Measuring physical quality of pelleted feed by texture profile analysis, a new pellet tester and comparisons to other common measurement devices

C. Salas-Bringas[1], L. Plassen[1], O.-I. Lekang[1] and R. B. Schüller[2]

[1]Dep. of Mathematical Sciences and Technology, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway.
[2]Dep. of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway.

ABSTRACT
There is an increasing need for measurements of physical quality of pelleted feed that can correlate well with the product quality found in the trading line. This article explores the use of texture profile analysis, Holmen durability tester and the use of a future potential new tester. A short review to other common measurements devices is also given in this article.

INTRODUCTION

By pellet quality we understand all those properties of extrudates and pelleted feed that are of interest to the producers and consumers both nutritionally and physically.

Only physical quality of pelleted feed and the most common measurement equipments will be mentioned in this article.

The physical behaviour of animal feed pellets is mainly determined by the components added and their treatment during manufacture. Feed pellets have been described as brittle materials[1]. Thomas et al.[2] describes feed pellets as three-phased materials composed of solid particles, liquid and gas.

Nowadays, Norwegians farmers are pressing the feed producers to manufacture pellets which can resist the stresses during transport and storage better, meaning having the least breakages and formation of dust as possible. Also there is an increasing pressure to trade products with certified qualities.

There are a number of quality testing equipments today in the market, which have been extensively used, but the physical characterization given by them, does not always correlate well with the physical quality found at the moment of use. The breakages occur during feed production, trading and final delivery to the animals. Researchers addressing problems within the trading lines have not been published, but pneumatic transport is believed to be one of the main causes of breakages. Moreover, the stresses that the pellets are subjected to can also vary between different producers and consumers. A parameter predicting quality after an extended period of usage or handling could be a good help to improve trading problems.

Physical quality standards in the feed can also be an important help for an orderly marketing and for future application of feed control laws. Without feed quality standards the purchaser has no assurance that a packaged feed will be of the identity and quality he or she expects. Traders in distant markets cannot buy with confidence if there are no standards that can specify the kind of quality to be delivered. Uniform standards intelligently applied can promote trade to the eventual benefit of producers and consumers. Physical quality measurements during production can also be a great help to produce firmer pellets and to improve process efficiency by using control loops.

The following measurement equipments will be addressed in this article: texture analyzer, Holmen durability tester, Borregaard durability tester and a working principle to assess the creation of a new tester.

Texture analysis

Feed technologists mainly use texture analysers to determine the maximum peak force that produces breakages (hardness) and to estimate the tensile stresses. Stiffness through elasticity measurements is a parameter that also describes physical quality, but has not been extensively used. Texture measurements can correlate well with the damages due to the loads during storage, but their determination is slow and requires trained personnel, making hard its use for continuous measurements at feed plants.

Holmen durability tester[3]

This tester is widely used and was created twenty four years ago. The Holmen tester simulates the pneumatic handling of pellets by using a closed air circulation path through right angled bends that produces pellet attrition[2,3,4] (see Fig. 1). A sample of 100 g circulates for a time which is set by the operator, the alternatives are 30, 60, 90 and 120 s. Quantification of unbroken pellets (*UBP*) through sieving is used to estimate the physical quality and is referred as "pellet durability index".

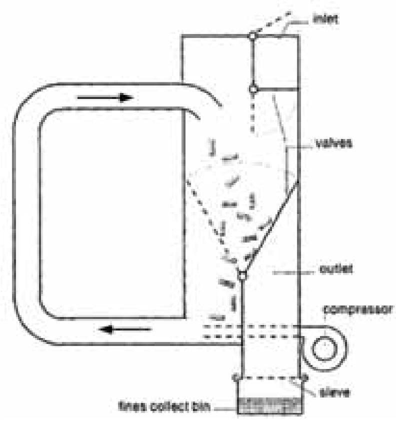

Figure 1. Holmen durability pellet tester.[2]

Other common methods used to determine pellet quality

Another tester, the Borregaard pellet durability tester[5] that is also been recently called "new Holmen pellet durability tester"[a], is shown in Fig. 2.

In this tester, a blower forces air to flow at high velocity and is directed vertically upward into a pile of pellets. The air throws the pellets into the air against a filter and out to the side where they fall against the sides of a hopper. The pellets then slip down the sides of the hopper back to the bottom again and into the air stream where they are again thrown upwards in the air jet. This results in repeated collisions between the pellets and the wall of the tumbling chamber causing formation of dust and breakage. The perforations provided in the sides of the hopper allow the fines to drop through into the fine collecting chamber.

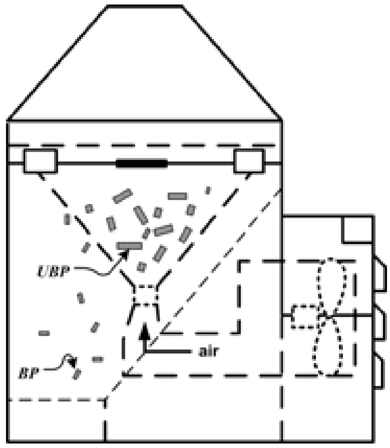

Figure 2. Borregaard pellet durability tester. The figure has been modified from Payme, J.D.[5] to indicate where the unbroken pellets (*UBP*) and broken pellets (*BP*) are situated.

As in the traditional Holmen durability tester (Fig. 1), the quantification of *UBP* through sieving is used to estimate the physical quality. *UBP* is normally found as "pellet durability index".

None of the pellet testers in the market today is built for using two different sizes of sieve simultaneously, therefore nowadays is not possible to obtain the fractions of *BP* and dust (*D*) which are the fractions representing waste. Some animals are able to eat broken pellets like chickens, but like in most of the animal cages, the dust stays left and represents waste. Other animals like cows avoid the consumption of small particles of broken pellets, so what is considered waste depends

[a] TekPro, North Walsham, UK.
http://www.tekpro.com/tekproproducts2.asp

on the particle size, type of feed and the age of the animal.

Developing a working principle for a new pellet tester

As it was commented earlier, today the industry and many researchers use the term "durability" to name the percentage of pellets over a single strainer after a specific testing time. Durability is a term more appropriate to describe the ability of goods to remain useful after an extended period of time and usage, this type of measurement concept is what is sought by consumers and producers. By measuring physical quality after different periods of testing time, it can be possible to describe durability in terms of quality decline versus handling. In the new tester, quality of feed pellets will be measured by circulating pneumatically the feed thought a piping system one, two and three times. *UBP*, *BP* and *D* will be measured each time and used as an indication of quality decline versus a numbers of tests where stresses are applied.

MATERIALS AND METHODS

Design features of the working principle of the new pellet tester

To help to understand the testing principle and the tests, a detailed description is given with reference to Fig. 3. 100 g of feed pellets are fed on a belt conveyor driven by a DC motor that is connected to a controllable power supply. Through the power supply is then possible to regulate manually the speed of the belt, and thus to control the flow rate of pellets to produce a pneumatic transport in a dilute phase. The conveyor conveys the pellets to a cone where a stream of air moves the pellets inside a number of transparent PVC pipes. The pellets then impact repeatedly the bends and surface of the pipes creating breakages and dust in the feed. A Line Vac (EXAIR Co, Cincinnati, USA) is used to produce a stream of air into the system through a positive pressure at the inlet of the pipes. The Line Vac is connected to a supply of compressed air.

The internal diameter of the pipes is 0.0212 m and the length of all pipes together is 37.56 m. At the end of the piping, a container is placed to receive and to collect the pellets. This container is also connected to a vacuum that is used to increase the air speed into the pipes. In this way, the pellets are transported by the positive and negative pressure at the inlet and outlet of the pipes respectively. A description of the air speed inside the pipes is given in Fig. 3.

All tests were done by setting the same conditions of pressure. Measurements of air speed (v) were assessed by a Pitot Tube (Velocicalc 8346, Saint Paul, MN, USA) in the positions indicated in Fig. 3.

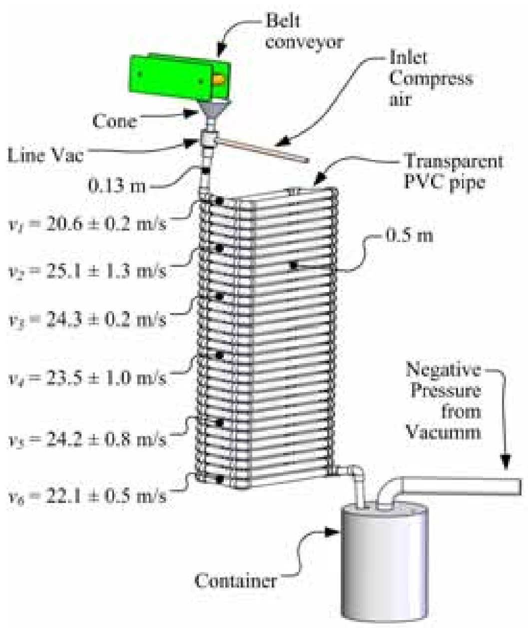

Figure 3. Assembly used to simulate pneumatic transport conditions. This system will be used to evaluate the principle of a potential new pellet tester. The figure shows averages of air speed (v) ± the standard error of the mean (n = 3).

Physical quality measured by the new pellet tester

Samples of feed pellets were separated from the batch and sieved to test the quality of the *UBP* only. A screen size with an aperture of 3.15 mm for the pellets having 4 mm diameter, 2.5 mm for the pellets having 3.0 mm diameter and 2.0 mm for the pellets having 2.5 mm diameter were used [b].

[b] ASTM 11-61 - Screen Sizes for Pellet and Crumbles Durability Tests. American Society for Testing and Materials.

Samples of pellets (100 g) over this sieve were then used for the tests. The samples were weighed in a scale (Mettler Toledo, model PT1200, Greifensee, Switzerland). Each of these samples were scattered homogeneously over the belt conveyor to start the test. All tests were repeated three times.

After each test, the pellets collected in the container (see Fig. 3) were sieved during 30 s with an amplitude of 1.5 mm by using two different sizes of strainers having in the bottom a collecting pan mounted in a vibratory sieving machine (Retsch AS200 Control, Haan, Germany). The pellets over the first sieve are considered as *UBP* (%), the size of this strainer was the same as the ones used to prepare the samples.

$$UBP\,(\%) = \frac{UBP\,(g)}{Initial\ weight\ of\ sample\,(g)} \cdot 100 \quad (1)$$

The particles collected between the first and second sieve were considered as broken pellets *BP* (%) see Eq. 2. The size of the second strainer was 500 μm for all tests and its purpose is to separate the *BP* (%) from *D* (%).

$$BP\,(\%) = \frac{BP(g)}{Initial\ weigh\ of\ sample\,(g)} \cdot 100 \quad (2)$$

Then, the particles bellow the 500 μm sieve, collected in the pan, were used to estimate *D* (%) as follows:

$$D\ (\%) = \frac{D\,(g)}{Initial\ weight\ of\ sample\,(g)} \cdot 100 \quad (3)$$

Since the new tester works with a negative pressure from a vacuum, the smallest and lightest particles lifted by the air are sucked out of the container. This quantity of dust will be considered as *Missing dust* (%) since it is not weighed and collected. *Missing dust* (%) can be estimated through Eq. 4.

$$Missing\ dust\,(\%) = 100 - [UBP(\%) + BP(\%) + D\,(\%)] \quad (4)$$

The *Total dust* produced by the action of the tester, was estimated through Eq. 5.

$$Total\ dust\,(\%) = D\,(\%) + Missing\ dust\,(\%) \quad (5)$$

Three tests were carried for each type of pellets. The pellets were transported one, two and three times inside the piping. This was recorded as number of runs. Averages of *UBP* (%), *BP* (%), *Missing dust* (%) and *Total dust* (%) were estimated after each run number, they were plotted using the standard error of the mean (±SE) to describe the repeatability of the tests.

To discriminate quality, the following criteria's will be used: the quantity of *UBP* (%) is proportional to the quality of the feed, the quantity of *BP* (%) is inversely proportional to the quality of the feed, the quantity of *Total dust* (%) is inversely proportional to the quality of the feed. *UBP* (%), *BP* (%), *Missing dust* (%) and *Total dust* (%) will be measured in both, the new tester and the Holmen tester versus the different extensions of usage.

<u>Physical quality measured by Holmen tester</u>

Samples of feed pellets were extracted from the original batch and prepared following the same procedure used for the new tester. The tests were also repeated three times.

The particle size analysis of the feed after Holmen tester was made following the same sieving procedure used in the new tester. *UBP* (%), *BP* (%), *Missing dust* (%) and *Total dust* (%) were then plotted versus the *Testing time* (s). The sieve of the Holmen tester (see Fig. 1) was not used because involve a manual sieving that can vary among the different tests. Also since it is only one sieve and does not allow the measurements of *BP* (%) and *D* (%).

Three tests were carried for each type of pellets using Holmen tester during 30 s, 60 s and 90 s.

<u>Texture analysis; measurements of stress and elasticity</u>

Maximum tensile stress: measurements of hardness for each pellet were obtained by measuring the first peak force *(F*) in Newtons during a diametric compression in a TA-HDi Texture Analyzer (Stable Micro Systems Ltd., Surrey, UK).

For each type of feed there were measured 60 pellets, but subdivided in groups of two different lengths (n = 30) to determine whether the maximum tensile stress is influenced by the length of pellets or not. The same tests were also used to determine elasticity.

Figure 4. Diametrical compression of a feed pellet using a cylindrical probe, SMS P/45**.**

The maximum tensile stress (σ) for cylindrical specimens, is estimated using Eq. 2.[8]

$$\sigma \approx \frac{F}{\pi\, r\, L} \qquad (2)$$

Where r and L are the radius (m) and length (m) of the pellets, respectively.

Finding a representative tensile stress through Weibull analysis: a representative value of σ was estimated using Weibull distribution through the accumulated Weibull probability plot of y and x (Eq. 3 & Eq. 4), where the dependent variable is represented by Eq. 3, and the independent variable by Eq. 4, as follows:

$$y = \ln\left[\ln\left(\frac{1}{1-\left(\frac{i-0.5}{n}\right)}\right)\right] \qquad (3)$$

$$x = \ln(\sigma) \qquad (4)$$

Where i is the observation number, assigning a number between 1 to n in a sorted table by ranking the failure stresses in ascending order.

Applying a linear regression, it will be obtained an equation $y = ax + b$, where a represents the Weibull modulus which is dimensionless and is inversely proportional to the coefficient of variation (a = 1.2/CV) when compared to a normal distribution. Through a was calculated the CV used in the error bars on Fig. 8. a is often expressed as m in literature.

A representative stress was estimated through the scale parameter σ_0 which is the stress level (*MPa*) that causes failure in 63.2% of the pellets. σ_0 can be obtained by using the y-intercept, b, following Eq. 5, b is normally expressed as ($m \ln \sigma_0$).

$$\sigma_0 = \exp(-(b/a)) \qquad (5)$$

The results will be presented in a graph σ_0 versus the length of pellets.

Measurements of elasticity: elasticity was determined through the "Youngs modulus of elasticity" or modulus of elasticity (E), which is the slope of the stress-strain curve. E (*MPa*) will be used to tell about the rigidity or stiffness of the pellets. Since E is a function of the strain, it was decided to determine E from Eq. 6.

$$E = \frac{\partial \sigma}{\partial \varepsilon} = \frac{\partial\left(F/(\pi\, r\, L)\right)}{\partial\left(\Delta d/(d)\right)} \qquad (6)$$

Where d is the diameter (m) of the pellets and Δd is the change in diameter (m) due to F (N) during the compression.

E was calculated by the slope of the straight line connecting the points where the 25% of the maximum load is achieved and the inflexion point in the stress-strain curve (see Fig. 7). The calculation of E was made by the software Texture Expert Exceed V2.61 (Stable Micro Systems Ltd., Surrey, UK). The results are presented using the averages of E in a graph E versus pellet length (mm). CV is used in the error bars.

RESULTS AND DISCUSSIONS

Physical quality measured by the new pellet tester

The results given by the tests showed that it was possible to discriminate quality from the *UBP* (%). The lowest breakages were registered for the pellets having 2.5 mm of diameter, followed by the pellets having 4.0 and 3.0 mm in diameter (ref. Fig. 5a).

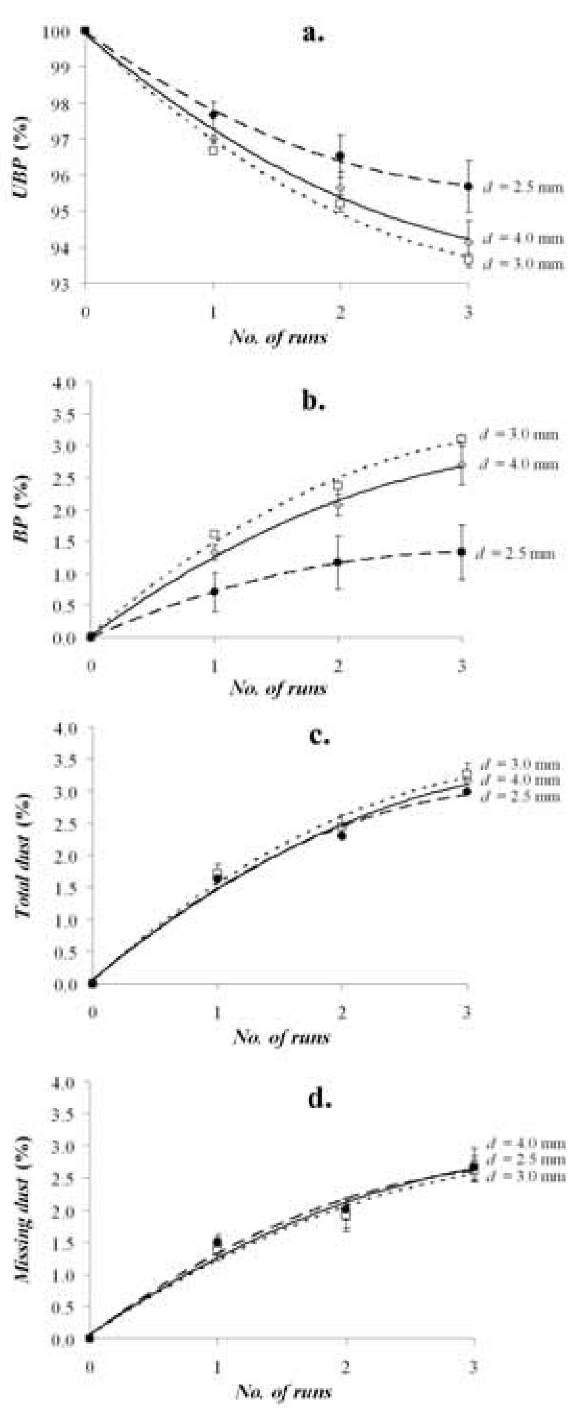

Figure 5. Averages (n = 3) of *UBP* (%), *BP* (%), *Total dust* (%) and *Missing dust* (%), in the new tester for three different types of pelleted feed. The error bars represent the standard error of the mean.

The quantity of *BP* (%), Fig. 5a, shows that the pellets having 2.5 mm diameter present the lowest amount of *BP* (%), followed by the pellets having 4.0 and 3.0 mm of diameter. The same quality order was observed in the *UBP* (%), Fig. 5b.

The *Total dust* (%) produced by the new tester in the three types of pellets, shows that all feeds formed similar amounts of dust (see Fig. 5c). Even the slightly difference of *Total dust* (%) between pellets shows the same quality order found when analysing the *UBP* (%) and *BP* (%).

The amounts of *Missing dust* (%), Fig. 5d, was high with respect to the *Total dust* (%), Fig. 5c. In the case of the new tester, high amounts of *Missing dust* (%) is a positive factor to avoid material inside the tester which can be mixed with the sample of a subsequent test since it is sucked out. Accumulation of dust from feed can also be dangerous since it is explosive.

From all the measurements of *UBP* (%), *BP* (%), *Total dust* (%) and *Missing dust* (%) obtained in the new tester, it can be seen that the best quality was observed in the pellets with d = 2.5 mm, followed by the pellets with d = 4.0 mm and d = 3.0 mm, respectively.

All the trends given by *BP* (%), *Total dust* (%) and *Missing dust* (%) show a power law type of curve when increasing the numbers of runs. These trends could be used as an indication of the quality decline after a period of usage or tests.

<u>Physical quality measured by the Holmen tester</u>

In the Holmen tester (Fig. 1) it was found that the feed having 4.0 mm of diameter, presented the highest quality according to the *UBP* (%). Similar and also lower amounts of *UBP* (%) were found in both, the feed having 3.0 and 2.5 mm of diameter (ref. Fig. 6).

From the measurements given by the Holmen tester, it can be seen that in the pellets with d = 4.0 mm was observed the highest quality when *UBP* (%), *BP* (%) and *Total dust* (%) are used as quality parameter. However, *Missing dust* (%) was not correlated with this tendency.

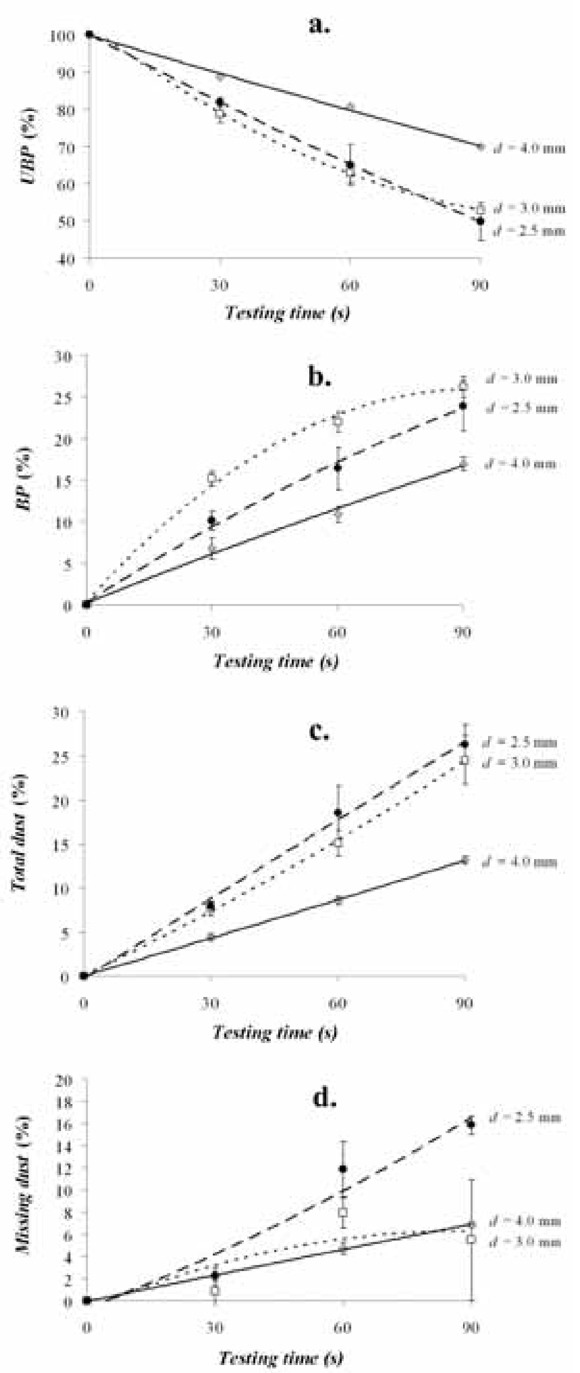

Figure 6. Averages (n = 3) of *UBP* (%), *BP* (%), *Total dust* (%) and *Missing dust* (%), in the Holmen tester for three different types of pelleted feed. The error bars represent the standard error of the mean.

From Fig. 6a., by looking *UBP* (%), is possible to observe that different feeds presents different trends when the testing time increases, d = 4 mm and d = 2.5 mm presents a linear reduction of its value, but d = 3.0 mm decreases in a more asymptotic manner. From this graph is not possible to tell whether the feed of 3.0 mm is better than the feed having 2.5 mm in diameter.

After a number of runs, in two of the tests (d = 3 mm) were observed no *Missing dust* (%), here it was collected more material than the initial sample. This was due to the *Missing dust* (%) that was kept from previous tests, came out of the Holmen tester and was mixed with the running sample. The biggest excess of sample was obtained after 90 s and was quantified in 35.4%. The tester was checked and cleaned by the producers few months before these tests occurred. Similar problems have been observed in other apparatus. Great care should be exercised when using the Holmen tester.

Texture analysis; measurements of stress and elasticity

To understand the measurement method better, a detailed description of the results from a single texture analysis is described in Fig. 7.

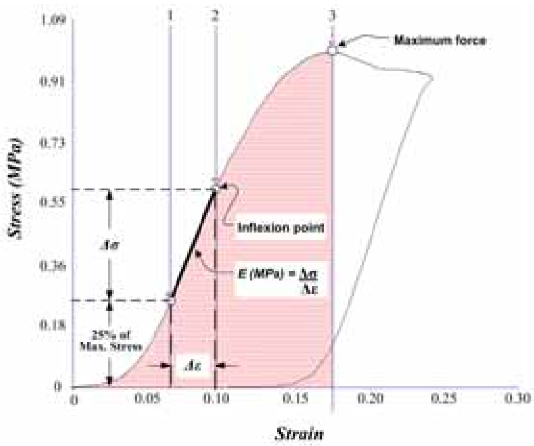

Figure 7. Texture profile analysis of one of the pellets (d = 4 mm) having a ductile behaviour. The graph shows the slope from where E (*MPa*) was estimated and a ductile type of failure. Also is shown the maximum force that was used to estimate σ_0 (*MPa*).

Aarseth and Prestlokken[1], describes feed pellets as brittle materials, but Fig. 7 shows a large yielding in the 4 mm pellet that belongs to a ductile material. Therefore, not all feed pellets are brittle materials. These pellets were made for horses and were rich in fibres.

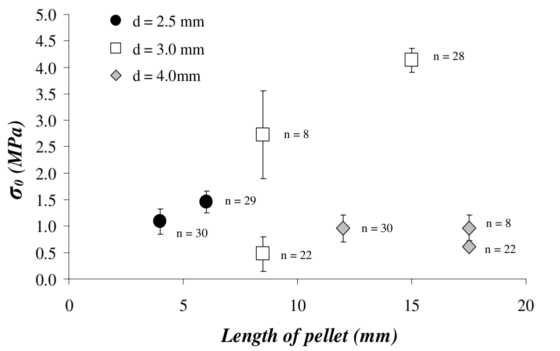

Figure 8. Maximum tensile stress that produces failure in 63.2% of the pellets. Stresses from three different types of pelleted feed having three different diameters are shown. The error bars represent the CV that was estimated through the Weibull modulus.

Both, the feed having 3.0 mm and 4.0 mm in diameter presented, pellets have different σ_0 for a similar length. This separation of groups with different σ_0 was possible by visualizing two trends in the accumulated Weibull probability plot (see case of 3.0 mm pellets on Fig. 9). The specimens were separated in two groups making two new Weibull probability plots.

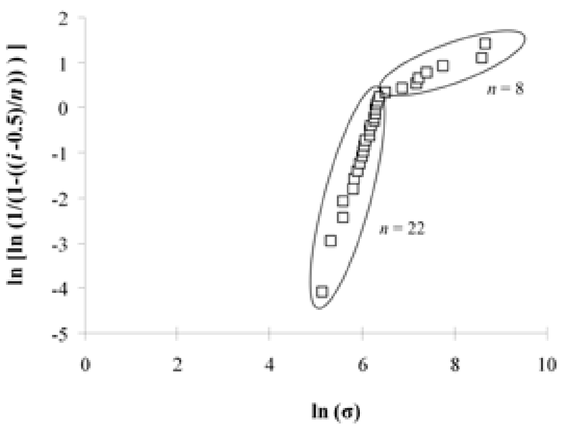

Figure 9. Weibull probability plot for the 3.0 mm pellets having a length of 8.5 mm.

By looking at Fig. 8 it is not possible to clearly differentiate quality between the three types of feed, but it is possible to observe in two feeds (d = 2.5 mm & d = 3.0 mm) that longer pellets presents higher tensile stresses. Pelleted feed are materials which are made by a mixture of different grinded ingredients (mainly cereals) having different particles sizes, they are anisotropic. It is possible that higher tensile stresses were found in the longer pellets because the chances for the coarser particles or more dense areas to hold the diametrical force increases when increasing the length of the pellets. The higher strength for diametrical compression given by the longer pellets is possibly not fully correlated with the resistance to the breakages produced when the pellets hits the surfaces during pneumatic transport, because the forces comes from different directions. The alignment of fibres during manufacture could produce differences in strength when the forces are applied from different axis.

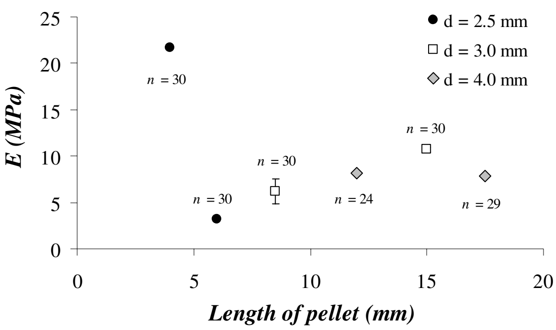

Figure 10. E for three different types of pelleted feed having three different diameters. Each feed was separated in two groups of different lengths. The error bars represents the CV.

Also from Fig. 10, is possible to observe that the length is a parameter affecting the stiffness of the pellets when testing in a diametrical compression. The relation between stiffness-length was different for the different feeds. Only one type of feed (d = 4.0 mm) had the same stiffness and also σ_0 when testing different lengths, these pellets were rich in fibres.

In both cases, the Holmen and the new tester, different sizes of pellets travelled at different speeds, therefore the stresses affecting each pellet are different. This is the same situation that can be expected during pneumatic transport in the factories and in the farms.

The main differences from testing quality in Holmen and the new tester are that in Holmen tester, different sizes and densities of pellets travel different distances during the same testing time. In the new tester all pellets travel the same distance, like in a pneumatic transport in the feed plant or in the farm from one place to another.

Measurements of physical quality by other common methods

One of the main limitations given by most of the testers today, is that the use of a single sieve for giving a quality index, does not allow the quantification of both *BP* and *D* which are the fractions considered as waste. Also, the no use of a quality result that relates physical quality with different periods of usage or handling, will not help to reduce the trading problems that exist today.

In some opportunities, a same batch of feed has been reported as having an acceptable quality by some farmers, whereas other farmers have been reported this feed as bad quality.

The amount of feed that is traded is increasing and the size of a feed plant can be as the size of a paper mill. Improvements in the measurements of pellet quality can contribute greatly to the growth of this industry, since can increase confidence when trading feed.

CONCLUSIONS

There is a need for new physical quality testers that can give good correlation with the quality that is found during the trading line, a tester to be used by the industry and consumers. Texture by measuring tensile stress and elasticity is a good method to characterize the physical properties of the feed, but it didn't correlate well with the quality found after a period of usage during pneumatic transport conditions tested in Holmen and a new tester. The Holmen durability tester is unreliable since it keeps high amounts of dust inside the apparatus. Both the Holmen and the Borregaard testers measure quality by using one strainer that does not allow the quantification of broken pellets and dust that are considered as waste, also they do not describe how quality is affected after an extended period of usage or handling. The working principle for a new tester, having pneumatic transport conditions, seems to be a good option to characterize quality after an extended period of handling, but more development and tests have to be done until a reliable method is obtained.

ACKNOWLEDGMENTS

This research has been conducted through a cooperation between the Dep. of Animal Sciences and Aquaculture, Dep. of Mathematical Sciences and Technology and Dep. of Chemistry, Biotechnology and Food Science from the Norwegian University of Life Sciences. The financial support received for this research, which comes from the Business Liaison Office of the Norwegian University of Life Sciences and from Felleskjøpet Fôrutvikling, are gratefully acknowledged. The Centre for Feed Technology (FôrTek) and Felleskjøpet (Ski) are acknowledges for providing the feed pellets used in the experiments.

REFERENCES

1. Aarseth, K. A. and Prestlokken, E. (2003), "Mechanical Properties of Feed Pellets: Weibull Analysis", *Biosystems Engineering.*, **3**, 349-361.
2. Thomas, M. and van der Poel, A.F.B. (1996), "Physical quality of pelleted animal feed. 1. Criteria for pellet quality", *Animal Feed Science and Technology.*, ***61***, 89-112.
3. Payme, J.D. (1983), United States Patent number 4,512,180.
4. Payne, J.D., Rattink, W., Smith, T. and Winowski, T. (1994), "The Pelleting Handbook", Borregaard Lignotech. pp. 72.
5. Payne, J.D., (1998), European Patent number EP 0 856 730 A2.
7. Li, Y., Wu, D., Zhang, J., Chang, L., Wu, D., Fang, Z. and Shi, Y. (2000), "Measurement and statistics of single pellet mechanical strength of differently shaped catalysts", *Powder Technology*. **113**, 176-184.