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Fluidized Bed Granulation Parameters Effect on Urea Granule Physical Properties

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Abstract

The aim of this study is to determine the effect of different airflow patterns and process conditions on the physical properties of granules produced using fluidized bed granulation technique. It was observed that spiral airflow was the most important factor to produce granules with required size and density under similar process conditions if compared with normal airflow. From ANOVA, binder spray pressure and bag shake duration showed the strongest influence on hardness of granules on both types of airflow patterns. Optimization studies for spiral and normal airflow proved that granules with desired density and hardness can be produced at middle level of wind velocity and binder spray pressure together with high level bag shake duration. For spiral airflow, the optimum value for wind velocity, binder spray pressure and bag shake duration was 28 m/s, 0.31 MPa and 60 s respectively; for normal airflow, it was 25 m/s, 0.20 MPa and 15 s respectively.

Keywords: Air flow pattern; Spiral; ANOVA; Density; Hardness; Wind velocity; Binder spray pressure; Bag shake duration; Response surface methodology.

Nomenclature

g/cm^3	granule density	N	granule hardness
Hz	fan speed	rpm	binder feed rate
MPa	binder spray pressure	w/v%	binder concentration
m/s	fluidized air velocity		

1. Introduction

Fluidization is normally applied in chemical/physical-based operations. In chemical operations, it is used to know the solid-gas reaction; in physical operations, it can be used for transportation, heating and mixing of fine powder, combustion of coal and so on. The changes in the parameters such as the gas velocity, size and density of particles will change the behavior of fluidized bed. The bed considered as fluidized only if the gas velocity reached the incipient fluidization point. It is the point at which the pulling force was equal or greater than the force of gravitation (Smith 1980).

The development of fluidized bed granulation was begun when Wurster reported his fluid bed experiments were success to prepare the compressed tablets using air suspension (Wurster 1959). Fluidization is a process which subjects a granular material in solid state to behave like a fluid. While, granulation is an enlargement process that gathers fine particles into a larger mass of aggregates by spraying binder solution to the dry powder bed (Roy *et al*. 2009). It can be categorized into two types, either wet granulation or dry granulation. With the used of liquid binder, the granulation is classified as a wet process. The binder solution is sprayed onto the solid particles to agglomerate them and the formed granules are then going through the drying process to extract the excess solvent to form permanent bonds between particles (Villa *et al*. 2016).

Fluidized bed granulation can be classified into three different types which are top spray, bottom spray and tangential spray. Each of this technique has its own function in granulating the seeds. For instance, top spray and tangential spray of fluid bed are commonly applied in granulation process while the fluid bed bottom spray is normally applied in industry of pharmaceutical to make film coating and layering with superior properties (Srivastava and Mishra 2010) .

One of the factors that affect the size and strength of granule formed is the concentration in binder solution. It has been reported that increase in the binder concentration of binder solution will increase the size of granules (Kivikero 2010; Patel *et al*. 2010). As the drying process is occurred simultaneously in fluidized bed granulator, the solvent evaporates and creates a stronger liquid bonding and steady agglomerates when binder solution with higher concentration is applied. This in turn will increase the size of granules.

Nucleation and growth mechanism in fluidized bed granulation were influenced by the droplet size of binder. When the size of droplet was tinier than solids, distribution mechanism developed, and collisions occurred between the wetted particles to produce the nuclei (Patel *et al*. 2010).

Shaking of filter bags in fluidized bed granulator was important to achieve a successful granulation process. This was because the particles for the process may built up a thick layer on the surface of fabric filter bags. This phenomenon affected the pressure drop to increase and caused the fluidization occurred improperly. Hence, the cleaning process for the filter bags was necessary through the periodic shaking of the bags. The relationship between the shaking cycle of the filter bags with the size distribution of granules produced in fluidized bed granulator. The result showed that the distribution of particle size was able to improve by optimizing the bag shake duration (Rawley 1989) .

The pattern of air flow was depend on the gas distributor applied where its function was to distribute the fluidization gas evenly through the powder bed to enhance performance of gas-solid contacting. The gas distributor used affected the volume of gas bypassed (Ouyang and Levenspiel 1986). Hence, a lot of designs for distributor plate have been generated to improve the effectiveness and efficiency of fluidization process. The plate designs will also affected the hydrodynamic in bed and the heat and mass transfer rate in fluidization process (Wormsbecker and Pugsley 2007) .

Wind velocity or the fluidizing air velocity will decide the characteristics and granule growth mechanism as it influenced the mixing of particles, distribution of binder, drying rate and process steadiness (Vengateson and Mohan 2016) . An experiment had been conducted to study the effect of different excess fluidising gas velocity ranging from 0.15 m/s to 0.525 m/s (Smith and Nienow 1983) . The results indicated that the particle growth rate was decreased at high excess gas velocity. When the gas velocity was high, it increased the particles circulation rate and caused the bed quenching to reduce and formed larger agglomerates . Furthermore, the high velocity of gas caused the energy between particle-particle collisions and particles with the wall of chamber increased and break the solid bridge combining the particles in primary seeds (Veliz Moraga *et al*. 2015).

The aim of this study is to determine the effect of different airflow patterns and process conditions on the physical properties of granules produced using fluidized bed granulation technique.

2. MATERIALS AND METHODS

2.1 Material Preparation

The starting material or seeds used for this study was commercial urea N46 fertilizer granules ($(CO(NH_2)_2)$) which had about 46% nitrogen content. 150g of urea granules were ground into powder form by using the commercial blender. This process will take about 10 minutes to finish. The formed powder was then filtered by using electromagnetic sieve shaker with sieve tray of 1 mm mesh size to isolate the coarse particles.

2.2 Binder Preparation

The binder solution was prepared in a mixing ratio of 3:2. The total volume which combined volume of solute and solvent was 400 ml and it was stirred and heated continuously on a hot plate stirrer at 325 rpm and 60 °C.

2.3 Fluidized Bed Granulation

Table Top Spray Fluidized Bed Granulator machine produced by Changzhou Jiafa Granulating Drying Equipment Co., Ltd was used as the main granulation equipment in this study. The granulator could produced 500 grams of granules per batch of production with a maximum fan speed of 50 hertz (Hz) and able to fluidize the heated air up to 100 °C. Its chamber can be divided into two parts, top and bottom. The bottom chamber together with the required distributor plate either perforated or spiral air distributor was connected to the inlet air plenum and locked after the top chamber which attached with four fabric filter bags installed to the bottom chamber with the prepared urea seeds put inside the bed of chamber. Figure 1 showed schematically the main part of the fluidized bed granulation process.

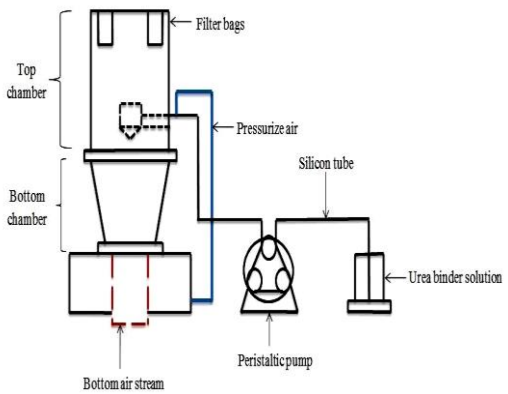


Fig.1. Equipment and experimental setup for fluidized bed granulation.

The top spray nozzle was installed vertically inside the column which entered from the side of top chamber at various selected height. It was then connected to the pressurize air. The 60 w/v % urea binder solution was channeled and fed by peristaltic pump through silicon tube which connected to the nozzle at pre-determined pulse rate and spray pressure to produce an atomized binder droplet.

Electromagnetic sieve shaker were used to select granules with the size of 2 to 4mm (Ivell and Nguyen 2014) . MD-300S electronic densimeter and VinSyst portable tablet hardness tester were used to determine the true density and crushing strength of granules that were formed. Each reading obtained was the average of five samples.

The optimal response was obtained using the response surface methodology with central composite design for a quadratic model response variables of the wind velocity, spray pressure and bag shake duration

3. Results

3.1 Effect of Airflow Pattern and Process Variables on Granule Size.

Table 1, Table 2 and Fig. 2 summarized the results of different types of airflow and process conditions on the total amount of desired urea granules produced from 200g of urea powder seeds. The other conditions in granulation such as binder feed rate, binder concentration, inlet air temperature was remained constant at 3.5 rpm, 60 w/v % and 45 ºC respectively.

Table 1 Proportion of granules formed using spiral airflow fluidization

Wind Velocity (m/s)	Spray Pressure (MPa)	Bag Shake Duration (s)	Percentage of Granules Formed (%)
23.00	0.25	37.50	0.63
9.00	0.25	37.50	2.28
37.00	0.10	15.00	2.91
23.00	0.10	37.50	2.43
37.00	0.40	15.00	1.00
9.00	0.10	15.00	2.01
23.00	0.40	37.50	1.61
37.00	0.10	60.00	4.97
9.00	0.40	15.00	2.32
23.00	0.25	15.00	2.21
23.00	0.25	60.00	4.08
9.00	0.40	60.00	1.58
37.00	0.25	37.50	0.05
37.00	0.40	60.00	2.15
9.00	0.10	60.00	0.00

Percentage of desired granule formed for fifteen run of experiments in each airflow pattern was shown in Fig. 2. Formation of granules were strongly affected by the air distribution patterns in fluidized bed unit. Zero percentage indicated no granules were formed for the specified experiment. The spiral distributor plate showed better granule formation against the normal plate.

This might be explain by the better gas distribution which can increase the effectiveness of gas-solid contact and maximize the movement of particles thus improved the quality of fluidization.

Table 2 Proportion of granules formed using normal airflow fluidization

Wind Velocity (m/s)	Spray Pressure (MPa)	Bag Shake Duration (s)	Percentage of Granules Formed (%)
23.00	0.25	37.50	0.23
9.00	0.25	37.50	0.80
37.00	0.10	15.00	0.00
23.00	0.10	37.50	1.86
37.00	0.40	15.00	3.15
9.00	0.10	15.00	2.10
23.00	0.40	37.50	5.88
37.00	0.10	60.00	0.00
9.00	0.40	15.00	5.91
23.00	0.25	15.00	0.27
23.00	0.25	60.00	0.00
9.00	0.40	60.00	0.25
37.00	0.25	37.50	0.00
37.00	0.40	60.00	0.00
9.00	0.10	60.00	2.32

It was observed that in average less than 6 % of desired granules were produced from 200g of initial input urea powder. Most of the granules formed were either undersize/oversize or formation of big lumps due to overwet as shown in Figs. 3 (a), (b) and (d). Overwetted powder bed became defluidized causing unformed granules during unsuccessful runs.

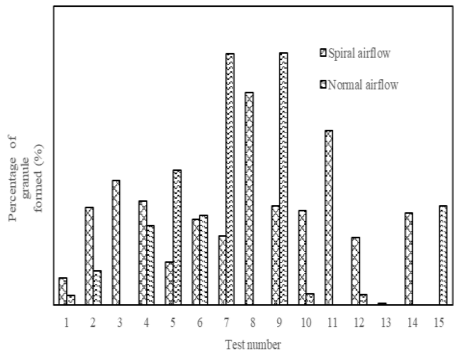


Fig. 2. Illustrate the proportion of granules formed at each run for the normal and spiral airflow.

At maximum fluidized air velocity of 37 m/s and 0.4 MPa binder spray pressure most of the granules formed were undersize as shown in Fig. 3 (a). High velocity of gas caused the particles circulation rate to increase and when the small droplets of binder come into contact with the small seed particles and will form smaller granules. This was due to the fact that binder droplets of smaller size could only gather less particles, resulting in the formation of smaller granules. An increased in the fluidization air velocity would significantly increase the amount of fine granules formed (Charinpanitkul *et al*. 2008). Under this two conditions, left over of fine particles adherent to the four filter bags at the end of granulation process as shown in Fig. 4 (a).

Table 3 Effect of airflow pattern under same process conditions on granule density

Run	A: Wind Velocity (m/s)	B: Spray Pressure (MPa)	C: Bag Shake Duration (s)	Density (g/cm^3)	
				Spiral	Normal
1	23	0.25	37.5	1.4531	1.1335
2	9	0.25	37.5	1.0435	0.9146
3	37	0.10	15.0	0.9775	0.0000
4	23	0.10	37.5	1.4215	1.0225
5	37	0.40	15.0	1.454	1.1328
6	9	0.10	15.0	1.363	1.5048
7	23	0.40	37.5	0.946	1.0595
8	37	0.10	60.0	1.1919	0.0000
9	9	0.40	15.0	1.3165	0.9845
10	23	0.25	15.0	1.3609	1.3264
11	23	0.25	60.0	1.7408	0.0000
12	9	0.40	60.0	1.1670	1.2340
13	37	0.25	37.5	1.2346	0.0000
14	37	0.40	60.0	1.3357	0.0000
15	9	0.10	60.0	0.0000	1.0856

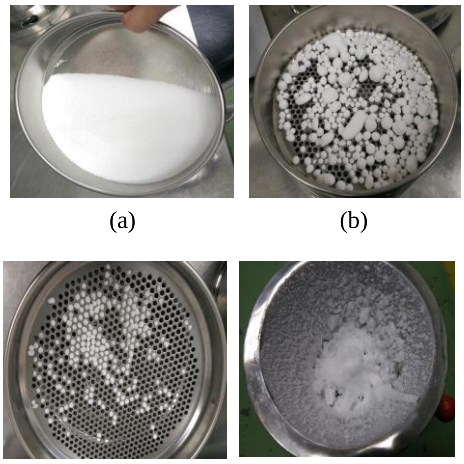


Fig. 3. Urea granules formed: (a) Undersize (b) Oversize (c) Desire granule size (d) Lump.

Lower nozzle spray pressure might cause an undesired droplet size of binder which may lead to the failure of granulation process. Overwetted powder bed will occur when the binder droplets were distributed unevenly and too large to wet the small urea particles. Wet agglomerates will then formed through the liquid bridge between the particles causing the powder bed to defluidize and adhere together to form a big lump of particles (K.Saleh and P.Guigon 2007). This phenomenon was known as wet quenching as presented in Fig. 3 (d). It was observed that if the low wind velocity and spray pressure applied, more wet particles collided and adhere to the wall of chamber due to fact that the solidification time for large wet agglomerates was longer as shown in Fig. 4 (b).

Table 4 Effect of airflow pattern under same process conditions on granule hardness

Run	A: Wind Velocity (m/s)	B: Spray Pressure (Mpa)	C: Bag Shake Duration (s)	Hardness (N)	
				Spiral	Normal
1	23	0.25	37.5	1.2406	1.2000
2	9	0.25	37.5	1.0500	1.0875
3	37	0.10	15.0	1.0380	0.0000
4	23	0.10	37.0	0.5750	0.9800
5	37	0.40	15.0	0.9540	0.8596
6	9	0.10	15.0	1.3970	3.9080
7	23	0.40	37.5	1.7570	1.8655
8	37	0.10	60.0	0.4750	0.0000
9	9	0.40	15.0	0.9670	4.3125
10	23	0.25	15.0	0.8600	1.6398
11	23	0.25	60.0	1.6350	0.0000
12	9	0.40	60.0	2.2200	3.3046
13	37	0.25	37.5	0.0000	0.0000
14	37	0.40	60.0	0.0000	0.0000
15	9	0.10	60.0	0.0000	1.1346
8	37	0.10	60.0	0.4750	0.0000
9	9	0.40	15.0	0.9670	4.3125

(a) (b)

Fig. 4. Problems in fluidized bed granulation process: (a) Particles remained at filter bags (b) Particles adhere to chamber wall.

3.2 Effect of Airflow Pattern and Process Variables on Granule Density

Table 3 and 4 summarized the results of spiral/normal airflow pattern and different process conditions on the density and hardness of urea granules produced. Figure 5 illustrated the density gained by urea granule from each batch of granulation process under equal process conditions for two different airflow pattern. The density of granules was ranging from about 0.98 g/cm^3 to 1.74 g/cm^3 for spiral airflow while it was ranging from 0.91 g/cm^3 to 1.50 g/cm^3 for normal airflow. The results showed that different airflow pattern influenced the density of granule produced in the fluidized bed granulation process. Spiral airflow can provide better performance in producing urea granule which can meet the minimum theoretical density of 1.20 g/cm^3 (Lee and Kopytowski 1979). The percentage of desired granule density produced in spiral and normal airflow was 73% and 20% respectively. Spiral airflow provide adequate drying time thus allowed proper fluidization of granules and provided enough time to allow diffusion of the moisture from the granulation core to the surface. This may well contribute to increase density value using the spiral airflow fluidization method compared to the normal air flow (Gao *et al*. 2000).

xANOVA analysis showed that both models were significant due to p-value obtained was 0.0073 (spiral) and 0.0011 (normal). Both models was smaller than 0.0500. Binder spray pressure and interaction between wind velocity and bag shake duration showed the most significant effect to the granule density for spiral and normal airflow respectively. The R^2 value for spiral airflow was 0.8892 while R^2 for normal airflow was 0.9353.

The effect of three process parameters on the granule hardness for spiral airflow was presented in Figs. 7 (a) to (c). Each surface plot for spiral airflow can offer an infinite number of combination of two input parameters when the other input parameter was kept at constant value. Interaction graphs were also presented in the same figure.

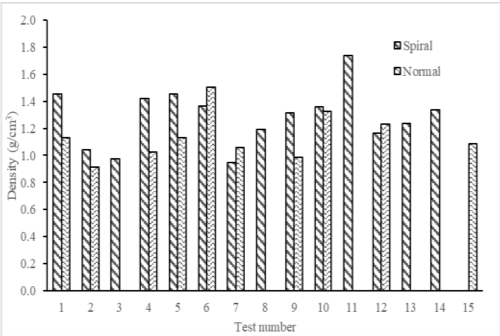


Fig. 5. Effect of airflow pattern on granule density under constant process conditions.

The 3D surface plot and interaction graph for spiral airflow in Fig. 7 (a), it was observed that there was no interaction between the wind velocity and binder spay pressure influenced the granule hardness. When the bag shake time was kept at constant, the wind velocity showed negligible effect on granule hardness if 0.1 MPa of binder spray pressure was applied. The granule hardness was increased with increasing both wind velocity and binder spray pressure and the granule hardness reached the maximum value of 2.1 N when maximum spray pressure and wind velocity of 0.4 MPa and 37 m/s were utilized respectively. This effect was attributed to the droplet size of binder. With higher spray pressure, more tiny binder droplets can be formed. This will enhance the formation of liquid bridges with small particles to increase the cohesive force between them and promote the strength of granule whereby penetration of liquid will improve the plasticity and hardness of granules (Patel *et al*. 2010).

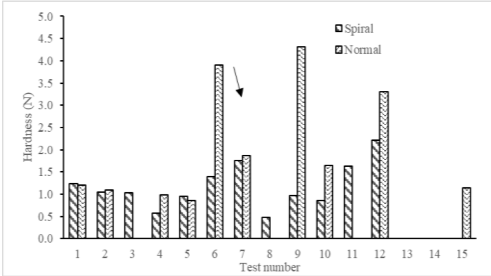


Fig. 6. Effect of airflow pattern on granule hardness under constant process conditions.

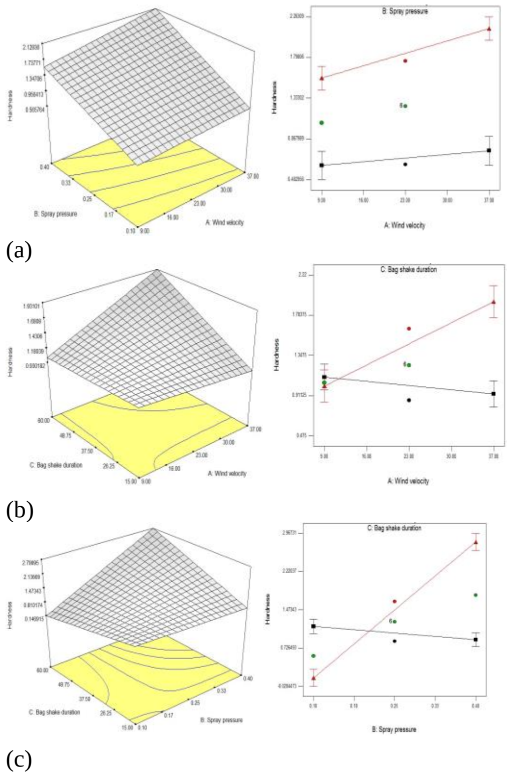
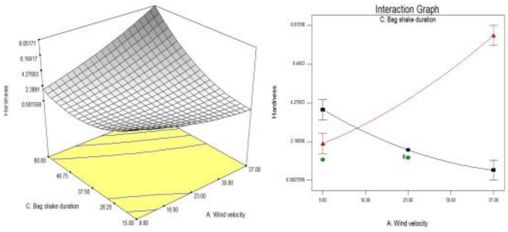


Fig. 7. Surface plots and interaction graphs of variables on granule hardness (spiral): (a) Wind velocity and spray pressure (b) Wind velocity and bag shake duration (c) Spray pressure and bag shake duration.

Figure 7 (b) illustrated the relationship between wind velocity and shake duration of filter bag and its effect on granule hardness for spiral airflow. At minimum bag shake duration of 15 s with binder spray pressure remained at 0.25 MPa, resulted in negative response when wind velocity increased from 9 m/s to 37 m/s. However, at higher bag shake duration of 60 s, the granule hardness was increased as the wind velocity increased. The granule hardness reached the maximum value of 1.9 N when maximum bag shake duration and wind velocity of 60 s and 37 m/s were utilized respectively. This finding was contrary to the discovery made by Rawley in 1989 where he suggested that the suitable shaking frequency is at about 15 s to 30 s (Rawley 1989). This can be explained due to increase frequency of filter bag shaking which may cause the disruption in the granulation process and applied additional stress on the granule produced.

The influence of binder spray pressure and bag shake duration on granule hardness for spiral airflow was presented in Fig. 7 (c). The binder spray pressure showed negligible effect on granule hardness at constant wind velocity of 23 m/s and bag shake duration of 15 s but increased as binder spray pressure increased with the bag shake time increased to 60 s.



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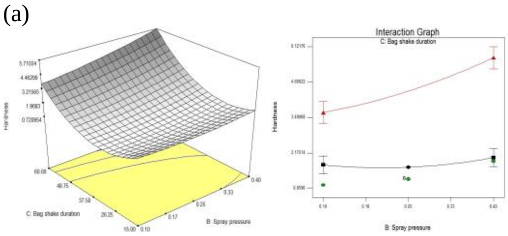
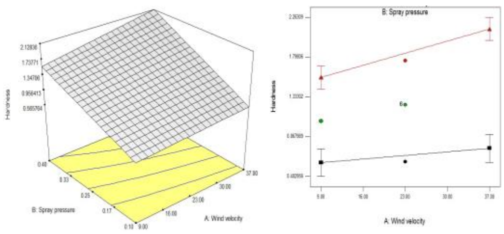


(b)

Fig. 8. Surface plots and interaction graphs of variables on granule hardness (normal) (a) Wind velocity and bag shake duration (b) Spray pressure and bag shake duration.

Figures 8 (a) and (b) illustrated the 3D plots process parameters against the granule hardness for normal fluidization airflow. Plots of 3D surface and two-factor interaction between wind velocity and bag shake duration in Fig. 8 (a) indicated that when the wind velocity increased from 9 m/s to 37 m/s with a constant bag shake duration of 15 s under normal airflow, minimum hardness of granule at 0.502 N was obtained. However, the graphs also showed that granule hardness can be gradually increased when increased the bag shake duration to constant value of 60 s. Maximum granule hardness of 8.052 N reached when maximum bag shake duration and wind velocity of 60 s and 37 m/s were applied respectively. This finding was similar to the result obtained in spiral airflow. Shake duration of filter bags gave stronger influence on granule hardness if compared to wind velocity. Longer pause shaking time of filter bags was required to prevent the disruption in granulation process.

Figure 8 (b) showed 3D surface and two-factor interaction plots between bag shake duration and binder spray pressure towards granule hardness. The interaction plot indicated there was no interactions between bag shake duration and binder spray pressure that can maximize the granule hardness. Weaker granule was produced because of bag shake duration. It can be seen that the hardness of granule increased with increasing the bag shake duration at 60 s. However, it showed that when wind velocity was kept at zero level of 23 m/s, the binder spray pressure showed negligible effect on granule hardness when 15 s of bag shake duration was applied. The granule hardness maintained at low level although the binder spray pressure increased. Binder droplet was difficult to reach and collide with the particles due to frequent shaking of bags and coalescence of droplets was easy to occur under normal airflow. This will give effect to the bond formation. The granules succeed to form under this condition will have weak bonding but larger granule size and void space. Thus, the hardness of granules lower. Lower crushing strength was required for diametrical fracture on the larger granules with smaller surface area and higher void spaces (Okor, Eichie, and Ngawa 1998).



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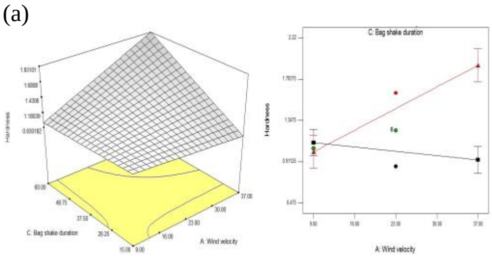

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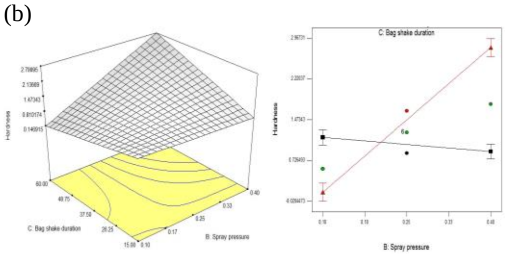


(c)

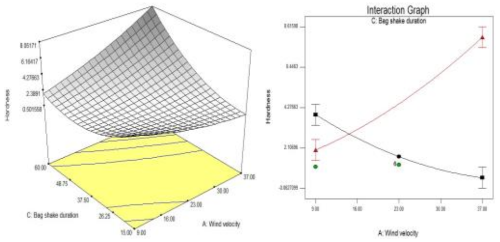
Fig. 9. Surface plots and interaction graphs of variables on granule hardness (spiral): (a) Wind velocity and spray pressure (b) Wind velocity and bag shake duration (c) Spray pressure and bag shake duration.

The effect of three process parameters on the granule hardness for spiral airflow was presented in Figs. 9 (a) to (c). Each surface plot for spiral airflow can offer an infinite number of combination of two input parameters when the other input parameter was kept at constant value. Interaction graphs were also presented in the same figure. By referring to 3D surface plot and interaction graph for spiral airflow in Fig. 9 (a), it was observed that there was no interaction between the wind velocity and binder spay pressure influenced the granule hardness. When the bag shake time was kept at constant, the wind velocity showed negligible effect on granule hardness if 0.1 MPa of binder spray pressure was applied. The granule hardness was increased with increasing both wind velocity and binder spray pressure and the granule hardness reached the maximum value of 2.1 N when maximum spray pressure and wind velocity of 0.4 MPa and 37 m/s were utilized respectively. This effect was attributed to the droplet size of binder. With higher spray pressure, more tiny binder droplets can be formed. This will enhance the formation of liquid bridges with small particles to increase the cohesive force between them and promote the strength of granule. Penetration of liquid will improve the plasticity and hardness of granules (Patel *et al*. 2010).

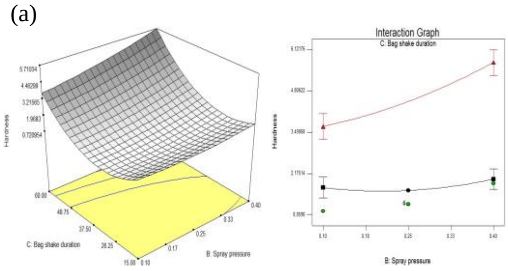
Figure 9 (b) illustrated the relationship between wind velocity and shake duration of filter bag and its effect on granule hardness for spiral airflow. At minimum bag shake duration of 15 s with binder spray pressure remained at 0.25 MPa, resulted in negative response when wind velocity increased from 9 m/s to 37 m/s. However, at higher bag shake duration of 60 s, the granule hardness was increased as the wind velocity increased. The granule hardness reached the maximum value of 1.9 N when maximum bag shake duration and wind velocity of 60 s and 37 m/s were utilized respectively. This finding was contrary to the discovery made by Rawley in 1989 where he suggested that the suitable shaking frequency is at about 15 s to 30 s. One of the possible reasons was because frequent shaking of filter bags will cause the disruption in the granulation process and applied additional stress on granule produced.

The influence of binder spray pressure and bag shake duration on granule hardness for spiral airflow was presented in Fig. 9 (c). It indicated that the binder spray pressure showed negligible effect on granule hardness at constant wind velocity of 23 m/s and bag shake duration of 15 s but increased as binder spray pressure increased with the bag shake time increased to 60 s. The increase in binder spray pressure and bag shake duration can improve the hardness of granule formed in the process.

Figures 10 (a) and (b) showed the effect of three process parameters on the granule hardness for normal airflow, presented through 3D surface plots and interaction graphs. Plots of 3D surface and two-factor interaction between wind velocity and bag shake duration in Fig. 10 (a) indicated that when the wind velocity increased from 9 m/s to 37 m/s with a constant bag shake duration of 15 s under normal airflow, minimum hardness of granule at 0.502 N was obtained. However, the graphs also showed that granule hardness can be gradually increased when increased the bag shake duration to constant value of 60 s. Maximum granule hardness of 8.052 N reached when maximum bag shake duration and wind velocity of 60 s and 37 m/s were applied respectively. This finding was similar to the result obtained in spiral airflow. Shake duration of filter bags gave stronger influence on granule hardness if compared to wind velocity. Longer pause shaking time of filter bags was needed to prevent the disruption in granulation process.



(a)



(b)

Fig. 10. Surface plots and interaction graphs of variables on granule hardness (normal) (a) Wind velocity and bag shake duration (b) Spray pressure and bag shake duration.

Figure 10 (b) showed 3D surface and two-factor interaction plots between bag shake duration and binder spray pressure towards granule hardness. The interaction plot indicated there was no interactions between bag shake duration and binder spray pressure that can maximize the granule hardness. Weaker granule was produced because of bag shake duration. It can be seen that the hardness of granule increased with increasing the bag shake duration at 60 s. However, it showed that when wind velocity was kept at zero level of 23 m/s, the binder spray pressure showed negligible effect on granule hardness when 15 s of bag shake duration was applied. The granule hardness maintained at low level although the binder spray pressure increased. Binder droplet was difficult to reach and collide with the particles due to frequent shaking of bags and coalescence of droplets was easy to occur under normal airflow. This will give effect to the bond formation. This may also due to the insufficient binder concentration in the process, causing overwetted seeds material which disrupted the granulation process via the liquid bridge between the particles. Consequently, contributed to the formation of lump and unformed granules at the bottom of the chamber. The granules succeed to form under this condition will have weak bonding but larger granule size and void space. Thus, the hardness of granules lower. Lower crushing strength was required for diametrical fracture on the larger granules with smaller surface area and higher void spaces (Okor, Eichie, and Ngawa 1998).

5. CONCLUSION

Airflow pattern, wind velocity, binder spray pressure and bag shake duration influence on the physical properties of urea granules formed. The results proved that change in airflow pattern had effective contribution to the density of granules. Most granules produced in spiral airflow were able to achieve the minimum density of 1.20 g/cm^3 under the same process conditions if compare to normal airflow. The experiment results also revealed that there were more granules within the size of 2 mm to 4 mm have been produced under spiral airflow due to good fluidization process.

From the ANOVA, all the input parameters showed significant influence on granule hardness. Binder spray pressure and bag shake duration showed the strongest influence on hardness of granules. It was postulated that increased in binder spray pressure will increase force between particles and this will promote the crushing strength of granules. Filter bags shaking was thought to influence the flow of the particles in granulation process. The suitable pause duration for next shaking should be determined to prevent disruption in process.

This result will give better understanding for fertilizer industry player in the region to produce urea fertilizer granules with improved properties by applying optimum process parameters to reduce caking tendency of urea fertilizer granules during storage.

By applying the Response Surface Methodology in the experiment, it was observed that the optimize value of each parameter with desirability of 0.950 and predicted hardness of 2.2199 N and density of 1.669 g/cm^3 could be obtained with 28 m/s for wind velocity, 0.31 MPa for binder spray pressure and 60 s for bag shake duration under spiral airflow. On the other hand, for normal airflow, the optimize parameters with desirability of 0.984 and predicted hardness of 1.5001 N and density of 1.496 g/cm^3 could be obtained with 25 m/s for wind velocity, 0.20 MPa for binder spray pressure and 15 s for bag shake duration.

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