droppings are done with varying sample size of 3mm and 6-10mm with varying drop height of 45cm and 180cm and Number of Drops are noted.

Experimental

Feed

A Feed composition of Zirconium oxide, carbon, starch, moisture is thoroughly mixed in pug mill.

Experimental Feed quantity: 5kg

Feed divided into two halves (2.5kg+2.5kg) is added into two successive and different time intervals depending on type of experiment.

Moisture added

Moisture of 200ml (8% of Feed) is added during the first time interval and no moisture is added during second time interval.

Time of rotation

Varying different sets of time of Rotation like TOR(5+5), TOR(7.5+7.5), TOR(5+10), TOR(10+10), TOR (5+15) minutes respectively.

Figure 7. Experimental Rotary drum Granulator

Experimental rotary drum granulator

Rotary drum granulator has length 90cm and diameter of 36cm. Its L/D Ratio is 2.5.

It is rotating in anti clockwise direction placed in between two rollers rotating clock wise direction with the help of 2HP Motor as shown in Figure 7. It rotates at 31-33 rpm

Coking

Natural dried granules are loaded into a retort. The top lid of retort is bolted and nitrogen inlet and exhaust lines are assembled. The retort is now placed in a furnace. The nitrogen metering pipe is connected and the system is leak tested by pressurizing to 2 psig. A cooling water line is also connected. The system is flushed with nitrogen for ½ hr. The charge is then soaked at 650 ^{o}C for 12hrs to remove off gases N_2, H_2O and CO_2. The furnace is switched off and granules are allowed to cool in the furnace for 6 hrs. It is then cooled for 36 hrs in a cooling station. This process decomposes and removes starch in the form of off gases (CO_2, H_2O) as per the following reaction. Porous granules are obtained with this process.

$$(C_6 H_{10} O_5) n \longrightarrow 6C + 5H_2O$$

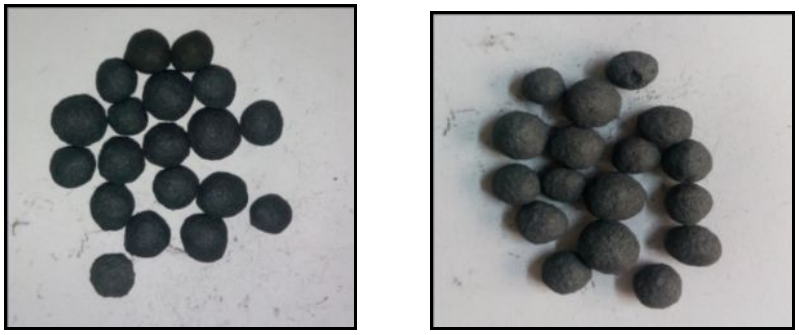

Figure 8. Samples of 6-10mm Granules before and after coking

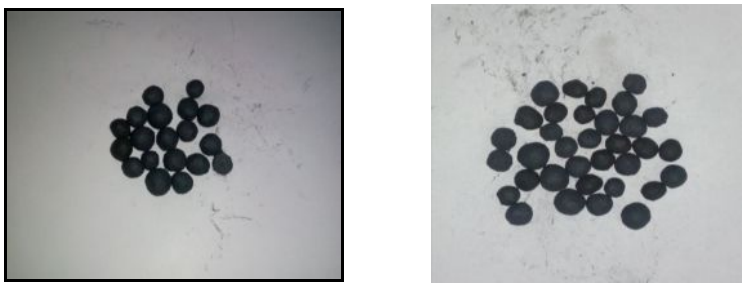

Figure 10. Samples of 3mm granules before and after Coking

Figure 12. Sample of different size of granules 3mm and 6-10mm

Set of experiments with varying time of rotation (tor)

TOR 10 minutes

a) TOR (5+5)

Total feed Quantity : 5 kg
Total Moisture added : 200 ml
Total Time of Rotations : 10 minutes

Procedure

Half quantity of feed (2.5kg) is taken and sprinkle 200ml of moisture on to the feed (8% of feed) in Rotary drum granulator and made it to rotate for half time interval (5minutes).Then add another half quantity of feed (2.5kg) without adding any moisture on to the feed and made it to rotate for another half time interval (5minutes). Remove the feed from Rotary drum granulator and made into sieve analysis of different size granules (3mm and 6-10mm). Weight and noted down the weight of respective (3mm and 6-10mm) wet granules as shown in Table1.

TOR 15 minutes

a) TOR (7.5+7.5) and TOR (5+10)

Total feed Quantity : 5 kg
Total Moisture added : 200 ml
Total Time of Rotations : 15 minutes

Procedure

Half quantity of feed (2.5kg) is taken separately for TOR (7.5+ 7.5) and TOR (5+10) in two different containers. Sprinkle 200ml of moisture on to the feed (8% of feed) in Rotary drum granulator and made it to rotate for half time interval 7.5minutes for TOR (7.5+ 7.5) and 5minutes for TOR (5+10). Another half quantity of feed (2.5kg) is added without adding any moisture to the feed and made it to rotate for another half time interval 7.5minutes for TOR (7.5+ 7.5) and 10minutes TOR (5+10). Remove the feed from Rotary drum granulator and made into sieve analysis of different size granules (3mm and 6-10mm). Weight and noted down the weight of respective (3mm and 6-10mm) wet granules as shown in Table1.

5.3. TOR 20 minutes

a) TOR (10+10) and TOR (5+15)

Total feed Quantity : 5 kg
Total Moisture added : 200 ml
Total Time of Rotations : 20 minutes

Procedure

Half quantity of feed (2.5kg) is taken separately for TOR (10+10) and TOR (5+15) in two different containers. Sprinkle 200ml of moisture on to the feed (8% of feed) in Rotary drum granulator and made it to rotate for half time interval 10minutes for TOR (10+10) and 5minutes for TOR (5+15). Another half quantity of feed (2.5kg) is added without adding any moisture to the feed and made it to rotate for another half time interval 10minutes for TOR (10+10) and 15minutes TOR (5+15). Remove the feed from Rotary drum granulator and made into sieve analysis of different size granules (3mm and 6-10mm). Weight and noted down the weight of respective (3mm and 6-10mm) wet granules as shown in Table1.

Table 1. weight of different sizes of granules based on different time of rotation (TOR)

S.NO.	Experiment type	Weight of Wet granules (3mm)	Weight of Wet granules (6-10mm)
1.	TOR 10 minutes TOR (5+5)	2.4	0.4
2.	TOR 15 minutes a)TOR (7.5+7.5)	2.6	0.5
	b)TOR (5+10)	1.2	1.4
3.	TOR 20 minutes a)TOR (10+10)	2.1	0.7
	b)TOR (5+15)	1.3	0.9

Drop tests on wet granules (before coking)

A sample of 3 pellets of each experiment are taken and done repeated droppings with varying sample size 3mm, 6-10mm with varying drop height 45cm, 180cm and noted number of drops as shown in table 2.

Table 2. Drop tests on wet granules (before coking)

S.no.	Experiment type	Drop test (3mm)		Drop test (6-10mm)	
		45 cm	180 cm	45 cm	180 cm
1.	TOR 10 minutes TOR (5+5)	140,171,147	5,4,5	25,28,20	2,3,2
2	TOR 15 minutes a)TOR (7.5+7.5)	243,228,233	8,10,7	34,25,40	4,5,3
	b)TOR (5+10)	217,231,225	14,21,11	149,121,91	6,8,7
3.	TOR 20 minutes a)TOR (10+10)	114,118,131	3,5,3	44,38,52	2,2,2
	b)TOR (5+15)	143,155,148	14,8,3	26,30,22	4,4,3

Results and Discussion

A Schematic representation as shown in Figure 13 and Figure 14 determines how the weight of different size granules increasing and decreasing or increasing by varying time of rotation. More production is observed of desired size 6-10mm granules at TOR (5+10) condition and 3mm at TOR (7.5+7.5) condition.

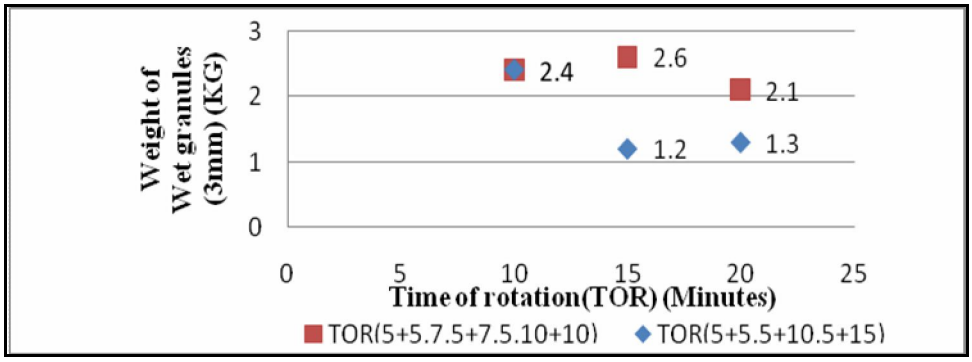

Figure 13.Weight of Wet Granules (3mm) vs Time of Rotation (TOR)

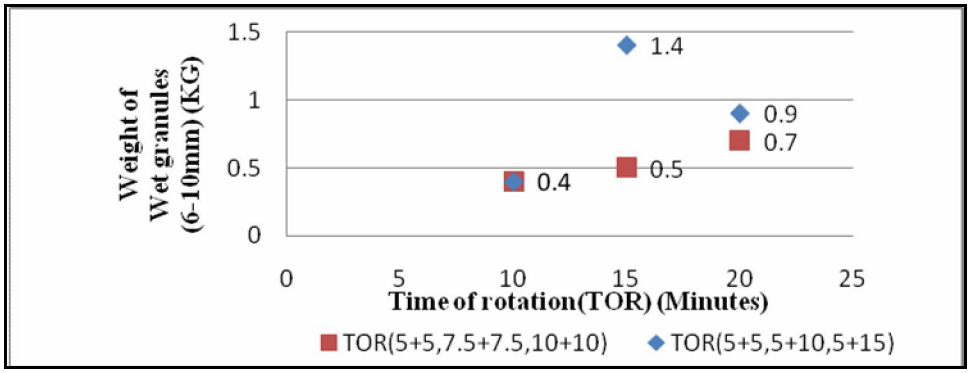

Figure 14.Weight of Wet Granules (6-10mm) vs Time of Rotation(TOR)

As shown in Figure 15 and 16 determining the no. of droppings where 3mm size of granules are breaking at 45cm and 180cm respectively. From this figures we can see more no. of droppings are done at the condition TOR (5+10) in both the cases and from 45cm more no. of droppings are at TOR (7.5+7.5) condition.

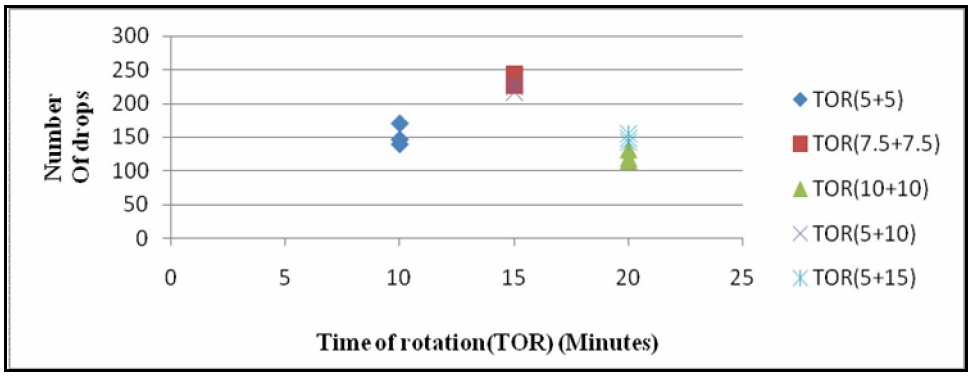

Figure 15. Number of Drops from 45cm vs Time of Rotation ((TOR) for 3mm Size of Granules

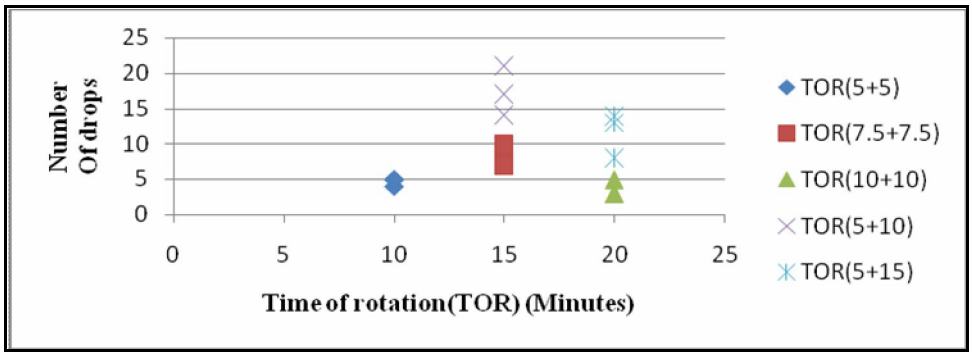

Figure 16. Number of Drops from 180cm vs Time of Rotation((TOR) for 3mm Size of Granules

As shown in figure 17 and 18, determining the no. Of droppings where 6-10 mm size of granules are breaking at 45cm and 180cm respectively. From this figures it is observed that more no. of droppings are done at the condition TOR (5+10). It is concluded that this condition TOR (5+10) is giving more strength to different size of granules.

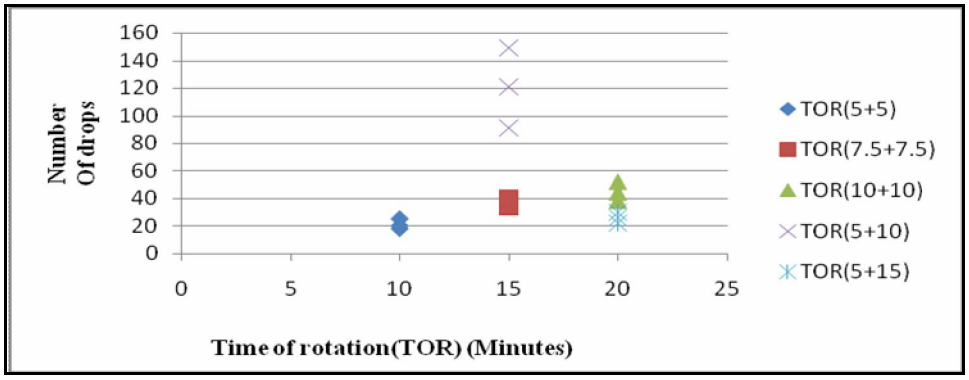

Figure 17. Number of Drops from 45cm vs Time of Rotation ((TOR) for 6-10mm Size of Granules.

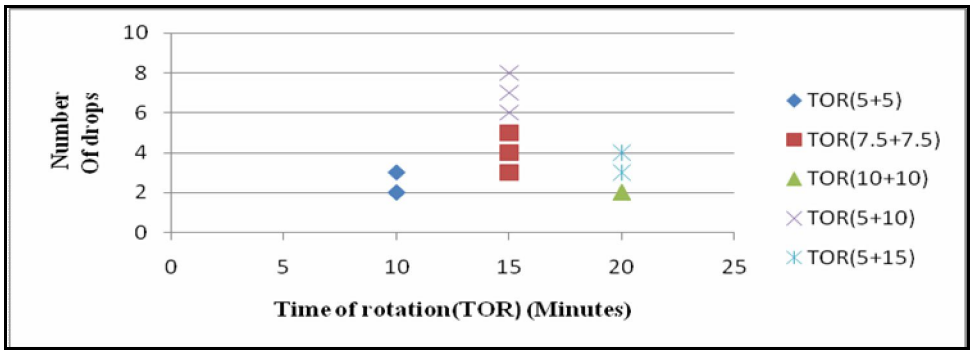

Figure 18. Number of Drops from 45cm vs Time of Rotation (TOR) for 6-10mm Size of Granules.

Set of experiments with varying time of rotations (TOR) after coking

Table 3.Weight of different size of granules based on different time of rotation (tor) after coking

S.NO.	Experiment type	Weight of dried granules (3mm)	Weight of dried granules (6-10mm)
1.	TOR 10 minutes TOR (5+5)	2.1	0.3
2.	TOR 15 minutes a)TOR (7.5+7.5)	2.3	0.4
	b)TOR(5+10)	1	1.2
3.	TOR 20 minutes a)TOR(10+10)	1.8	0.5
	b)TOR (5+15)	1.1	0.7

Table 4. Drop tests on dried granules (after coking)

S.no.	Experiment type	Drop test (3mm)		Drop test (6-10mm)	
		45 cm	180 cm	45 cm	180 cm
1.	TOR 10 minutes TOR (5+5)	2,2,2	1,1,1	1,1,1	1,1,1
2	TOR 15 minutes a)TOR (7.5+7.5)	2,1,2	1,1,1	1,2,1	1,1,1
	b)TOR (5+10)	4,3,2	1,2,2	2,2,1	1,2,1
3.	TOR 20 minutes a)TOR (10+10)	2,2,3	1,1,1	2,1,2	1,1,1
	b)TOR (5+15)	2,2,2	1,1,1	1,1,1	1,1,1

Results

After coking, starch and moisture are removed with natural drying as discussed in 4.5. So, Weight of two different sizes of granules is decreased as shown in Table 3 and from Figures 19 and Figure 20.

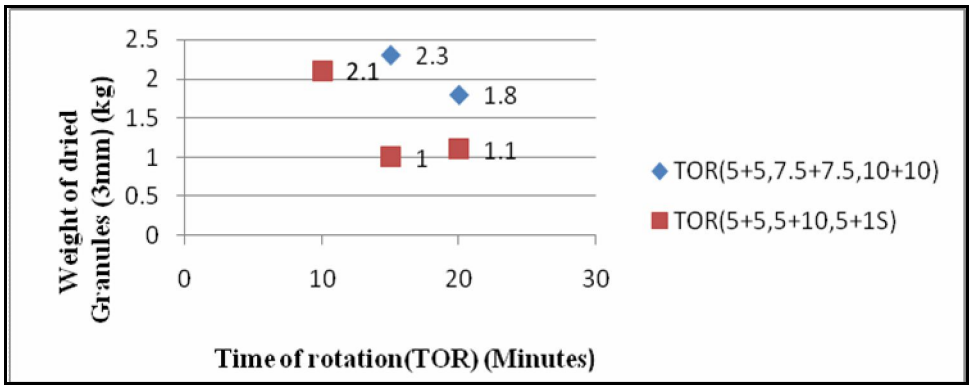

Figure 19. Weight of Dried Granules(3mm) vs Time of Rotation (TOR)

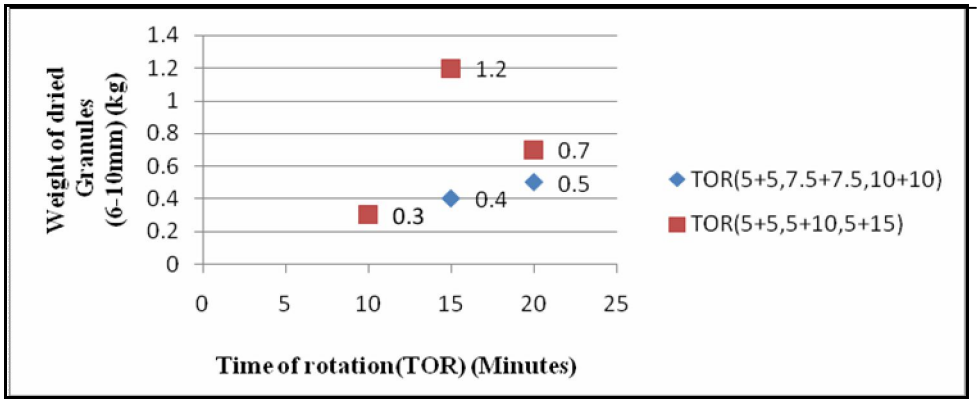

Figure 20. Weight of Dried Granules (3mm) vs Time of Rotation (TOR)

Number of droppings from 45cm and 180cm of different size of granules is decreased after coking as shown in Table 4, as also observe in figures 21 and 22. Thus the strength of granules is decreased after coking as binding agents, moisture and starch are removed during coking.

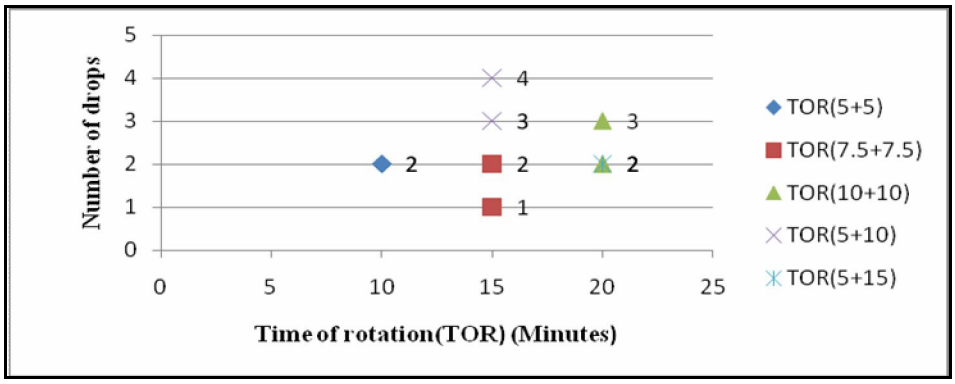

Figure 21. Number of Drops from 45cm of 3mm Size of Granules vs Time of Rotation (TOR)

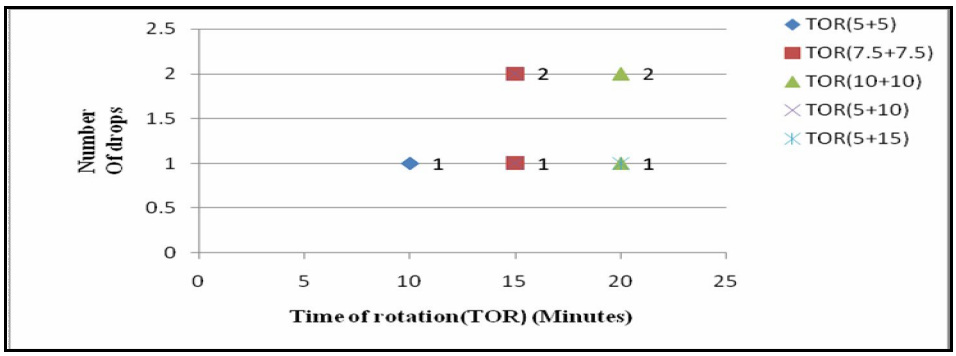

Figure 22. Number of Drops from 45cm of 6-10mm Size of Granules vs Time of Rotation(TOR)

From table 4 it is observed that at 180cm the no. of droppings for breaking of granule is almost same in all conditions expect at TOR (5+10) condition where it shows more no. of droppings.

Conclusion

As time of rotation increases, formation of desired granules also increases until an optimum condition is reached, then further increase in residence time leads to large granules (undesired) and vice versa (deformation of desired granules into small granules). Nucleation, layering, coalensence of granules should be done in optimum condition to obtain high strength granules. As we observed in TOR(5+5) condition, proper nucleation is done in first five minutes, absence of layering and coalensence is observed in second five minutes due to insufficient residence time. In TOR(5+10) condition, proper nucleation and layering is observed in five and ten minutes respectively. In TOR(5+15) condition, sufficient nucleation and more layering is observed in five and fifteen minutes respectively. Rest of the conditions are best for continous production of granules. This TOR(5+10) condition is to be considered as optimum condition in terms of production and strength of desired granules and further research should be recommended.

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References

1. James O., Althaus T., Forny L., Neideiretter G., Palzer S., Hounslow M. and Salman A.D., Bonding Mechanisms Involved in the Roller Compaction of an Amorphous Material, Chemical Engineering Science 86 (5th International Granulation Workshop), 2013, 61–69.
2. Eichie F.E. and Kkudehinbu A.O., Effects of particle size granules on some mechanical properties of paracetamol tablets , African journal of biotechnology, 2009, 8(21), 5913-5916.

3. Garcia E., Mesquita-Guimaraes J. and Miranzo P., Porous mullite and mullite–ZrO_2 granules for thermal spraying applications, Surface and Coatings Technology, 2011, 205 (17–18), 4304–4311.
4. Heinze "Handbuch der Agglomerationstechnik" (Handbook of Agglomeration Technology), Wiley-
5. VCH, Weinheim, (2000).
6. Lindberg N.O., The granulation process, in Industrial aspects of Pharmaceutics, E.Sandell, Editor. Swedish Pharmaceutical Press: Stockholm,(1993).
7. Agrawal R. and Naveen Y., Pharmaceutical processing – a review on wet granulation technology, Inter. J. Pharma. Frontier Res., 2011, 1(1), 65-83.
8. Gabriel I.T., Wet-granulation research with application to scale up China. Particuology, 2005, 3,191–195.
9. Kaur G., Gera M., Pallavi, Bassi A. and Tiwary K., International Journal of Drug Delivery, 2011, 3, 397-414.
10. Hapgood K., Nguyen T. and Shen W., A case study of drug distribution in wet granulation, In World Congress on Particle Technology, Sydney, Australia, 2000.
11. Barbosa-Cánovas, G.V. Foodpowders: Physicalproperties,processing, and functionality, Kluwer Academic/Plenum, New York, 2005.
12. Iveson S.M., Litster J.D., Hapgood K. and B.J. Ennis, Nucleation, growth and breakage phenomena in agitated wet granulation processes: a review, Powder Technology, 2001, 117, 3-39.
13. Summers M. and Aulton M., Granulation: In M. Aulton (Ed), Pharmaceutics, The science of dosage form design, Churchill Livingstone, Spain, (2002) 364-378.
14. Hapgood K.P., Litster J.D. and Smith R., Nucleation regime map for liquid bound granules, Aiche Journal,49, 2003, 350-361.
15. Parikh D.M., Handbook of pharmaceutical granulation technology, Informa Healthcare, Maryland, USA. 2005.
16. Aulton M.E., Pharmaceutics-the science of dosage form design. 2nd edition, Churchill Livingstone, Edinburg. 2002.
17. Kal Sastry V.S., Dontula P. and Hosten C., Power Technology, 2003, 130, 231-237.
18. Rao P. S. S., Suman V., Krishna V.V., Belwal S. and Rao M. B. Int. Journal of Engineering Research and Applications, 2015, 5(10), 60-64.
19. Salmon A.D., Jonathan M.J.H. and Seville P. K., Hand book of powder technology granulation. 2007.
20. Saravacos G.D. and Kostaropoulos A.E., Handbook of Food Processing Equipment, Plenum Publishers, 2003.
21. Rantanen J., Känsäkoski M., Suhonen J., Tenhunen J., Lehtonen S., Rajalahti T., Mannermaa J. and Yliruusi J., Next Generation Fluidized Bed Granulator Automation, AAPS Pharm. Sci. Tech., 2000,1(2), article 10.
22. Knop K. and Kleinebudde P., Excipients & Actives for Pharma, 2005, 15, 2-5.
23. 22. Mort P.R., Scale-up and control of binder agglomeration processes -Flow and stress fields, Powder Technology, 2009, 189 (2), 313-317.
24. Walker G.M., Drum granulation processes. Elsevier science, Amsterdam, Netherlands, 2007.
25. Kaliyan N. and Morey R. V., Densification Characteristics of corn stover and switchgrass, Transactions of the ASABE, 2009, 52(3), 907-920.
26. Li Y. and Liu H., High-pressure densification of wood residues to form an upgraded fuel, Biomass and Bioenergy, 2000, 19: 177-186.
27. Richards S.R., Physical testing of fuel briquettes, Fuel Process Tech., 1990, 25, 89-100.
28. Tabil L.G., Sokhansanj S., Crerar W. J., Patil R. T., Khoshtaghaza M. H. and Opoku A., Physical characterization of alfalfa cubes Hardness, Canadian Biosystems Engineering, 2002, 44(3), 55-63.
29. Adapa P. K., Schoenau G. J., Tabil L.G. and Singh A., Prediction of hardness and durability of alfalfa cubes processed from fractionated sun-cured and dehydrated alfalfa chops, Biosystems
30. Engineering, 2007, 98(4), 430-436.
31. Mani S., Sokhansanj S., Bi X. and Turhollow A., Economics of Producing Fuel Pellets from Biomass, Applied Engineering in Agriculture, 2006, 22(3), 421-426.
32. Temmerman M., Rabier F., Jensen P.D., Hartmann H. and Böhm T., Comparative study of durability test methods for pellets and briquettes, Biomass and Bioenergy, 2006, 30, 964- 972.

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