REPETITIVE TESTING OF THRESHED TOBACCO AS A MEANS TO EVALUATE THE MEASUREMENT OF LEAF PARTICLE SIZE DISTRIBUTION

By F. C. McCall and C. F. Abrams, Jr.[2]

This study was conducted to determine whether a particle size measurement apparatus (commonly referred to as the degradation sizer) could be evaluated by repeated tests of threshed tobacco samples. Six samples of flue-cured tobacco and twelve samples of burley tobacco were tested on the degradation sizer five to ten times each in order to determine the effect of repeated tests on measured particle size distribution. Repetitive tests of flue-cured tobacco samples were then conducted to determine the effect of sizer drive frequency and volumetric loading density on degradation sizer test results.

The particle size distribution of the samples, as measured by the degradation sizer, was found to decrease linearly (average R^2=.97) with repeated tests. The fraction of the sample which passed over the 1 x 1 screen decreased at an average rate of 1.78 percent of total sample weight per repetition (%/rep) for burley tobacco, 1.00%/rep for flue-cured tobacco. The combined fraction of the sample which passed over the 1 x 1 screen and the 1/2 x 1/2 screen decreased at an average rate of 1.31%/rep for burley and 0.52%/rep for flue-cured tobacco.

Increased sizer drive frequency was found to increase the measured particle size distribution in the region around the standard operating frequency of 530 rpm. The measured particle size distribution was also increased by increasing volumetric loading density.

The predictable linear decline of particle size distribution found to result from repeated tests made possible the use of threshed tobacco samples for evaluation of the degradation sizer.

Additional Key Words: Threshing, Degradation Sizer, *Nicotiana tabacum*.

INTRODUCTION

During industrial processing of tobacco, the leaf material is passed through various threshing and conditioning operations. The resulting size distribution of the pieces of leaf lamina is an important quality control factor. Measures of particle size distribution are used for process control in stemmeries and for product evaluations in the quality audit laboratories of threshed tobacco buyers.

Samples are taken from the threshed tobacco and fractionated using an oscillating multilevel sieve apparatus which is referred to as a degradation sizer. The degradation sizer is commonly fitted with four woven wire screens of square mesh configuration with wires spaced at 2.54 cm, 1.27 cm, .635 cm, and .318 cm (1 in, 1/2 in, 1/4 in, and 1/8 in, respectively) intervals. These are commonly referred to as 1 x 1, 1/2 x 1/2, 1/4 x 1/4, and 1/8 x 1/8 screens, respectively. The degradation test result then consists of five fractions (the fractions which pass over each of the four screens and the one which passes through all of the screens). These fractions are expressed as a percentage of the total sample weight. The two most important measures of threshed tobacco particle size distribution are the percent (by weight) of sample over the 1 x 1 screen and the total percent of sample over the 1/2 x 1/2 screen (the portions retained by 1 x 1 and 1/2 x 1/2 screens combined).

There are many factors which affect the accuracy of this measurement. Sampling methods, sample handling, and foreign objects all may affect the results. However, various measures are taken to limit the negative effects of these factors. The condition and operation of the degradation sizer may also be a source of error. Depth of sample material on the screens, wear of the screens, screen and bed alteration by adhering material (gum and dust), occlusion of screen openings by adhering material, and mechanical drive malfunction can all contribute to errors. Further, and perhaps more importantly, particle size distribution tests are made at many geographic locations throughout the world on many individual degradation sizers. While the sizers are of the same or similar design, variations in sizer performance exist for one or more of the above reasons. The need to assure that consistent information is obtained from different sizers or from the same sizer at different times provides the impetus for this work. The objective of this work is to develop a method to detect and quantify differences in the measurements of particle size distribution of threshed tobacco.

Ideally, the same sample of threshed tobacco could be moved from sizer to sizer and used as a calibration sample. The repeated use of threshed tobacco samples for degradation sizer calibration has been limited, however, due to the observed fragility of threshed tobacco. It has long been recognized that the particles in threshed tobacco samples break into smaller particles with handling. This breakage changes the particle size distribution within the samples, thus sizer results change with repeated tests of threshed tobacco samples.

The breakage in threshed tobacco samples during repetitive tests need not prevent their use in this manner, however, if the change in sizer results is predictable. If the change in degradation results due to sample breakage in repeated tests can be accurately quantified, the reduction of particle size may be accounted for. The data may then be adjusted to eliminate these effects, making possible the repetitive use of threshed tobacco samples for the detection and quantification of inconsistencies in degradation sizer results.

The approach of this work therefore, was (1) to determine the effect of threshed tobacco sample breakage on degradation sizer results in repeated tests and (2) to utilize repetitive tests of threshed tobacco samples to investigate two representative sources of inconsistency in degradation sizer testing, sizer drive frequency, and volumetric loading density.

[1]*Paper No. 12573 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, NC 27695-7643.* The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the product named, nor criticism of similar ones not mentioned.

[2]*Research Engineer and Professor, respectively, Department of Biological and Agricultural* Engineering, N. C. State University, Box 7625, Raleigh, NC 27695-7625.

Contribution received March 15,1990. Tob. Sci. 35: X–X, 1991.

MATERIALS AND METHODS

To determine the effect of sample breakage on degradation test results, threshed tobacco samples were repeatedly subjected to the degradation test. Each sample was tested on the degradation sizer. The resulting fractions were weighed, then recombined and mixed. The sample was then retested a number of times and discarded. Twelve samples of burley and six samples of flue-cured tobacco were tested in this manner.

The burley samples, ranging from 1.4 to 2.9 kg, were collected at the discharge of the redrier (the point immediately prior to packing) at K.R. Edwards Leaf Tobacco Company (KRE), Smithfield, NC. This collection was typical of sample collection for stemmery degradation tests. The 2.8 to 3.0 kg flue-cured samples were taken from one hogshead and reconditioned together at KRE in accordance with customer quality audit test procedure. Each sample of both types was placed in a plastic bag which was then sealed and transported to North Carolina State University (NCSU), Raleigh, NC. These samples were stored and tested at room conditions (≈ 30° C, 20% rh). Each sample was removed from its bag and agitated by hand to separate particles that had been pressed together during storage and to restore the "fluffiness" of the sample. The sample was then spread evenly over the entire conveyor which was operated for 7.5 minutes to deliver the sample to the top screen. After the entire sample had been sized by screens, the screens were cleaned of adhering tobacco. The fractions were then weighed, recombined, and mixed. The sample was then tested again in like manner. Each test required about 15 minutes. Five to ten tests were performed on each sample. Total testing time for each sample, therefore, ranged from 1.25 to 2.5 hours.

The data obtained from each sample were analyzed individually. This was deemed necessary due to the differing initial particle size distributions of the samples and the likelihood of differing rates of sample breakage. Linear regression of percent over the 1 x 1 screen and the total percent over the ½ x ½ screen versus run number was performed on the data from each sample.

Repetitive tests of threshed tobacco were conducted to determine the effect of machine and operator variation on degradation sizer function. Sizer drive frequency and loading density were taken as representative sources of machine and operator variation, respectively, based on observation of degradation tests in industrial settings. Variation in drive frequency has been observed among degradation sizers in industrial settings. Uneven or incomplete distribution of the tobacco sample on the loading conveyor by operators has resulted in a variable loading density, particularly on the 1 x 1 screen.

Investigation of sizer response to drive frequency from 490 to 570 rpm was undertaken (the standard drive frequency is 530 ± 30 rpm). Two 2.7 kg samples of reconditioned flue-cured tobacco were tested fourteen times each. The first sample was tested first at 490 rpm, and then retested at differing speeds in the following order: 510, 520, 530, 540, 550, 570, 570, 550, 540, 530, 520, 510, and 490 rpm. The second sample was tested in like manner beginning and ending with 570 rpm.

Degradation sizer response to varying loading density was similarly investigated. Two 2.7 kg flue-cured samples were tested utilizing from 50 to 100% of the length of the feed conveyor. This provided volumetric loading densities of .0064 to .013 m^3/min. As in the frequency investigation, each sample was utilized so that the first and last tests were conducted at the same loading density.

Assuming a linear model of the effect of repeated tests on degradation results, beginning and ending each set of repetitions with the same value of the input variable (drive frequency or loading density) allowed the determination of the rate of decline of the percent over the 1 x 1 screen and total percent over the ½ x ½ screen for each sample as follows:

$$\text{Rate of Decline} = \frac{\text{Initial Value} - \text{Final Value}}{\text{Number of Runs} - 1} \quad [1]$$

This rate of decline was then used to adjust the data to eliminate the effect of sample deterioration. This was accomplished according to the formula:

$$\text{Adjusted Value} = \text{Observed Value} + \text{Rate of Decline} \ (\text{Run} - 1) \quad [2]$$

where "Run" = the number of the repetition corresponding to the observed value (i.e., a given data point was obtained on either the first, second, third, etc. test of a sample).

Data from the two samples were also normalized to equate the means of the two sets of data and allow direct comparison of results from samples with different initial particle size distributions. The adjusted values for each tobacco sample were averaged separately. The difference between these averages was computed and then subtracted from each individual adjusted data point obtained with the sample with the higher mean value. The adjusted and normalized data were then plotted against drive frequency and volumetric loading density to illustrate sizer response.

RESULTS AND DISCUSSION

The effect of sample breakage on repeated sizer test results is a uniform decline of the percent over the 1 x 1 screen and total percent over the ½ x ½ screen. This uniform decline is quantified by the results of the linear regression of each set of repetitions, **Tables 1–4.** The consistently high r^2, confidence level ($1-\alpha$), and low root mean square error (RMSE) values indicate the high degree of significance for a linear model of sample deterioration for 18 samples of differing tobacco types, sample weights, and numbers of repetitions.

The slope of the fitted line represents the rate of decline of percent over the 1 x 1 screen and total percent over the ½ x ½ screen. The rate of decline is significantly higher for the burley samples than for the flue-cured. This situation is as expected due to the greater observed fragility of burley tobacco. This difference is indicative of variations in fragility which may exist among tobacco samples of different types, grades, stalk positions, moisture contents, etc. Within the burley and flue-cured groups the rate of decline varied roughly 15% ($1\sigma_{n-1}$) of the average rate. Thus, for tests involving a large number of similar samples, determination of the rate of decline of a control group will allow reasonably reliable prediction of the rate of decline of each additional similar sample. For tests involving a smaller number of samples the rate of decline may be determined separately for each sample tested, as performed for the drive frequency and loading density investigations reported herein.

The ability of the linear model to account for the decline in sizer test results provides a sound basis for the application of repetitive testing to the evaluation of degradation sizer function.

The relationship of sizer function to varied drive frequency is displayed graphically (with cubic spline) in **Figures 1 and 2.** In **Figure 1,** the 1 x 1 fraction is seen to decrease as drive frequency increases from 490 to 510 rpm, and increase nearly linearly at roughly 0.09%/rpm from 510 to 550 rpm. The initial decrease in the percent over the 1 x 1 screen is thought to reflect a change in particle motion resulting from the increasing energy supplied with increasing frequency. As more energy is supplied, particles are turned on end and separated, thus presenting the two smaller dimensions (thickness and width) of sample particles to the screen openings. The increased energy also aids in the

Tobacco Science, 1991, 35-2, p. 6-10, ISSN. 0082-4523.pdf

separation of particles which provides more opportunities for each particle to pass through the screen.

Over 510 rpm, sufficient energy is available to turn and separate the tobacco particles, and percent over the 1 x 1 screen begins to increase in proportion to sample velocity. A linear increase in sample velocity with increasing frequency has been analytically predicted for the upper range of the one hop per cycle region, roughly 450 to 560 rpm (Winkler, 1979). Sample velocity appears to be the controlling factor for percent over the 1 x 1 screen from 510 to 550 rpm where increasing velocity and correspondingly decreasing dwell time on the screen result in increasing the 1 x 1 fraction. Particle motion changes again as the one hop per cycle regime ends at about 560 rpm. This change in particle motion indicates that some change in sizer function may be expected above 560 rpm, although not shown by these data.

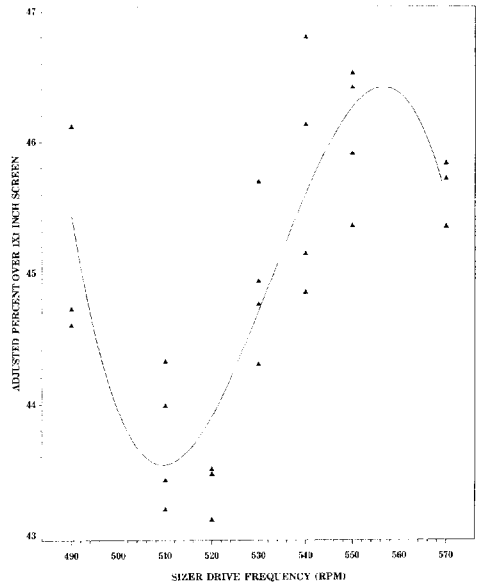

Figure 1. Effect of degradation sizer drive frequency on the percent of flue-cured tobacco sample passing over a 1 x 1 inch screen. Adjusted for sample breakage and normalized.

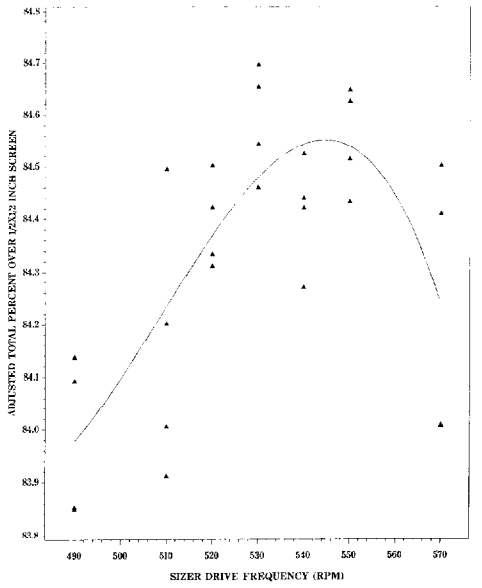

Figure 2. Effect of degradation sizer drive frequency on the total percent of flue-cured tobacco sample over a ½ x ½ inch screen. Adjusted for sample breakage and normalized.

The response of total percent over the ½ x ½ screen has been subjected to less analysis. A nearly linear region exists from 490 to 540 rpm where total percent over the ½ x ½ increases at roughly 0.01%/rpm (**Figure 2**). Total percent over ½ x ½ decreases above 550 rpm.

This information can be used for several industrial applications. The linear increase from 510 to 550 rpm indicates that within the normal operating tolerance of 10 rpm, the 1 x 1 screen fraction can be expected to vary up to 0.9 percentage points as a result of drive frequency. While this variation within the frequency tolerance may be acceptable, variation in either the stroke or inclination of pan trajectory is also likely to have an effect on sizer function in that these variables affect particle velocity (Gaberson, 1972). The tolerances of stroke and inclination, which are much greater than that of frequency, thus seem particularly important. Determination of the effects of these mechanical characteristics with repetitive tests should provide a sound basis for the establishment of tolerances for frequency, inclination, and stroke which will provide an acceptable level of variation.

An understanding of sizer response to frequency may also lead to the determination of the optimum frequency for limiting the effects of varying mechanical input. The 1 x 1 percent graph, **Figure 1,** indicates that operation around 555 rpm will reduce the likelihood of change in 1 x 1 percent with varying frequency. A 10 rpm range centered on 555 rpm will encompass a variation of less than 0.2% compared to the variation of 0.9% for any 10 rpm region centered between 525 and 545 rpm.

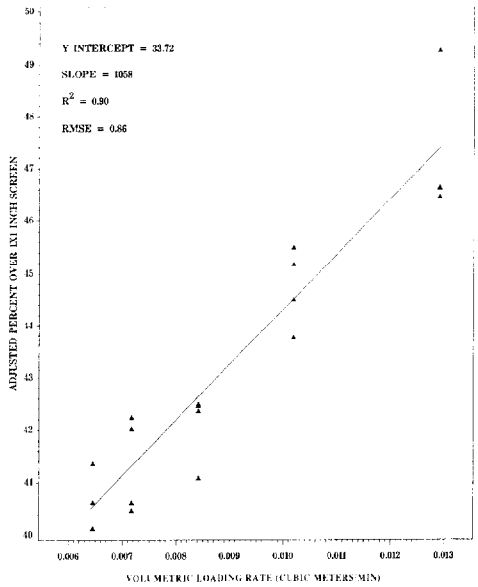

Figure 3. Effect of volumetric loading rate on the percent of flue-cured tobacco sample passing over a 1 x 1 inch screen. Adjusted for sample breakage and normalized.

A similar look at the total over the ½ x ½ screen, **Figure 2,** would indicate that operating frequencies between 520 and 550 rpm tend to reduce fluctuation of total over the ½ x ½ response due to frequency. In order to define the optimum frequency however, determination of the relationship of sizer precision to frequency will be necessary.

Sizer response to loading density is presented in **Figures 3 and 4.** Both 1 x 1 percent and total percent over the ½ x ½ screen increase linearly with increasing loading density. The 1 x 1 fraction increases roughly 1058% per m^3/min.

Total percent over the ½ x ½ screen increases roughly 155% per m3/min. These results reflect the general perception that 1 x 1 percent and total percent over the ½ x ½ screen increase with increased loading density. Two applications of this result are clear. First, any variation in load-

ing density will cause a variation in sizer results. The effect on 1 x 1 percent is considerable. A reduction of the percentage of the belt utilized from 100 to 90% will yield an increase in the 1 x 1 fraction of up to 5 percentage points. A similar, but smaller, effect on the total percentage over the ½ x ½ screen will result as well. An increase of up to 0.5 percentage points could be expected.

The second application of the relationship between loading density and sizer function involves its implication regarding degradation tests of samples of varying density. Given a constant sample weight, volumetric loading density will vary with sample bulk density. Thus, a light burley sample and a heavy flue-cured sample with identical particle size distributions may generate markedly different degradation sizer results. Also, the drop from stemmery to audit results may be explained in part based on loading density. Audit samples appear to be more compact than redried samples due to the flattening effect of pressing into containers. This would cause a lower volumetric loading rate in audit tests and a correspondingly lower 1 x 1 percent.

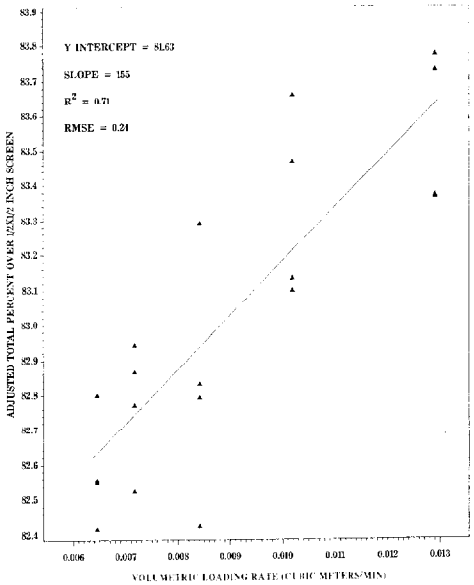

Figure 4. Effect of volumetric loading rate on the total percent of flue-cured tobacco sample over a ½ x ½ inch screen. Adjusted for sample breakage and normalized.

The results of this investigation indicate that repetitive tests of threshed tobacco can provide a means of degradation sizer optimization. Determination of degradation sizer response to a wide range of inputs such as drive frequency and volumetric loading density may allow selection of the optimum level of these inputs to increase sizer accuracy, reduce variation on each individual sizer, and reduce the likelihood of differences from machine to machine.

Repetitive testing of tobacco may also be applied to degradation sizer calibration. First, repetitive tests may be used directly to evaluate collocated sizers. This is of limited utility however, since degradation sizers are operated at many diverse locations. Repetitive testing with tobacco cannot be applied to comparisons of machines at distant locations due to sample breakage in transport and storage. In order to compare disperse machines, a durable calibration sample is needed. Second, repetitive tests enable the development of a durable sample based on degradation sizer response to specific inputs; durable sample may be developed with which the degradation sizer will respond as it does in repeated tests of threshed tobacco.

Table 1. Linear decline in the percentage of burley tobacco samples passing over a 1 x 1 inch screen during repeated tests of each sample.

Sample	Weight	Reps	Decline	r^2	1−α	RMSE
	kg		%/Rep			%
1	1.6	5	−2.01	.985	.9992	.450
2	1.6	5	−1.61	.986	.9993	.356
3	1.5	5	−1.74	.995	.9999	.222
4	1.5	5	−2.04	.945	.9945	.898
5	1.5	5	−2.00	.986	.9993	.443
6	1.4	5	−1.74	.989	.9995	.330
7	1.4	5	−1.45	.977	.9985	.408
8	1.9	5	−1.48	.898	.9952	.915
9	1.6	5	−1.78	.965	.9972	.619
10	1.9	5	−1.60	.984	.9991	.377
11	2.9	5	−2.27	.984	.9981	.693
12	2.8	10	−1.69	.983	.9999	.682
Avg.			−1.78			.533
Std. Dev.			.26			

Table 2. Linear decline in the percentage of flue-cured tobacco samples passing over a 1 x 1 inch screen during repeated tests of each sample.

Sample	Weight	Reps	Decline	r^2	1−α	RMSE
	kg		%/Rep			%
1	2.8	6	−1.01	.852	.9945	.775
2	3.0	7	−1.08	.978	.9999	.354
3	3.0	6	−1.03	.996	.9999	.129
4	3.0	7	−1.23	.967	.9999	.490
5	2.9	7	−0.76	.771	.9942	.883
6	2.9	7	−0.88	.888	.9991	.669
Avg.			−1.00			.550
Std. Dev.			.16			

Table 3. Linear decline in the total percentage of burley tobacco samples not passing through a ½ x ½ inch screen during repeated tests of each sample.

Sample	Weight	Reps	Decline	r^2	1−α	RMSE
	kg		%/Rep			%
1	1.6	5	−1.52	.996	.9999	.154
2	1.6	5	−1.44	.966	.9983	.424
3	1.5	5	−1.33	.994	.9949	.156
4	1.5	5	−1.10	.990	.9997	.173
5	1.5	5	−1.27	.997	.9999	.116
6	1.4	5	−1.18	.997	.9999	.010
7	1.4	5	−1.12	.986	.9994	.213
8	1.9	5	−1.05	.954	.9972	.363
9	1.6	5	−1.21	.996	.9999	.117
10	1.9	5	−1.18	.956	.9973	.401
11	2.9	5	−1.72	.982	.9997	.290
12	2.8	10	−1.62	.994	.9999	.370
Avg.			−1.31			.232
Std. Dev.			.22			

Table 4. Linear decline in the total percentage of flue-cured tobacco samples not passing through a ½ x ½ inch screen during repeated tests of each sample.

Sample	Weight	Reps	Decline	r^2	1–α	RMSE
	kg		%/Rep			%
1	2.8	6	–.458	.983	.9999	.111
2	3.0	7	–.600	.983	.9999	.173
3	3.0	6	–.505	.979	.9999	.183
4	3.0	7	–.591	.984	.9999	.197
5	2.9	7	–.445	.932	.9997	.259
6	2.9	7	–.530	.989	.9999	.123
Avg.			–.522			.167
Std. Dev.			.065			

ACKNOWLEDGEMENT

The authors wish to thank the K. R. Edwards Leaf Tobacco Co. for the provision of threshed tobacco samples. We also thank Universal Leaf Tobacco Co. and Philip Morris USA who provided the financial support for this project.

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