International Journal of Metallurgical Engineering 2012, 1(4): 48-59
DOI: 10.5923/j.ijmee.20120104.02

Optimization of Disc Parameters Producing More Suitable Size Range of Green Pellets

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Abstract Pelletization is an agglomeration technique, beneficial with finer iron ores over other agglomeration processes. For Corex and Blast furnace feed, a certain size range of pellets is required for attaining the operating bed permeability along with other furnace parameters for smooth operation. The size distribution of pellets mainly depends on the nature of raw materials, balling equipment, disc inclination, disc rotating speed, rim height, size of the feed, feed rate, amount of moisture added, nozzle combination and position, residence time in disc pelletizer etc. The present work is aimed at to optimize the operating parameters improving the disc pelletizer efficiency which can enable to choose more suitable green pellets size range (8-12) so as to improve the plant productivity and minimizing the oversize and undersized green pellets. Experiments were conducted with varying disc inclination, disc rotation, nozzle combination or position and feed rate keeping other parameters constant to produce the desired size range (8-12 mm) pellets. The properties viz, green compressive strength (GCS), drop strength, moisture content, loss on ignition (LOI) of green pellet were tested and recorded. The experimental observation shows that finer the particle size, more the compactness and thereby, higher the green compressive strength and drop strength of pellets. The disc inclination of 430 is the optimum value at which maximum efficiency of balling disc was observed. At higher feed rate, the disc rpm needs to be increased to nullify the effect of decreased required size range. At JSW Steel Ltd., upon implementation at pellet plant the benefits are as under. i)Production of indurated pellet increased by 95 t/day (i.e., ~ 0.9%). ii)Recirculation load of under/oversize pellets reduced from 20.06 to 11.55 %. iii)Unfired pellets reduced from 8.47 to 5.90 %.

Keywords Balling Disc, Inclination, Feed-Rate, Disc Slope, Rpm, GCS, Drop Number

1. Introduction

Pelletization is an agglomeration technique, beneficial with finer iron ores over other agglomeration processes .Pellet making involves balling of fine powders and dusts with addition of moisture (8.5-9.5 %) and binder in a rotating disc or drum to produce green pellets and subsequently indurating the same on a moving grate to produce fired pellets[1].Drum pelletizer is used for batch process while disc pelletizer is used for continuous process. At JSW Vijayanagar unit, green balls are formed using disc pelletizer. There are a total of 6 discs rotating at an average rpm of 7.7, all inclined at angle of ~ 44-47o. The disc feed (mix of finely ground ore, fluxes, moisture and binder) combine together in a rolling action of disc to form green balls. The disc's rotation carries the feed material to top of the disc from where particle starts rolling back to bottom under its own weight. Atomized sprays of water are directed at the rolling mass as the nucleated balls descend down. The particles of ore coated with water, collide with adjacent particles and because of surface-tension effects of water coating combine to form large particles and start to form "seed pellets" which acts as nucleus. Further rolling of nucleus in the disc causes the ball to grow. As seeds grow larger they gradually migrate from disc bottom to the charge surface achieving the desired product size range. By this time they reach to the lip of the disc sidewall and overflow to the collecting conveyor[2]. Green pellets with big size variation have been observed at exit point of the disc. The end product from disc consists of both undersize and oversize pellets. The present work is aimed at reduction in size distribution of green pellets ejecting out of discs by optimizing the disc efficiency. This is done by varying different parameters like disc rotation, nozzle positions and its operating conditions effecting pelletizing disc efficiency. The present work will help user department in minimizing size variation leading to a better bed permeability on the pallet car thereby producing a better quality fired pellets.

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Published online at http://journal.sapub.org/ijmee

2. Literature Review

Green pellet formation takes place in two stages, i.e., Nucleation followed by growth[9], which depends on the following factors[3].

2.1. Disc Slope and Rim Height

The disc slope is determined by the dynamic angle of repose of specific material. To overcome this angle, the disc slope must always be slightly steeper which is shown by Bhrany in Fig. 1. If 'α' is the dynamic angle of repose and 'β' the tilt angle of the disc bottom, the latter must be greater than α.

At too steep an angle, the charge would no longer be lifted by friction. The tilt angle for high production rates with a minimum diameter of 6 mm varies between 45-48^o depending on the frictional coefficient of ore and the lifting coefficient. The rim height is also determined by the tilt angle. Filling volume is dependent on both factors.

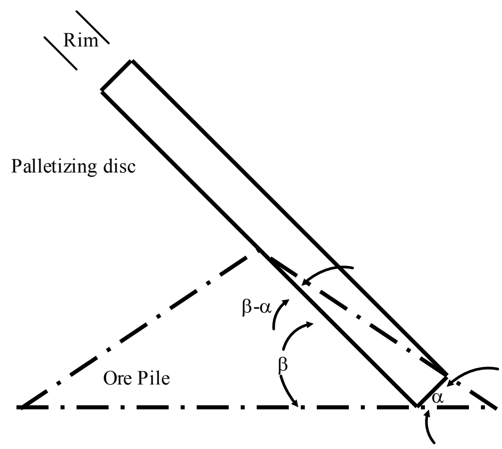


Figure 1. Orientation of Disc Pelletizer

2.2. Residence Time of Material in the Disc Pelletizer[10]

Residence time is the average time a particle spends in any particular system. This measurement varies directly with the amount of substance present in the system[4]. If residence time is less, particles of smaller size will form and vice-versa provided feed rate, disc rpm and disc inclination remain constant.

2.3. Disc Rotating Speed[10]

In centrifugal equipment, as soon as the pellets are formed from loose agglomerate the torus profile is observed .The torus is characterized by the regular and stable movement of the pellets[13].Near, the wall the direction of pellets was almost equal to the tangential line, near the centre, the angle increases and direction of pellets was more inside (radial) oriented[12].At lower disc speed, larger size green pellets form. The reason being due to insufficient speed, charge partially remain in a relative position of rest while at excessive speed the material moves upward without rolling down due to centrifugal force. It is slung against the rim and no longer comes off so that no relative rolling movement is possible[3]. The limiting speed is the speed at which entire feed on the disc is centrifuged without rolling[5].

2.4. The Size of the Feed

The granulation characteristics can be evaluated in terms of moisture content, granulation time & mean granule diameter[11] which directly depends upon the feed particle size distribution. The ease with which material can be rolled on the disc is directly proportional to the surface area of the article. The feed should be <100 mesh (150 micron) in size, with more than 60% as -325mesh (45 micron). A right combination of size and shape of feed particles lead to maximum mechanical interlocking and surface-tension/capillary force with different particles to obtain strong green pellets[6].

2.5. Amount of Water Added[10]

The formation of pellets on the disc pelletizer depends primarily on the moisture content added during granulation process. If moisture content is less than the critical amount, its distribution tends to be non uniform, major being present in the granulated material leaving the non-granulated materials relatively dry. If moisture added in the process is more than the critical amount, growth rate increases but pellets produced are liable to deformation due to its plasticity[5].Also, the torus movement stabilized by changing the elastic properties of dry pellets to plastic and inelastic with addition of wet pellets[13].So, moisture should be optimum and with this condition the effect of pellet-wall collision as well as pellet-pellet collision will be less pronounced than the visco-elastic properties of pellets.

2.6. Nozzle Combination or Position

It is also a form of water addition while balling which helps in growth of pellets by helping in layering and assimilation by stabilizing the water film surrounding the nuclei to maintain the capillary action[15].And, the effectiveness of Pelletization is dependent on wettability. The wettability is the most important factor which decides whether the porosity can create strong capillary force that affects particle-to-particle adhesion[14].The stability of capillary force can be further enhanced with the proper orientation of nozzles used for moisture addition. In the present study, there are four fixed nozzles; two near the respective stoppers, one near the feeding side and last one near the periphery.

2.7. Disc Inclination[10]

Balling mainly depends on inclination of disc which primarily affects the angle of repose. The extent to which charge is lifted along the kidney shaped trajectory and size of the zone occupied by charge are functions of the angle of repose of the material being pelletized which itself is dependent on angle of inclination of disc. At lower disc inclination, angle of repose will be smaller[8].

2.8. Feed-rate

Rate of feeding also affects granulation kinetics. As we increase the feed-rate we need to increase the disc rpm otherwise, the desired size range will decrease due to decrease in residence time.

A particle on disc is subjected to four forces namely frictional force, centrifugal force, gravitational-force (which is counter-balance by normal reaction). Various forces acting in different direction are as follows:

Normal reaction: N

Friction force: f

Centrifugal force: $m\omega^2R$

Gravitational force: $[mg.\cos\theta\ \hat{j}) + mg.\sin\theta\ i]$

These forces upon balancing reduce to following equation:

$N = (mg.\cos^2\theta + \mu\ \omega^2\ mR + mg.\cos\theta - m\omega^2 R.\cos\theta) / (\mu^2 + \cos^2\theta)$

Where, N = normal reaction

m = mass of the green ball formed

R = radius of Disc

θ = angle of inclination of Disc

g = acceleration due to gravity (9.81 $m/s^{2)}$

μ = coefficient of friction

ω = angular velocity of disc

For a pellet to be ejected out form the disc this net force should be greater than its gravity component i.e. $N > mg.\cos\theta$

This equation shows that as particle size increases the force required to eject is more. The value of N for present plant condition, i.e., m = 0.0049 kg, R = 3.75 m, θ = 47 degree, g = 9.8 m/s^2, μ= 0.66, ω = 7.7 rpm is found to be 0.039369 N.

3. Experimental Set-up

For optimizing balling disc efficiency, a series of experimentation have been planned. It includes green pellet making at plant level with variations in the following process parameters

- Disc rpm
- Moisture addition
- Disc inclination
- Feed rate

Disc pelletizer No.5 was selected for online trial. Experiments were divided into various sets.

Set 1 deal with disc rotation, to be changed in descending order. An initial data has been collected from Disc 5 like rpm and feed rate. Altogether 8 samples were taken that serves as reference value for first set of experiments. Samples were collected on hourly basis and following test were done:

- Size analysis of green pellets
- Drop number
- GCS
- Moisture of green pellets and
- Feed moisture to the disc.

For set 1 experiment, following conditions were fixed and tests were conducted as done for reference samples.

Disc rpm	Feed rate, tph
8	130-140
7.5	130-140
7	130-140
6.5	120-130

Set 2 consists of trials of different nozzle combination. Disc 05(E) which, we have selected for trials has four nozzles, two near to the two stoppers, named A&B, one near to the feeding side, named C and fourth one is near to the periphery, named D as shown in fig.2

Figure 2. Balling disc with nozzle positions

Set 3 consists of trials of varying inclination with feed rates with consideration of best range of disc rpm & best nozzle combination.

4. Results and Discussions

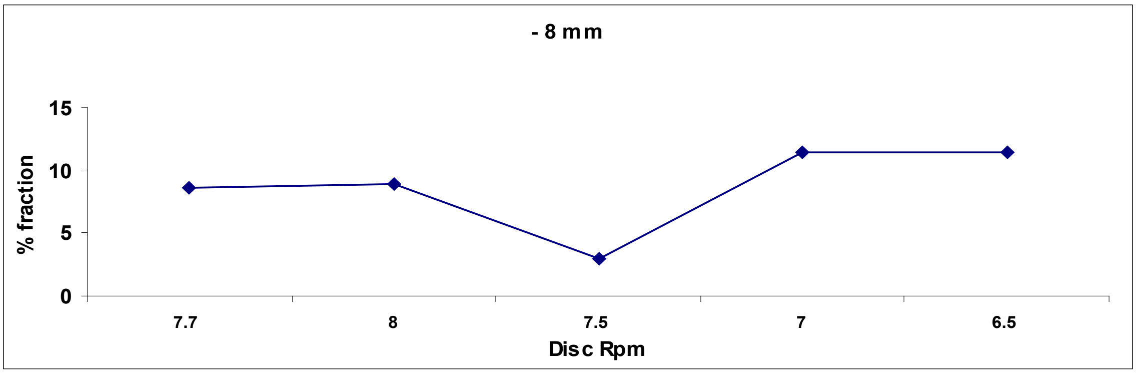
Experiments have been tried to be conducted with same type of raw materials. Here, some of the trials involve classifier fines which are coarser, so can affect balling process if added to a considerable amount but its amount was not much, so , we assumed that the presence of classifier fines have not much affect.

4.1. First Set Experiment

The physical and mechanical properties of green pellets are shown in Table 1. The disc rpm of 7.7 is taken as the reference value.

As shown in Fig.3, the quantity of under size (i.e., less than 8 mm) green pellets produced is more at all disc rpm other than 7.5 rpm. Therefore, the disc rpm should be around 7.5.

As shown in Fig. 4, the observations at different disc rpm for 8-10 mm size range pellets indicate that above and below the 7.5 d rpm, the quantity of pellets produced is less.



Figue 3. Fraction of -8mm size green pellet vs. Disc rpm

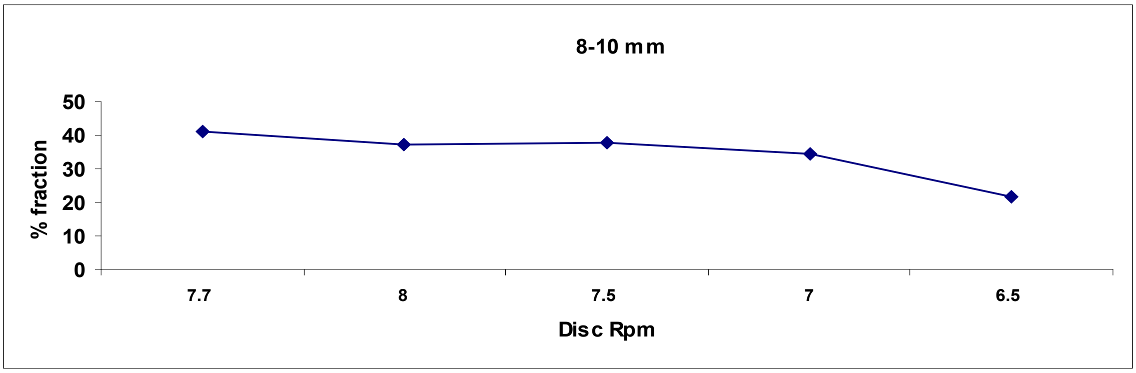


Figure 4. Fraction of 8-10mm size of green pellet vs. Disc rpm

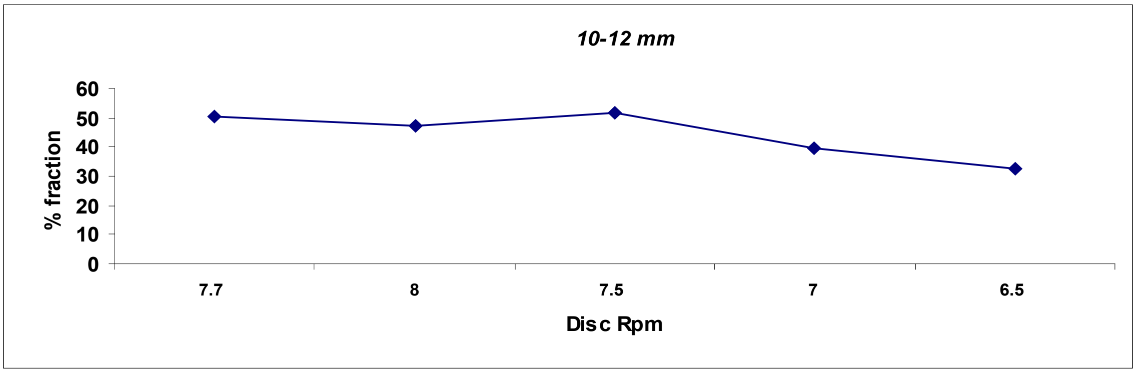


Figure 5. Fraction of 10-12mm size of green pellet vs Disc rpm

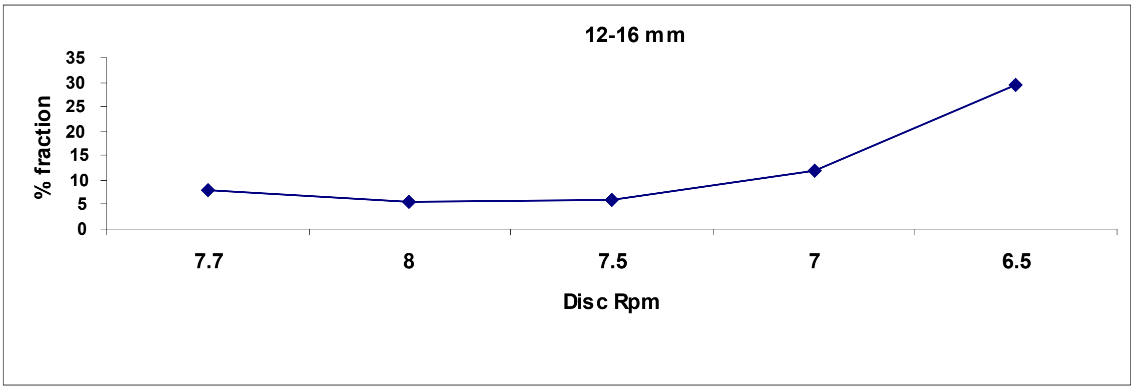


Figure 6. Fraction of 12-16mm size of green pellet vs Disc rpm

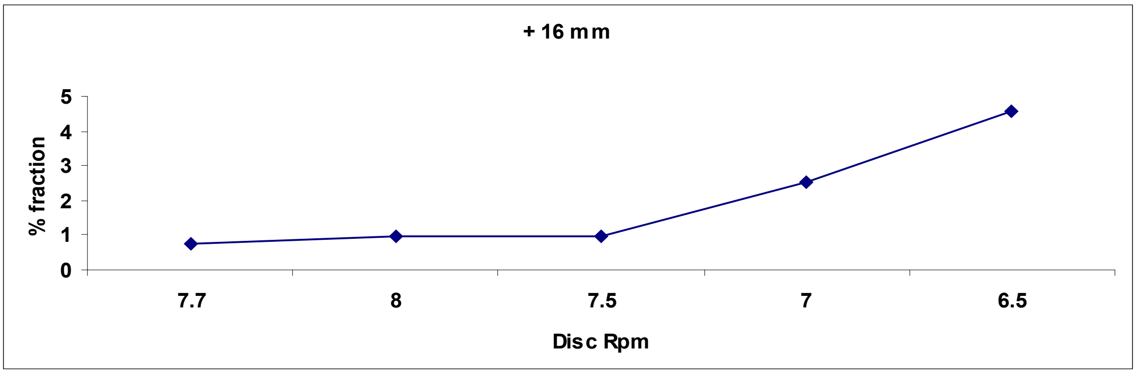


Figure 7. Fraction of +16mm size of green pellet vs Disc rpm

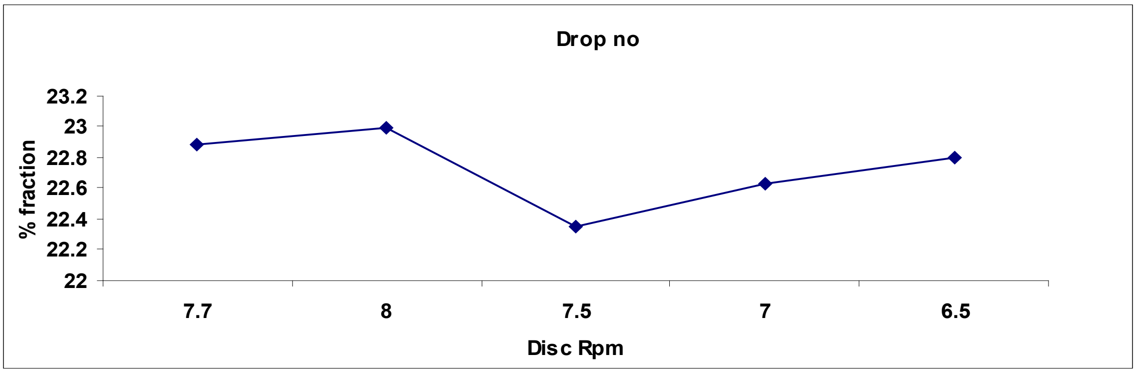


Figure 8. Drop No. vs Disc rpm

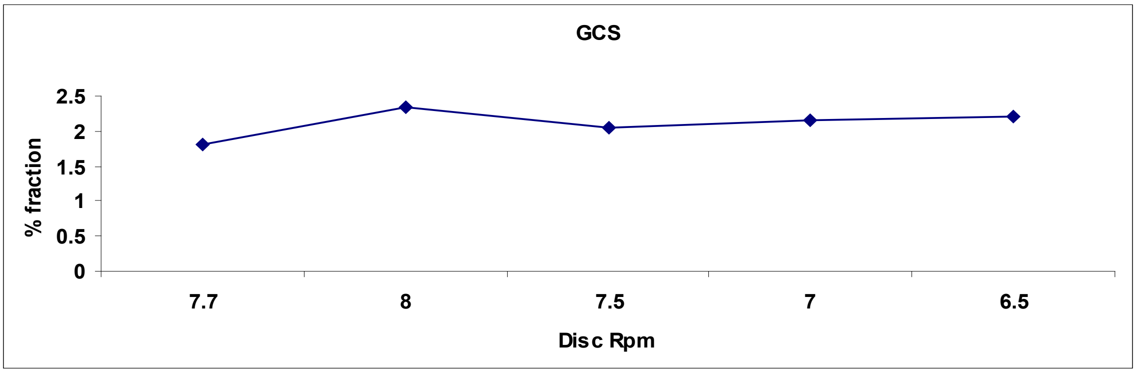


Figure 9. GCS vs Disc rpm

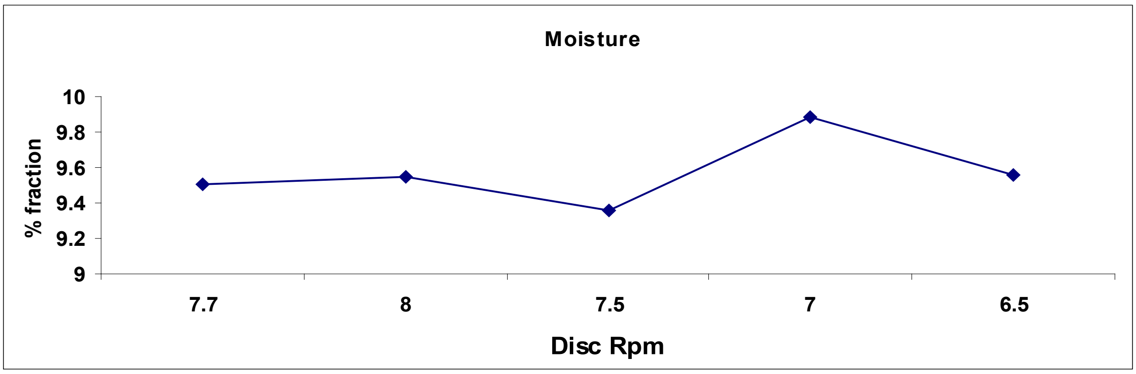


Figure 10. Moisture content vs Disc rpm

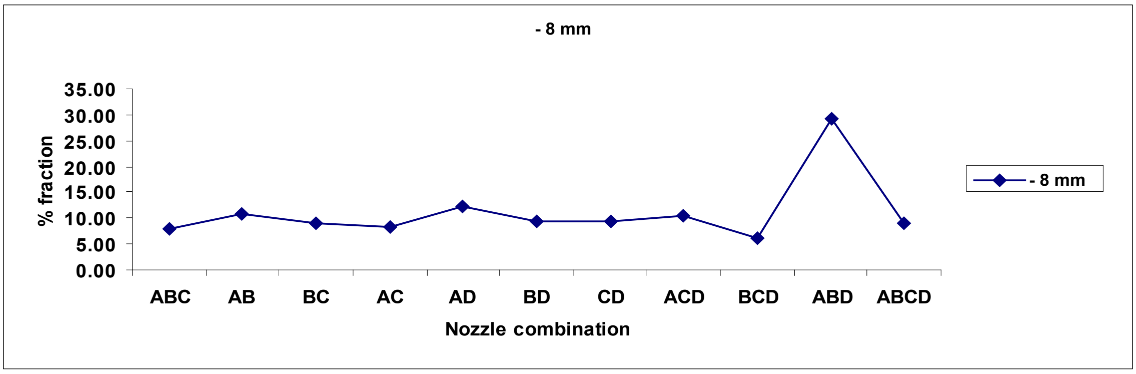


Figure 11. Fraction of - 8 mm green pellet vs nozzle combination

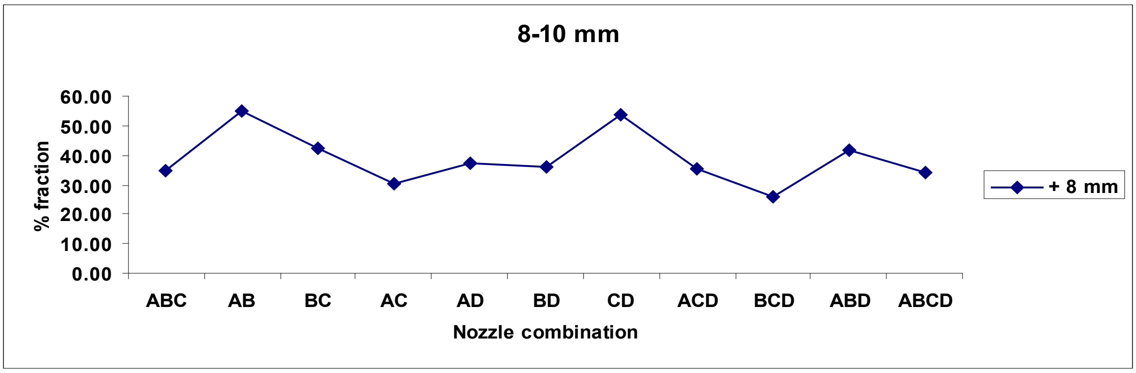


Figure 12. Fraction of 8-10 mm green pellet vs nozzle combination

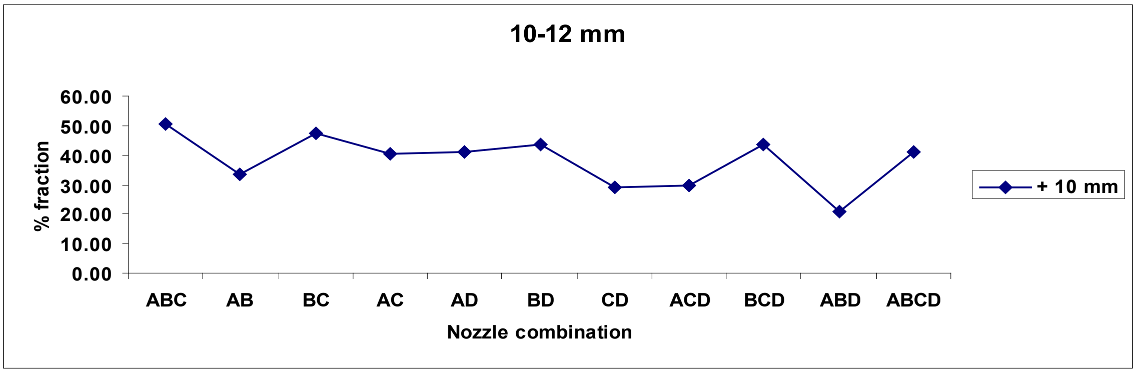


Figure 13. Fraction of 10-12 mm green pellet vs nozzle combination

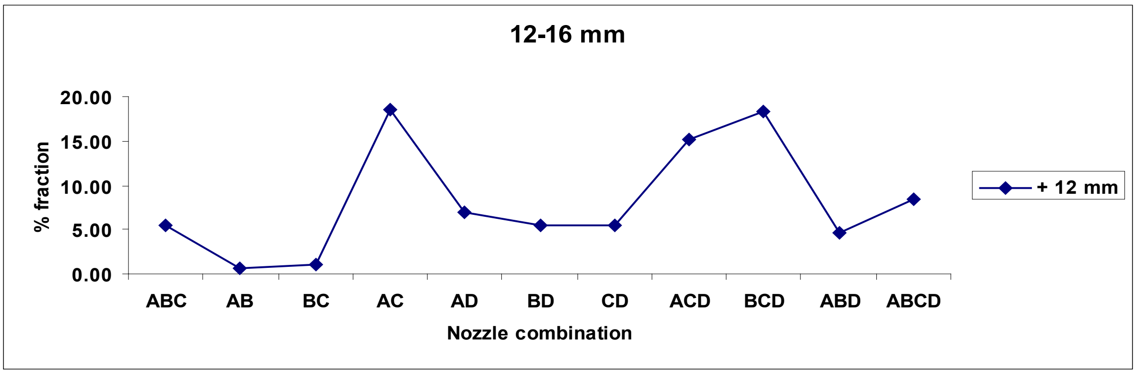


Figure 14. Fraction of 12-16 mm green pellet vs nozzle combination

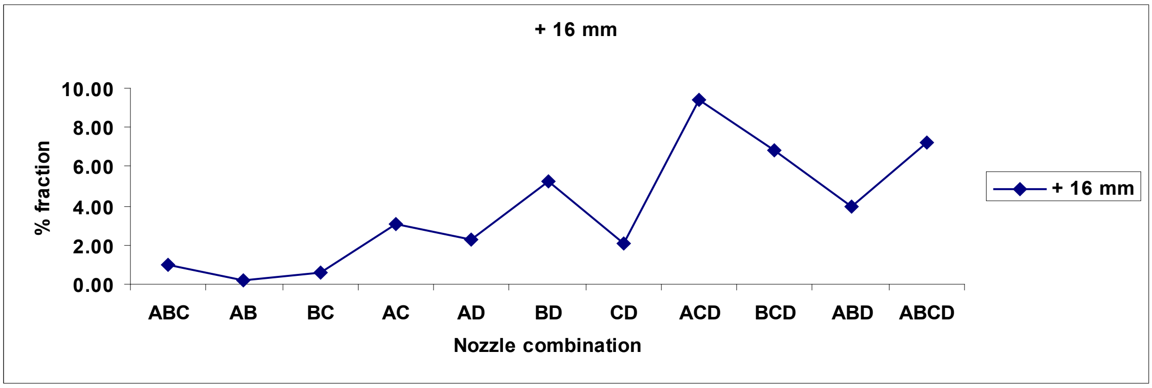


Figure 15. Fraction of +16 mm green pellet vs nozzle combination

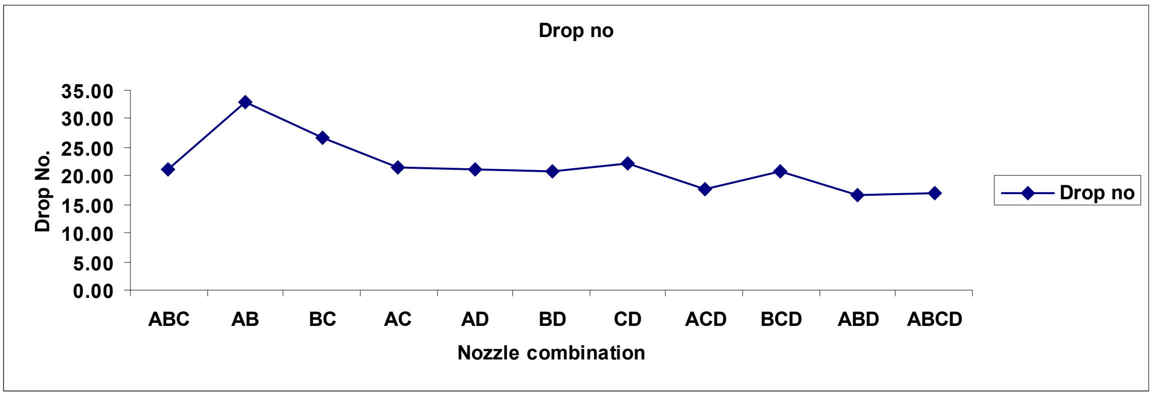


Figure 16. Drop strength vs nozzle combination

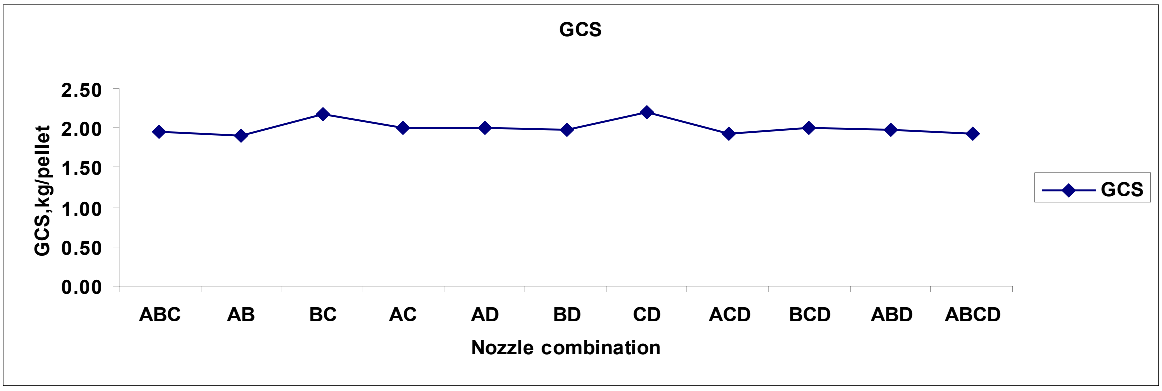


Figure 17. GCS vs nozzle combination

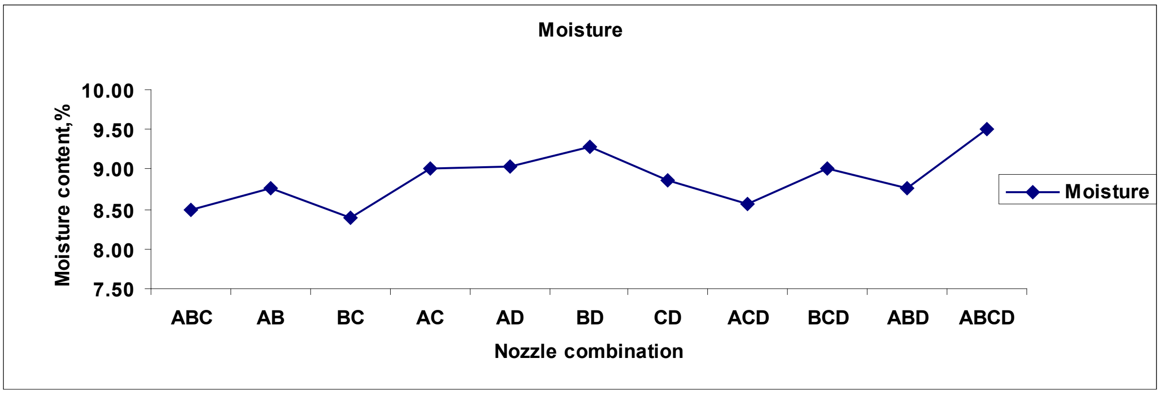


Figure 18. Moisture content vs nozzle combination

Table 1. shows physical and mechanical properties of green pellets properties. Variation in disc rpm

Disc rpm	-8 mm, %	8-10 mm, %	10-12 mm, %	12-16 mm, %	+16 mm, %	Drop Strength, Nos.	GCS, kg/pellet	Moisture, %
7.7	8.60	41.09	50.19	7.97	0.75	22.89	1.82	9.51
8	8.85	37.14	47.48	5.55	0.98	22.99	2.35	9.54
7.5	2.95	37.70	51.59	6.01	0.95	22.35	2.04	9.36
7	11.46	34.41	39.51	12.09	2.52	22.63	2.16	9.89
6.5	11.38	21.83	32.71	29.50	4.58	22.80	2.21	9.56

Table 2. shows physical and mechanical properties of green pellets properties. Variation in nozzle combination

Nozzle Comb.	-8 mm,%	8-10 mm, %	10 -12 mm,%	12 -16 mm,%	+16 mm,%	Drop No.	GCS (kg/p)	Moisture (%)
ABC	7.84	34.90	50.81	5.46	0.99	21.29	1.96	8.48
AB	10.69	54.72	33.70	0.73	0.16	32.93	1.90	8.76
BC	8.85	42.08	47.29	1.15	0.64	26.68	2.17	8.40
AC	8.15	30.03	40.38	18.42	3.02	21.59	2.01	9.00
AD	12.36	37.50	41.06	6.85	2.24	21.24	2.00	9.03
BD	9.29	36.13	43.87	5.40	5.30	20.80	1.97	9.28
CD	9.45	53.98	28.98	5.48	2.11	22.32	2.19	8.85
ACD	10.34	35.44	29.58	15.25	9.39	17.52	1.93	8.57
BCD	5.96	25.64	43.31	18.27	6.81	20.93	2.01	9.00
ABD	29.12	41.67	20.68	4.60	3.93	16.49	1.98	8.77
ABCD	8.99	34.41	40.87	8.39	7.24	17.04	1.93	9.50

Similar results are obtained for 10-12 mm size range pellets (Fig. 5), which indicates that the 7.5 rpm disc revolution is the most suitable disc speed.

As shown in Fig. 6, the observations at different disc rpm for 12-16 mm size range pellets show that the quantity of pellets produced increases as the disc rpm decreases. However, as shown in Fig. 7, the oversize pellets (+16 mm) produced is maximum at 6.5 d rpm of disc speed. Therefore, the observations presented in Fig. 3 to 7 suggest that the disc rpm of 7.5 is the most suitable speed for production of desired size range green pellets.

From Fig. 10, we see that the moisture required for production of green pellets at disc speed of 7.5 rpm is the lowest (i.e., 9.2 to 9.4 %) and hence, the disc rpm of 7.5 is more suitable.

To summarize the above observations, it is to be noted that at lower disc rpm (i.e. 6.5 rpm) the fraction of larger size (i.e., more than 12 mm) pellets is more. With gradual increase in disc rpm, the fraction of smaller size pellets (less than 12 mm) as well as the undersize (less than 8 mm) increases. The reason might be due to collapse of larger size pellets caused by the impact energy and rotational kinetic energy which increases with increase in rotational speed[7]. Further, it can be seen from Fig. 3 - 7 that at 7.5 disc rpm both undersize and oversize fractions are lowest. Drop strength is found in the range of 25 - 30. This is very high in comparison to the norm (15 - 20). The reason contributing to this may be higher percentage of fines in the feed material.

4.2. Second Set Experiment

We have set the feed-rate of 120 tph and disc rpm of approx. 7rpm and with various nozzle combinations, collected the green pellets, tested their properties which are as follows:

As seen in Fig.11, undersize is minimum in ABC & BCD combination and maximum in ABD combination

Fig.12 shows 8-10mm size green pellet is higher in AB & CD combination and minimum in BCD combination.

Similarly, Fig.13 shows 10-12mm size green pellet is maximum in ABC combination.

Above Fig.14 shows 12-16mm is higher in AC & BCD combinations.

Fig.15 shows oversize is higher in ACD, BCD & ABCD combinations and minimum in AB & ABC combinations.

Drop strength is higher in AB, BC & ABC combinations as shown in Fig.16.

GCS has not much variation for different nozzle combinations as above Fig.17 shows.

Moisture content is least in ABC & BC combinations as shown in Fig.18.

The results obtained from the above trials shows that the best nozzle-combination is ABC with little adjustments in nozzles B & C as it delivered the highest output of desired size range. Nozzle D doesn't have much effect. Nozzle C helps in formation of new nuclei and stabilization the earlier formed nuclei as well as initial growth. Nozzles A & B facilitate in further growth by coalescence and assimilation. Nozzle D should not be opened unless the moisture level is lower than 9 %.

4.3. Set 3 Experiments

In these trials, we have fixed the best nozzle combination ABC, varied the disc rpm in the range of 7-7.5, changed the disc inclination and at each inclination, we have changed the feed-rates, and recorded the properties of green pellets which are as follows

Above, Fig.19 shows that desired green pellet is more at 130 tph; moisture content is also higher at this feed rate. At 140 tph the undersize and oversize pellets is higher. So, 120 tph is the desired feed rate.

In Fig.20, it is observed that due to addition of higher moisture at 130 & 140 tph, desired size range observed is higher. 120 tph gives the higher value of desired green pellet size. The following two trials of 45 & 46^0 show the clear figure as the moisture content is almost the same at all feed rates.

Fig.21 and fig.22 shows that as feed rate is increasing desired size range is decreasing. So, 120 tph is best amongst the three feed rates. Drop strength & GCS are found almost similar.

Now, arranging the trials readings at the same feed-rate & varying inclination, following trend of properties obtained.

Similar to the observations of feed-rate trials Fig.23-25 show that as disc inclination increases, desired size range of pellets decreases with some exceptions due to higher moisture addition in some trials. So, 43^0 is the most suitable amongst the four values.

Table 3. shows physical and mechanical properties of green pellets properties. Variation in feed-rate (at 43^0)

Nozzle Comb.	-8 mm%	8-10 mm%	10-12 mm%	12-16 mm%	+16 mm%	Drop no	GCS(kg/p)	Moist-ure (%)	Disc Inc.	Feed-rate (tph)
ABC	6.69	31.73	50.01	8.34	3.23	24.62	2.08	9.50	43^0	120
ABC	2.83	17.57	55.69	21.41	2.50	22.85	2.08	9.83	43^0	130
ABC	10.38	34.68	42.44	7.70	4.81	21.97	2.10	9.40	43^0	140

Table 4. shows physical and mechanical properties of green pellets properties. Variation in feed-rate (at 44^0)

Nozzle Comb.	-8 mm%	8-10 mm%	10-12 mm%	12-16 mm%	+16 mm%	Drop no	GCS (kg/p)	Moist-ure (%)	Disc Inc.	Feed rate (tph)
ABC	3.18	19.43	48.66	23.80	5.45	19.28	1.88	8.48	44^0	120
ABC	7.24	46.58	35.34	5.84	5.00	25.20	1.75	9.50	44^0	130
ABC	6.17	31.69	50.44	7.15	4.55	25.56	1.57	10.00	44^0	140

Table 5. shows physical and mechanical properties of green pellets properties. Variation in feed-rate (at 45^0)

Nozzle Comb.	-8 mm%	8-10 mm %	10-12 mm %	12-16 mm %	+16 mm %	Drop no	GCS (kg/p)	Moisture (%)	Disc Inc.	Feed rate (tph)
ABC	7.24	27.73	50.28	11.34	3.41	21.99	2.12	9.67	45^0	120
ABC	11.76	36.94	39.22	9.54	2.54	23.29	2.16	9.50	45^0	130
ABC	10.81	38.89	34.86	12.47	2.97	22.75	2.05	9.63	45^0	140

Table 6. shows physical and mechanical properties of green pellets properties. Variation in feed-rate (at 46^0)

Nozzle Comb.	-8 mm%	8-10 mm%	10-12 mm%	12-16 mm %	+16 mm %	Drop no	GCS (kg/p)	Moistu-re (%)	Disc Inc.	Feed rate (tph)
ABC	5.43	21.68	53.42	16.90	2.56	24.64	1.97	9.53	46^0	120
ABC	21.16	34.83	26.12	12.72	5.17	23.51	1.89	9.00	46^0	130
ABC	18.83	43.80	30.04	4.20	3.13	23.99	2.03	8.10	46^0	140

Table 7. shows physical and mechanical properties of green pellets properties. Variation in disc inclination (at 120tph)

Nozzle Comb.	-8 mm%	8-10 mm %	10-12 mm %	12-16 mm %	+16 mm%	Drop no.	GCS (kg/p)	Moistu -re (%)	Disc Inc.	Feed rate (tph)
ABC	3.55	24.70	60.56	9.32	1.87	21.62	1.58	9.60	43^0	120
ABC	3.18	19.43	48.66	23.80	5.45	19.28	1.88	8.48	44^0	120
ABC	7.24	27.73	50.28	11.34	3.41	21.99	2.12	9.67	45^0	120
ABC	5.43	21.68	53.42	16.90	2.56	24.64	1.97	9.53	46^0	120

Table 8. shows physical and mechanical properties of green pellets properties. Variation in disc inclination (at 130tph)

Nozzle Comb.	-8 mm%	8-10 mm %	10-12 mm %	12-16 mm %	+16 mm%	Drop no	GCS (kg/p)	Moistu -re (%)	Disc Inc.	Feed rate (tph)
ABC	2.83	17.57	55.69	21.41	2.50	22.85	2.08	9.83	43^0	130
ABC	7.24	46.58	35.34	5.84	5.00	25.20	1.75	9.50	44^0	130
ABC	11.76	36.94	39.22	9.54	2.54	23.29	2.16	9.50	45^0	130
ABC	21.17	34.83	26.12	12.72	5.17	23.51	1.89	9.00	46^0	130

Table 9. shows physical and mechanical properties of green pellets properties. (Variation in disc inclination (at 140tph)

Nozzle Comb.	-8 mm%	8-10 mm%	10-12 mm %	12-16 mm %	+16 mm %	Drop No.	GCS (kg/p)	Moistu re (%)	Disc. Inc.	Feed Rate (tph)
ABC	10.38	34.68	42.44	7.70	4.81	21.97	2.10	9.40	43^0	140
ABC	6.17	31.69	50.44	7.15	4.55	25.56	1.56	10.00	44^0	140
ABC	10.81	38.89	34.86	12.47	2.97	22.75	2.05	9.63	45^0	140
ABC	18.83	43.80	30.04	4.20	3.13	23.99	2.03	8.10	46^0	140

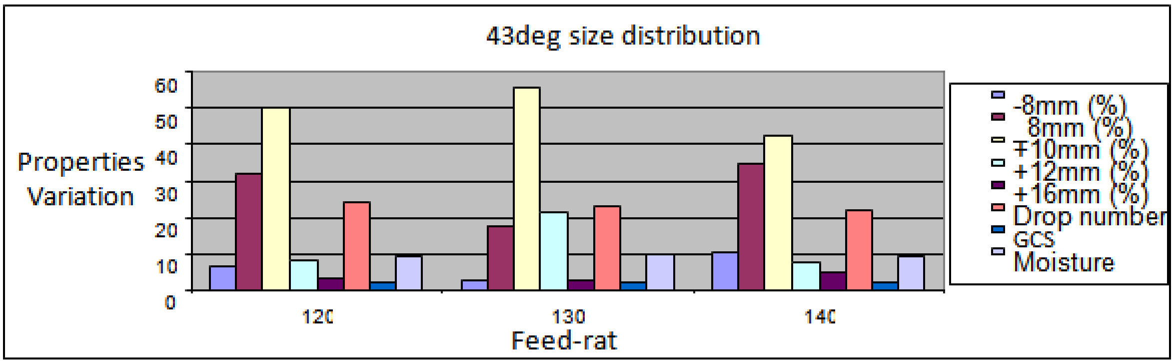


Figure 19. Properties variation vs. feed-rate (tph) at 43deg of disc inclination

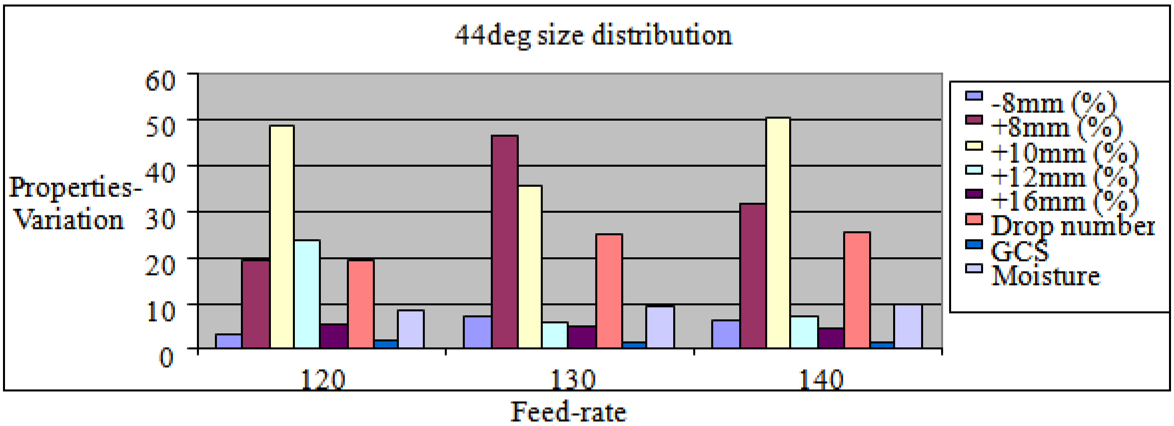


Figure 20. Properties variation vs feed-rate (tph) at 44deg of disc inclination

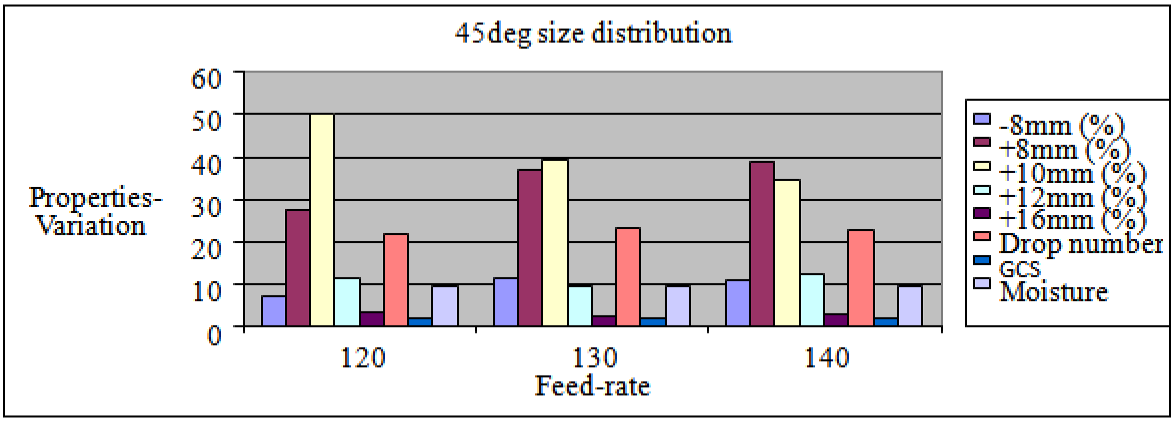


Figure 21. Properties variation vs. feed-rate (tph) at 45deg of disc inclination

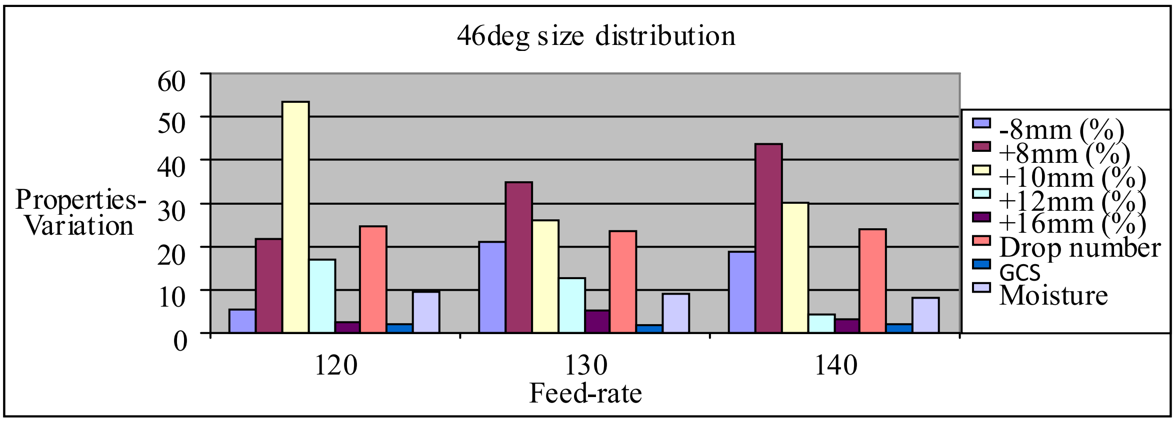


Figure 22. Properties variation vs. feed-rate (tph) at 46^0 of disc inclination

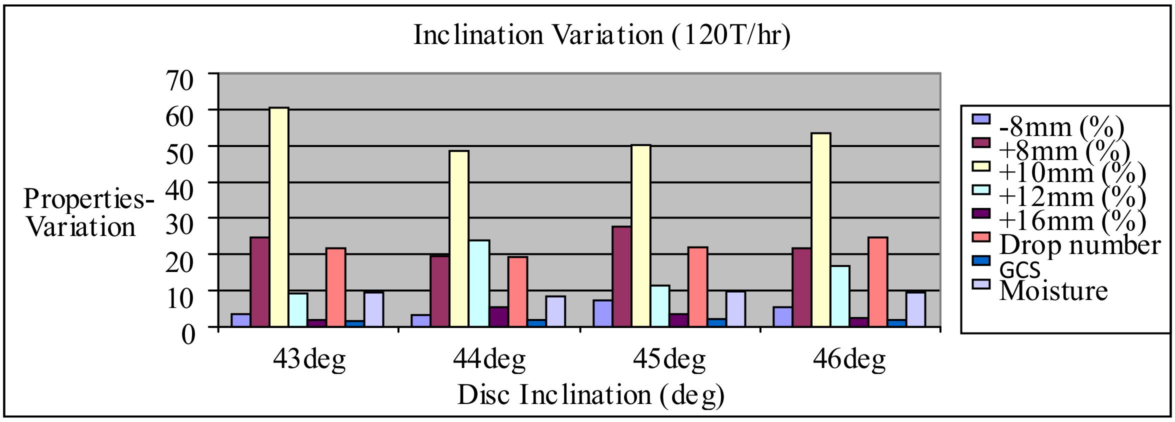


Figure 23. Properties variation vs. disc inclination at feed-rate of 120tph

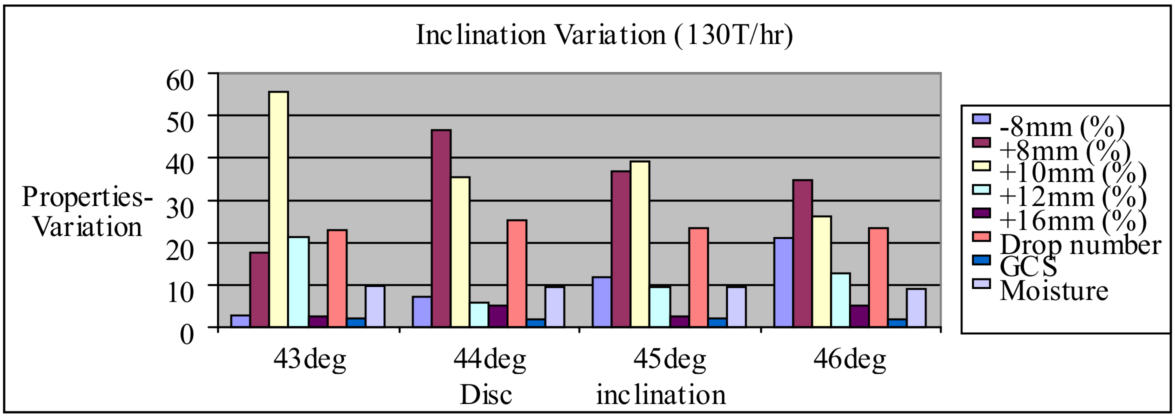


Figure 24. Properties variation vs. disc inclination at feed-rate of 130tph

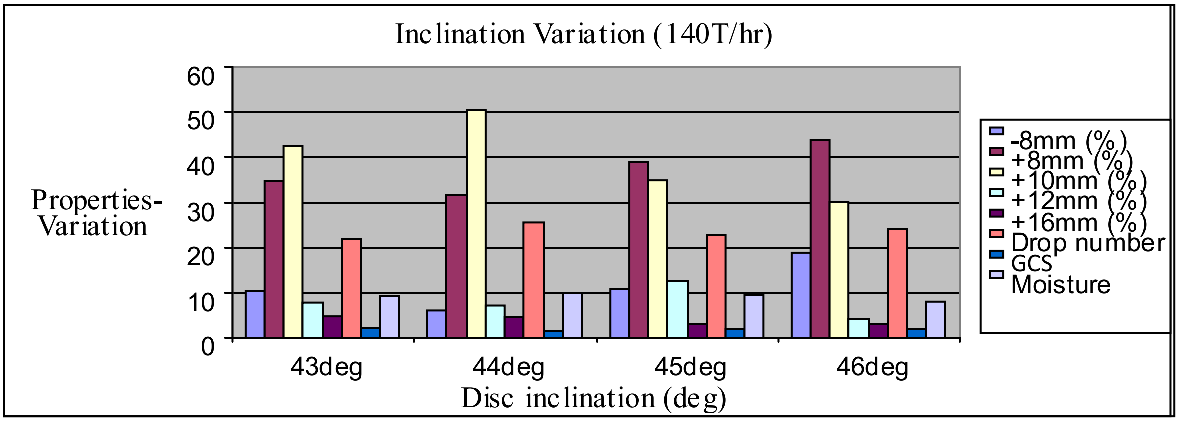


Figure 25. Properties variation vs. disc inclination at feed-rate of 140tph

5. Conclusions

1. The disc rpm has a direct effect on balling process, i.e., with decrease in disc rpm desired size range increased except at 8 rpm due to collision between balls formed and impact amongst them.

2. Finer the particle size, more the compactness and thereby, higher the compressive strength and drop strength.

3. Best nozzle combination is ABC. The C nozzle is used for formation of new nuclei and stabilization of already formed nuclei. Nozzles A & B at the two stoppers side assist the growth process by layering and also by assimilation of smaller balls.

4. With increase in disc inclination the desired size range decreased. The angle of 43^0 is the optimum value at which maximum efficiency of balling disc was observed.

5. With increase in feed rate, the desired size range decreased. It was observed that the feed rate of 120 tph is the most preferred one for desired size range of pellets. At higher feed rate, the disc rpm needs to be increased to nullify the effect of decreased required size range,

6. Techno-economics

The improved green ball size range will be beneficial in following ways:

1. Production of fired pellets has been increased from 10254 T/day to 10413 T/day from Apr-Jun 2010 to Dec-Feb 2011. This increase of 159 T/day is due to minimizing of oversize and undersize green pellets.

2. Product quality has been improved since its better size range serves good bed permeability while induration.

- CCS improved from 216 to 242.31.
- Unfired pellets decreased from 8.47 to 5.58 %.

3. Energy consumption will be minimized since the energy required for recycling the oversized green pellets while crushing is prevented to some extent. This can be easily revealed from the fact that recirculation load has been decreased from 20.06 to 11.55%. Also, the continuous availability of fresh material to the indurating furnace increased.

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