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Pelletizing Process Parameters for Enhancing Pellet Durability

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***Abstract**: The use of cotton waste or rice husk pellets for renewable heat and power generation has tremendously increased worldwide, especially in United State and India. But, the established raw materials for sustaining this surge in demand of cotton waste or rice husk pellets have drastically depreciate over period of years. To overcome these future challenges, Cotton waste or rice husk feedstock, that have never been used for pellets hitherto, was incorporated to Pine to produced either homogenous or heterogeneous (Pine and Cotton waste or rice husk cotton waste or rice husk) pellets. The pellets were produced using a large scale Buhler pellet mill by adding 10% and 20% Cotton waste or rice husk to Pine feedstock at three initial moisture content levels (10%, 11.5% and 13%) and steam conditioned temperatures (50°C or 70°C).*

The strength and durability of the pellets produced were measured using both standard durability testers (Ligno, tumbling box) and a modified rotary impact tester. The results indicate that pellets containing 10% Cotton waste or rice husk was less durable by almost 1% pellet durability index (PDI) values compared to pure Pine cotton waste or rice husk pellets. However, no significant further decrease in durability was observed between the heterogeneous pellets containing 10% and 20% Cotton waste or rice husk to Pine. Also, increase in steam moisture content of the heterogeneous feed stocks from 11.6% to 16.8% at 50°C have resulted to increase in PDI by 0.6% measured from the pellet durability testers.

The study has showed that steam conditioning of the heterogeneous feedstock at 50°C can be used to improve pellet quality during pelleting. Similarly, the use of 10% to 20% Cotton waste or rice husk in place of Pine feedstock can boost the supply of pellets in the international market because Cotton waste or rice husk cotton waste or rice husk is currently an unexploited biomass resource.

The abstract is to be in fully-justified italicized text, at the top of the left-hand column as it is here, below the author information. Use the word "Abstract" in 10 point Times, boldface type at starting to the column, initially capitalized. The abstract is to be in 10- point, single-spaced type, and may be up to 3 in. (7.62 cm) long. .

1. INTRODUCTION

Cotton waste or rice husk pellets are the current major source of renewable energy used in place of fossil fuels for heat and power generation and locally in our domestic heating boilers. India is one of the largest pellets consumer in the international pellet market and their level of pellet usage for renewable energy production was anticipated to reach about 26% by the year 2020 [1]. The proposed target may probably not be realistic without exploiting other available biomass resources to compensate the future needs. The unrelenting increase in demand is also driven by the effort to mitigate carbon emission from the environment.

The research aimed to investigate how to incorporate other existing biomass material such as Cotton waste or rice husk to Pine cotton waste or rice husk (feedstock) and important pelleting process parameters to produce pellet that can compensate for the future pellets scarcity.

Pine and Cotton waste or rice husk cotton waste or rice husk species were selected for this research because the two biomass feedstocks can contribute to greener energy environment are found in abundance at forests located in India. Similarly, Serrano et al. (2011) has found that adding 2%, 7% and 12% of Pine sawdust to straw has resulted in 1% pellet durability index (PDI) increment. Also, Pine cotton waste or rice husk is a well-known feedstock for durable pellets production and highly rich in calorific energy [2]. Thurs, no investigation has been reported on combined effect of adding Cotton waste or rice husk to Pine feedstocks to produce pellets.

Pellets of both heterogeneous and homogenous feedstocks were manufactured using a conventional large scale Buhler type pellet mill through pelletization. The pellet mill consists of cylindrical shape die and mounted rollers. The rollers rotate to create a small pocket gap where the cotton waste or rice husk powder (feedstock) drop in between the two rollers rotating close to the die channels. The rollers apply pressure to compact and extrude the feedstock through the die channels at high temperature and pressure. The compressed feedstock form a pellet due to skin friction between feedstock layers and die channel wall during pelleting [3].

Pelleting process parameter such feedstock moisture content and temperature are important process factors because, moisture content and steam conditioning of the compressed feedstock could adversely affect the natural binders and fibre layers arrangement. Moisture content and steam conditioning temperature can also act as a medium of heat transfer between the feedstock particles to soften the fibres and ease secretion of inherent binders (e.g. lignin, cellulose and hemi-cellulose) during pelleting [9]. Insufficient moisture content could leads to excessive skin friction to builds up, against the die channel wall during dry pelleting. On the other hand, if the feedstock moisture content exceeded the required wetness, it can leads to feedstock slippery within the die channels, which consequently results in poor compaction and weak pellets production which often jeopardise the benefits of pelleting [4]. However, other pelleting process parameters such as (die length and diameter, die speed, gap between the die and rollers) can also influence pellets breakage tendencies, though, they often remain fixed [5]–[8]. This is because adjusting any of these parameters could lead to product wastage in the pelleting process. Thurs, moisture content and steam conditioning
temperature were selected for this research because it can easily be adjusted to improve the strength and durability of the pellets during pelleting. Pellets made from different sources or feed stocks are likely to behave differently in their level of breakdown and related problems they present. As result, there is also a pressing need for pellet producers, sellers and buyers to gain a useful indication of the likely levels of pellet breakdown in the handling and delivery processes, so that they can make sensible judgements on what pellets to buy from different sources that are available at different prices. However, there are substantial limitations with the existing test equipment; firstly, they do not expose the pellets to the impact conditions experienced in a real handling chain, and secondly there is a lack of comparability (or even correlation) between the results from the different tests.

Equally, several observations have been made by the industrial workers as to whether the existing standard pellet durability testers (Ligno and tumbling box), predict the actual impact conditions experienced by the pelleted particles in a real handling system; during which they are for example conveyed or blown through a pneumatic pipeline, and get broken down due to impacts with the bends. Although these two pellet durability testers were the most accepted industrial standard means of measuring pellet durability. The acceptance is largely due to compactness and low price of the equipment, speed and ease of use and repeatability. The Ligno test has been identified to have less repeatable results and is more sensitive to pellets produced with added binders or fats during pelleting, whereas the tumbling box produces more repeatable results with less consideration on the pellet types. In addition, the tumbling box test takes not less than 10 minutes to run a single test [10]–[12]. Temmerman et al, (2006) has reported that no correlation exists between the two standard testers' PDI results and recommend that the results should not be correlated [13]. Additionally, the standard pellet durability testers have several other limitations particularly; the impact processes inside the testers do not simulate the velocity conditions of particles in a real delivery pipeline or other handling system. The velocities in the testers are much lower and particle concentration is much higher, both of which are known to have a strong effect on the degradation process [14]. It was thought that this could be investigated by using a comparative pellet durability test method to evaluate the available standard pellet durability tester (i.e. Tumbling box and Ligno tester) against the rotary impact tester, that has been specially developed to simulate breakage of large particles in pipelines [15].
In this study the combined effect of raw materials (i.e. adding Cotton waste or rice husk to Pine cotton waste or rice husk) and the importance of pelleting process parameters (moisture content and steam conditioning temperature) on pellet strength and durability will be tested. The sensitivity of different test equipment to degradation tendencies of the different batches of pellets produced will be measured, to determine if correlation exist between their pellet durability index PDI values. The PDI of the pellet produced may differ; therefore, this will be relevant to the pellet producers, sellers and users to ensure satisfactory quality

2. MATERIAL AND METHOD

Pine and Cotton waste or rice husk cotton waste or rice husk species were used in this research, the two cotton waste or rice husk logs were debarked and chipped using PX-800Y chipping machine. The chipped cotton waste or rice husks were stored in a shelter for 30 days at ambient atmospheric temperature (≈23℃) condition. The cotton waste or rice husk chip loses its excess moisture content during this period before proceeding to milling. The milling process was conducted using a large scale industrial milling machine equipped with double sieve sizes where 3.2mm was placed below 4mm screen size. The use of two screen sizes is to ensure aggregate milling of the cotton waste or rice husk chips into the required particle sizes before pelleting, as this could have an effect on the bonding strength [16]. The particles size distributions of the milled samples were determined using a stack of different sieves sized in the order of 0.8mm, 1.6mm and 3.2mm respectively. The photographs of the chipped and milled Cotton waste or rice husk cotton waste or rice husk powder, alongside with the Pine cotton waste or rice husk powders are shown in figure 1.

Figure 1. The cotton waste or rice husk feedstock used for pellet production; (a) Pine cotton waste or rice husk powder, (b) Cotton waste or rice husk cotton waste or rice husk powder and (c) Cotton waste or rice husk cotton waste or rice husk chips

After milling, the heterogeneous or homogenous feedstock samples were thoroughly blended together for about 30-40 minutes, using a large blending container, to minimise any form of particle segregation in the feedstock before pelleting. During blending process, moisture content (MC) of the blend feedstock was also measured repeatedly using Adam PMB53 digital scale moisture analyser. The values were recorded after every 10 minutes interval to ensure adequate moisture distribution among the feedstock particles was attained prior to pelleting process. The blended feedstocks were stored in batches using different temporary silos for essential book-keeping exercise and for independent use of different feedstock batches.

2.1 Pelleting

The pellet manufacturing range was designed in accordance to Taguchi factorial design of experiments, see table 1 in section 5.1 [17]. This design of experiments was adapted because it is a well-known robust method of determining the independent multivariable process parameters for experiment optimization. The systematic design approach involved the use of three different factors, (i) Pine or Cotton waste or rice husk cotton waste or rice husk feedstocks and pelleting process parameters such as (ii) moisture content and (iii) steam conditioning temperature).

Table 1. Summary of pallet production plan

Experiment Order	**Steam Moisture Content %**	**Initial Moisture %**	**Comosition of Both content**	**Conditioning Temp. 0C**
1st	0	10.2	100	20
	0	13	100	20
2nd	0	10	80-20	20
	0	13	80-21	20
3rd	11.6	10.5	90-10	50
	13.3	11.5	90-10	50
	16.8	13.1	90-11	50
4th	13.5	10.2	100	70
	16.2	13.2	100	70
5th	13.6	11.5	100	50
	13.8	11.5	90-10	50
6th	13.6	11.5	100	50
	13.3	11.5	90-10	50
	13.2	11.5	80-20	50
7th	0	11.5	90-10	20
	13.3	11.5	90-11	50
8th	0	10	80-20	20
	13	10	80-20	70

During the pelleting process, the heterogeneous or homogenous feedstocks were combined by adding either 10% or 20% Cotton waste or rice husk to 90% or 80% Pine feedstock. The factorial design yields about seventeen possible combinations when including either steam conditioning at 50°C or 70°C temperature or without steam at 20°C temperature. The moisture content (MC) of the feedstock was also varied from 10%, 11.5% or 13% during pelleting process. The choice of the factors is determined the outcome of the experimental plan as shown in table 1.

During moisture analysis of the feedstock, prior to pelletisation process, it is likely to have either excess wet or dried feedstock. In case of over dried feedstock, the moisture content is elevated by spraying the required grams of distilled water into the feedstock and blend it continuously to achieve the required moisture distribution amongst the particles. Conversely, if the feedstock moisture content becomes too high, it was regulated using heat conduction process through the blending container

2.2 Steam conditioning

It is instructive to note that, the use of steam conditioning at 50°C or 70°C can introduce additional moisture ingress within the feedstock before pelleting, because steam conditioning involves injection of hot steam water to the feedstock. This increases the moisture content of the conditioned feedstock to vary it from what it was initially measured at during the blending process. In both case, either the conditioned or unconditioned feedstocks must pass through the conditioning chamber before proceeding to the flow region (just before the die), where samples of steamed powders were collected for steam moisture content analysis, using EN 14774-2 standard [18]. A computer logging system was used to log the measured data that includes steam conditioning temperature, pellet mill temperature and power consumption during pelleting. The pellets temperature was measured using a laboratory pellet sensor with 0.1 °C precision. Samples of hot pellets were collected directly from the pressing unit and sealed in thermally resistive plastic bags, for hot pellet moisture determination.

2.3 Cooling

Hot pellet samples were collected at constant temperature and production rate at one minute intervals. The mass of the pellets were recorded using a digital scale balance with 0.001g precision before and after being air-cooled for 24 hours, at ambient temperature (23℃). This was done to determine the amount of moisture migration (lost) during cooling.

Cooling is an important part of pellet quality assurance, because freshly manufactured pellets have moisture content hovering between 12% to 18% and temperatures between 60°C to 95°C [19]. Therefore, cooling of freshly manufactured pellets is important to avoid possible water condensation within pellets. Condensation is an undesirable process which may degrade the resultant pellets strength and durability.

2.4 Sieving

Sieved was manually conducted in accordance with the ISO 3310-2 standard [20]. Manual sieving was chosen over an automated sieving method, to minimise breakage of pellets due to mechanical shocks that pelleted particles encountered during automated sieving. A 3.15mm diameter round-holed sieve was used to separate clean pellets (> 3.15mm diameter) from fines (< 3.15mm diameter). The particle distribution of fines were also determined using stack of wire meshes sieves in the order of, 3.15mm, 2.36mm & 1mm diameters.

2.5 Influencing factors

2.5.1 Pellet moisture content

The moisture content of the pellets produced was determined in accordance with EN 14774-2 standard [18]. This standard emphasizes that pellet moisture content must not exceed 10% dry basis. This is because pellets containing more than 10% moisture content are classified as lower standard pellets. For more detail analysis of the method see [21]

2.5.2 Bulk and tapped density

The bulk density, BD, of pellets was measured in accordance with EN 15103 standard. A sieved sample of "clean" cotton waste or rice husk pellets (>3.15mm diameter) was poured into a five litre measuring cylinder with dimension 200mm diameter and 300mm height. The cylinder was filled until the pellets reached the top and formed an angle of repose cone. The pellets within the filled cylinder were compacted using a drop height method wherein the cylinder was dropped three times from approximately 150mm height onto a hard surface to compact the cotton waste or rice husk pellets. Excess pellets overshooting the top of the cylinder were removed and voids at the top surface of the cylinder, if any, were filled with pellets. The mass of the empty cylinder and mass of the pellets was measured. The bulk density of the pellets was calculated using equation 3.2:

$$BD = M/V$$

Where

M is the mass of the pellets; V is the volume of the cylinder

2.6 Pellet durability Test equipment

Pellet quality has a significant influence on boilers performance, and thus, it is important understand how durability test of pellets can be estimated using equipment. The industrial pellet durability testers are tumbling box, Holmen tester, and Ligno tester.

2.6.1 Tumbling box durability tester

The tumbling box pellet durability tester is the most commonly used industrial tester for measuring the kinetic wear and impact resistance of pellets during handling. The pellet durability test was conducted in accordance with EN15210-1 European standard [18]. Three samples of pellets were collected from each batch of pellets produced. The samples were manually screened using 3.15mm diameter round-holed sieve to separate fines (< 3.15mm diameter) from the clean pellets in accordance with ISO 3310-2 (ISO, 2010). A Hoffman R89P Riffle divider was used to randomly divide the clean samples into portions and the mass was measured using a digital scale balance.

A sample mass of 500 ± 10g of the clean pellets was loaded into the tumbling box compartment. The tester tumbled the pellets at fixed rotating speed of 50 ± 2 rpm for 10 minutes. The machine ceased automatically after 10 minutes testing period and the tested sample was retrieved from the tester. The retrieved pellets were manually sieved, to separate broken fines from the coarse pellets using (>3.15mm diameter) round-holed sieve. Finally, the pellet durability index (PDI) was calculated using equation 4:

$$PDI = M/Mo \times 100\%$$

Where:

M is the mass of coarse pellets after testing, and Mo is the initial mass of the pre-sieved coarse pellets before testing

2.6.2 Ligno tester

The Ligno tester was used in accordance with ÖNORM M 7135 Austrian standard. The initial test procedure adopted here was similar to that described in section 4.1. 100g ± 0.5g in mass of clean pellets was loaded into the Ligno tester. The tester uses about 70-80 mbar pumped air pressure to instigate random collisions of pellets and with the chamber walls. The pellets degrade to generate fines and dust during the process. The tester terminates automatically after 60 seconds. The broken and unbroken pellets were retrieved and their mass was determined using a digital weigh balance, with 0.01g precision. No sieving is required in Ligno test because the fraction of material above 3.15mm round holed separate automatically during the test. The pellet durability index (PDI) was calculated as in section 4.1 and recorded.

2.6.3 The rotary impact tester

The large scale rotary attrition impact tester was designed for assessing breakage of large particles (>1mm diameter) in industrial processes such as pneumatic conveying systems [23]. The ability of the rotary impact tester to determine particle breakage under controlled impact velocity (by adjusting the disc speed) and controlled impact angle (by choosing the target angle); are the key factors that facilitate the use of this tester for estimating the level of particle impact attrition in a pneumatic pellet delivery system. Particle concentration had less effect on this test (as opposed to actual pneumatic systems) because the pelleted particles are relatively large (6-8mm diameter) and free flowing, dispersing with little or no concentrated strand of flow even at high feed rates.

The test commenced by discharging the 2000g of pellets contained in the plastic bag into the feeding hopper and a table feeder was used to feed the pellets into the centre hole of the rotating accelerator disc at 33g/s feed rate. The disc rotates at a fixed speed which gives an impact velocity of 18.8m/s. The pellet flow is split within the rotary disc channels and accelerates tangentially to impinge against surrounding targets. The rotating disc speed was 576 revolutions per minute, measured using tachometer. It takes about 60 seconds to run a complete single impact degradation test from rotary impact tester. A vibrator to the enclosure around the test rig was also used along with manual brushing to facilitate retrieval the entire batch of coarse and fine pellets via the tester outlet. The retrieved pellets were sieved to separate the fines from the coarse pellets using a stack of wired mesh and round round-holed sieves. The sieves were arranged in descending order of 4.75mm, 3.15mm, 2.36mm and 1mm diameter respectively.

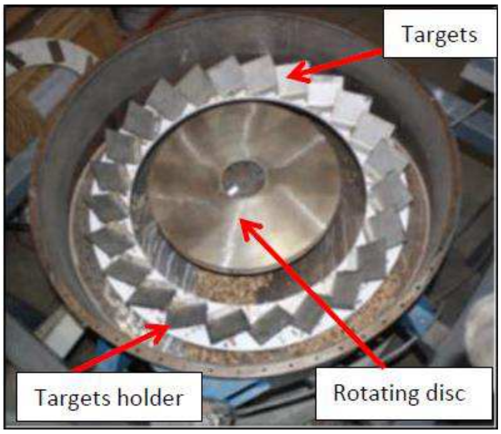

Figure 2. The rotary impact tester after the test (Bradley 1999)

The impact angle was fixed at 45°C throughout this test. The particle impact velocity, Vp, was calculated using equation (5) VP = $2\pi R$ cos ( ) n

3. RESULTS AND DISCUSSION

3.1 Factors affecting pellet strength and durability

The results obtained from the test programme are shown in a table with test settings in terms of methodology of pellet production using three distinct process parameters (moisture content and steam conditioning temperature) and biomass feedstock (Pine and Cotton waste or rice husk cotton waste or rice husk). The results show how the pelleting process parameters and feedstock variability affect the pellet strength and durability. Table1 presents the summary of parameters used during pellet production and their corresponding resulting bulk density.

The heterogeneous pellets containing 10% Cotton waste or rice husk and 90% Pine feedstock produced at 11.5% initial feedstock moisture content and 50°C steam condition temperature was observed to have slightly lower bulk density compared to the equivalent set of pellets that had 20% Cotton waste or rice husk content. The bulk density of homogenous pellets (100% Pine) produced at the same condition was higher in comparison to heterogeneous pellet samples. Generally, the change in pellet bulk density observed between both homogenous and heterogeneous pellets produced is between ± 10 %.

3.1.1 Effect of steamed moisture content

The result of pure and mixed pellets containing (10% cotton waste or rice husk) feedstock, produced at three different steamed moisture content (11.6%, 13.3% and 16.8%) are shown in figure 7. The pellets were all produced at 50°C steam conditioning temperature. The resulting pellet quality was evaluated using standard tumbling box, Ligno and rotary impact testers.

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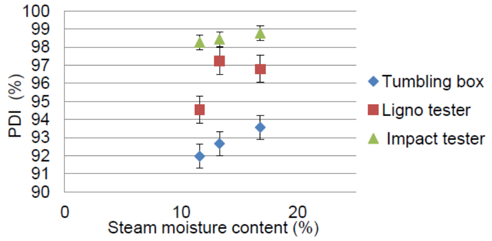

Figure 3. Pellet durability index (PDI) vs steam moisture content

The results in figure 3 indicate that PDI generally increased with corresponding increase in steamed moisture content. The anomaly was not simply due to experimental error because the durability tests were all repeated three times. The increase in PDI value was more sensitive on the standard (tumbling box and Ligno) testers, whereas, the rotary attrition impact tester result seemed to be less sensitive to steamed moisture content, although it did shows a significant increase in pellet durability.
The error bar values were calculated from average mean values of the standard deviation of the measured results and are multiplied by two to get 95% confidence interval.

3.1.2 Effect of adding Cotton waste or rice husk to Pine cotton waste or rice husk powder

Effect of blending (10% or 20%) Cotton waste or rice husk with (90% or 80%) Pine cotton waste or rice husk powder to produce heterogeneous pellets is shown in figure 4. The pellets were produced at 13.4% steamed moisture content and 50°C pre-conditioning temperature. The resulting strength and durability of the pellets were also evaluated using the three testers mention in section 3.4 above. From all indications the homogenous (100% Pine) showed more resistance to breakage.

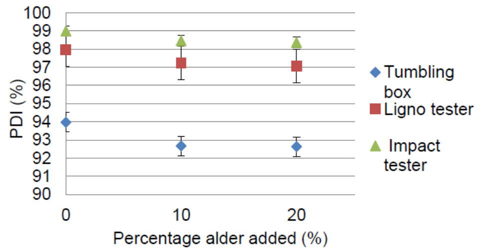

Figure 4. Pellets durability index (PDI) vs percentage cotton waste or rice husk

The pure Pine pellet was slightly more resistant to breakage compared to heterogeneous pellets containing 10% or 20% Cotton waste or rice husk. However, varying between 10% or 20% cotton waste or rice husk did not make any difference in the pellet breakage resistance.

3.1.3 Effect of steam conditioning temperature

The effect of steam conditioning temperature on pellet strength and durability during pelleting was examined by using pure Pine feedstock to produce pellets at two distinct steam conditioning temperatures (i.e. 20°C and 70°C). The breakage resistance of the steam conditioned and un-steam conditioned pellets was measured using three different pellet durability testers. The average pellet durability index (PDI) was also calculated and the results are presented in figure 5. The standard pellet durability testers (tumbling box and Ligno tester) indicated increase in pellet durability produced at 70°C steamed conditioning temperature compared to un-steam conditioned pellets produced at 20°C. However the rotary impact test was virtually insensitive to this increase in breakage resistance that occurred due to increase in conditioning temperature. This difference in breakage trends is probably due to the low impact energy in the standard tumbling box and Ligno tester contrasting with no significant change in breakage resistance when the impact energy was higher in the rotary impact tester.

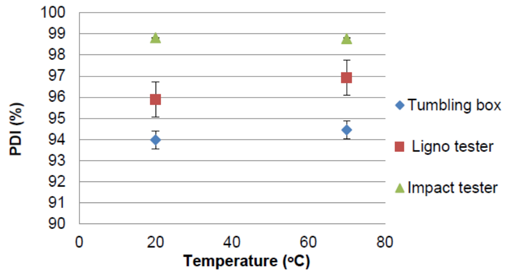

Figure 5. Pellets durability index (PDI) vs steam conditioning temperature

3.2. Correlation of pellet durability index values from different durability testers

The correlations between the PDI values from the two standard pellet durability testers (i.e. Ligno and tumbling box), and the modified rotary impact tester are shown in figure 6. The average mean values of the PDIs for each test batch are presented in figure 6 to 8.

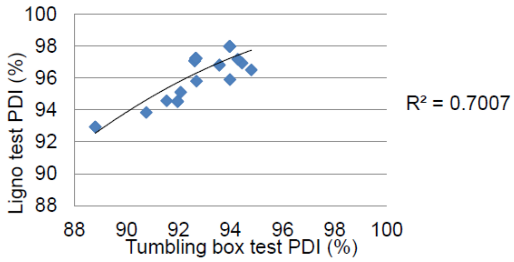

Figure 6. Correlation between Ligno tester vs tumbling box durability tester

The values of the pellet durability index (PDI) from the two standard testers (i.e. Ligno and tumbling box tester) depict the existence of slight correlation between the PDI results of the two standard testers, especially in the region below 96%, but with a very significant difference (typically 4% at the bottom of the trend line and 3% at the top). Given that the critically important factor is the fines content, i.e. 1-PDI, an uncertainty in correlation of up to 2% in (1-PDI), and a difference of around 3%, is extremely large when the maximum acceptable value of (1-PDI) in the EN Plus standard for pellet durability for commercial sale is 2.5%.

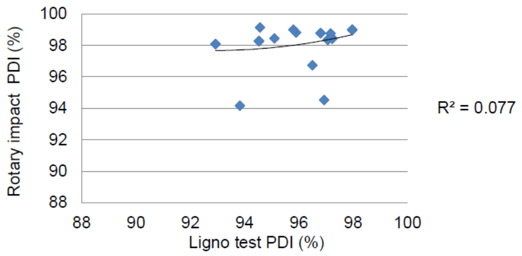

Figure 7. Correlation between rotary impact vs Ligno tester

The result in figure 7 compared the PDI values of rotary impact tester and that of Ligno tester. No correlation seems to exist between the values derived from the two testers; the R2 value was 0.07. This is likely to occur due to differences in the tester's breakage mechanisms due to different energy levels during the different pellet durability tests.

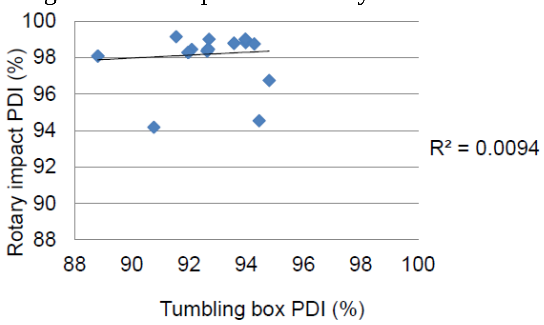

Figure 8. Correlation between rotary impact vs tumbling box durability tester

The results presented in figure 8 indicate poor correlation between the PDI vales of rotary impact tester versus tumbling box tester. The R2 value was 0.009, compared what was observed in figure 4.5. This seems to indicate that no appreciable correlation exists between the two tests. None of the two standard pellet durability testers correlate with the rotary impact tester. However, the two standard testers have some degree of correlation with each other, despite the fact that Ligno tester results being less repeatable with more scattered points, and a significant quantitative difference

Conclusion

The increase in steam conditioning temperature increases the pellets strength and durability to some extent; however this is at the expense of greater energy used in production.

Adding 10% to 20% Cotton waste or rice husk to Pine wood powder pellets have shown a degree of acceptable durability threshold values around ≥ 97.5% when tested with Ligno and rotary attrition impact tester but slightly lower in tumbling box and no other additional variation in durability was observed when 20% Cotton waste or rice husk was added

The pellets durability index (PDI) increased to some extent with increase in feedstock moisture content in both steam-conditioned and non-steam-conditioned pellets

Comparative evaluation of pellet durability index techniques:-

It is evident from the results that Ligno test was slightly less repeatable compared the tumbling box test, though this might suggest variation in the impact velocity (currently unknown and hard to measure) in the standard Ligno tester.

The rotary impact tester produced highly repeatable PDI values with less percentage error tendency compared has observed in both tumbling box and Ligno tester.

 The relatively poor correlation between the tests is a major cause for concern., Had there been a close correlation but just with an offset, the test results could be subjected to a "correction" for the difference, or the tests subject to an adjustment of duration, to obtain equivalence. However, the high scatter and the great lack of correlation in the most important range (97% to 100% PDI for commercial acceptability), even for the two testers accepted as "standard" and widely used for industrial quality control measurements, together with the much poorer correlation against the rotary impact test that was designed to simulate the conditions in a real conveying system, is clear evidence that industry should expect very little correlation between the PDI reading for a batch, and the actual pellet break-down seen in real deliveries.

Findings suggest that at the moment, the best recommendation is to use the rotary attrition impact tester for evaluation of pellet strength and durability because it produces highly repeatable results as well as being specifically designed to simulate the impact velocity in the real delivery system.

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