EVALUATION OF HVI TRASHMETER CALIBRATION

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Abstract

Research was conducted to investigate ways of reducing trash measurement differences between High Volume Instruments (HVIs) and the master instrument used for establishing trash measurement standards. To meet these objectives, several tile sets were constructed with circular and square particles of varying sizes to study the effects of particle size, particle shape and various contrasting backgrounds. HVI and master instrument measurements of total particle area and total particle count were made on these tile sets and on actual cotton calibration sets. Particle areas were also calculated from visual measurements made with a precision ruler and magnifying glasses. Results showed that particle areas measured with the master instrument agreed closely with areas calculated from visual measurements. HVI area measurements were inflated at an increasing rate as average particle size decreased. Corrections based on circular and square particles were developed and applied to HVI total area measurements. These corrections effectively eliminated the particle size inflation effect when all particles were equal in size and shape. Effectiveness of the corrections was reduced as measured particles became less uniform in size. Relative to standard test methods, the developed corrections were effective in improving HVI and master instrument trash measurement agreement on cotton trash calibration sets. Particle to background contrast results showed higher total particle area measurements as contrast increased on both the HVI and the master instrument.

Introduction

The video scan trashmeter is an integral part of the High Volume Instrument (HVI) cotton classification system. Particle area and particle count trashmeter measurements provide useful information about the trash content of raw cotton. Considerable research has been conducted on the development and adaptation of the HVI video scan trashmeter. Literature records evidence of the evolution of the cotton trashmeter from a crude analog scanning device to the presently utilized system which is based on digitally processed image analysis techniques (Taylor, 1985). A great deal of progress in the development and in the transfer of modern imaging technology to the modern cotton trashmeter is recorded.

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In addition to instrument developments, development of trash measurement standards has also improved the reliability of the HVI trash measurement (Randle, 1992). Special tiles that utilize a pattern of dark brown dots printed on light brown paper and plexiglass enclosed cotton samples with varying degrees of trash content are both utilized for instrument trash standards.

HVI trash measurement standards were first established for the Cotton Division in 1991 on a high resolution image analysis system owned by USDA's Agricultural Research Service in New Orleans, Louisiana. In 1995, the Standardization Section of the Cotton Division completed development of their own image analysis system. This system currently serves as the master instrument for determining values on cotton trash calibration materials for the USDA and for many other HVI users.

Particle count agreement between the HVI and the master instrument is good for both cotton and tile standards. Proper setting of the HVI trashmeter's threshold level will provide accurate count measurements. In addition, a proper threshold setting is a prerequisite for calibration of the particle area measurement.

Less than ideal particle area measurement agreement, between the HVI and trash standards, has existed since the first standards were established on the first master instrument in New Orleans. Measurement disagreement becomes most apparent when attempts are made to measure tiles and cotton standards on the HVI using the same calibration settings. HVI area agreement with the standards is acceptable as long as tiles are measured on tile calibration settings and cotton standards are measured on cotton calibration settings. The current practice, which involves having to maintain two calibration settings, not only complicates the calibration procedure, but serves only as a quick fix to an unknown area measurement problem.

Objectives

In general, the objective of this study was to investigate differences and similarities among HVI, master instrument and visual determinations of total particle area. More specifically the objectives were to:

1. investigate the effects that particle size, particle shape particle to background contrast and different thresholds each make on total particle area measurements made with the master instrument and the HVI trashmeter;

2. compare total particle area and particle count measurements made with the HVI trashmeter and the master instrument to visually made measurements;

3. develop relationships for correcting total particle area measurements; and

4. evaluate total particle area measurement corrections for their effectiveness in improving measurement differences between the HVI and the master instrument.

Methods and Procedures

Evaluation Materials

In order to meet the objectives of this study, four experimental tile sets were constructed by placing circular and square particles on paper. Tile particles were constructed in a computer drawing program and printed on quality bond paper using a 360 dpi laser printer. Particle sizes ranged from 0.1 to 0.015 inches in diameter or side length. Obtaining the reference diameters or side lengths of the particles in the four tile sets was achieved by visual measurements made on several of the particles using a precision ruler and magnifying glasses. In order to accurately visualize the 1/100th of an inch increments on the ruler, two magnifying glasses were used in series. The visual length measurements made on the particles were then converted into percent particle area.

Tile set No. 1 consisted of ten tiles with varying sizes and numbers of solid circles. The circles were of uniform size on each tile and their count was determined by calculating the number required to give approximately a one-percent particle area on each tile. The particles were uniformly distributed within the region of interest on each tile.

Tile set No. 2 was identical in every way to tile set No. 1 except for particle shape. The particles in the second tile set consisted of solid squares with side lengths equal to the diameters of the circular particles in the first tile set. The purpose of the first two tile sets was to evaluate the area measurement for varying particle sizes and shapes.

Tile set No. 3 consisted of one tile with mixed shapes (squares and circles) and sizes. The main purpose of this tile was to evaluate the effect of using the average particle size-based corrections when the particles being measured were not uniform. This tile was designed and printed in the same manner as the tiles in the first two tile sets.

Tile set No. 4 consisted of three tiles with solid circles printed on brown, gray and off-white paper using a plotter with a brown ink pen. Tile set No. 4 was designed to look at the particle to background contrast effect. The plotted dots were visually measured at 0.032 inches in diameter. These tiles were plotted in the same manner as tiles used for regular calibration except different colored papers were used to achieve varying particle to background contrasts. After the tiles were made, they were read on a cotton colorimeter to determine their color grades as related to cotton.

Tiles in tile sets No. 1, 2 and 3 were mounted under optical quality glass for protection after their particle sizes had been visually verified. The effect of the glass on instrument measurements was checked and found to be insignificant. Tiles in set No. 4 were not mounted under glass in order to eliminate any filtering effects that might influence the desired particle to background contrast.

In addition to the tile sets, two 12-cotton calibration boxes identified by boxes “B” and “F” were also included in the study. Each cotton included in a box is mounted in a plexiglass holder and has a varying amount of trash content.

Test Procedure

Testing began by evaluating all materials on the master instrument. The four constructed tile sets were read multiple times over several days with a high degree of confidence due to very low variability (generally less than 1% between measurements). Since boxes B and F are operational calibration boxes, they had values that were established prior to this study. But as a check, the boxes were measured again along with the tiles.

Instrumentation consisted of the Cotton Division’s master instrument system and three identical late model HVIs that were identified by their serial numbers 715, 744 and 745. The threshold level on each HVI system was calibrated using box B. Threshold calibration involved adjusting the threshold level until the average of the measured count values was within 0.5 units of the average of the established count. In order to obtain raw uncalibrated total particle area measurements, the slope and offset constants were set to 1 and 0, respectively. This effectively disabled the HVI calibration adjustment to allow all raw number adjustments to be done apart from the HVI systems.

In contrast to the master instrument procedure, all testing on the HVIs, with the exception of tile set No. 4, was accomplished in one uninterrupted run. Tile set No. 4 was constructed and measured at a later time on HVI No. 744. The measuring order for one replication was the three tile sets (1, 2 and 3) followed by cotton calibration boxes (B and F). Four replications were made on each test specimen and the values were averaged. As with the master instrument, measurement variability was low and the resulting average measurements had a high degree of confidence.

In order to measure cotton trash particles on a similar level to the eyesight of a cotton classer, the threshold must be set to a level that will enable proper measurement of various trash particle measurement conditions. Trash particles that are slightly covered by cotton lint or light colored trash particles are examples of threshold sensitive conditions. In order to study the effect of threshold level on highly contrasted black particles on a white background, tile set No. 1 was measured on HVI trashmeter No. 744 at three threshold levels.

Results and Discussion

Effect of Particle Size on Area Measurements

Figure 1 shows the resulting average measurements for circular tile set No. 1. Each tile is represented by its particle count on the x-axis. Total particle area for each tile is given in percent on the y-axis. The graph clearly shows a HVI area inflation effect that accompanies decreasing particle size. Square particle areas in tile set No. 2 were also inflated by the HVIs in much the same way as with the circular particles in tile set No. 1 (Figure 2). An important note is that the illustrated inflation effects would be reduced by some degree under normal calibration adjustments since the HVIs area calibration slope generally ranges between 0.55 and 0.70.

The bars on Figures 1 and 2 illustrate area measurements made visually and with the master instrument on the circular and square particle tile sets. The master instrument does not indicate any inflation effect and agrees well with visually determined areas.

Effect of Varying Threshold on Area Inflation

Figure 3 shows decreasing area inflation as the threshold setting was lowered from 915 (the proper setting) to 895 and 720. Observation of the 720 threshold setting revealed that the HVI trashmeter did not accurately count the particles on the 256 and 500 circular particle count tiles. An extra line on the graph was constructed to show the area measurement when adjusted to the number of particles that the HVI should have counted.

This exercise in varying instrument threshold may give some clue as to why there is an area inflation. That is, speculating from these results, the necessary threshold for proper counting of small cotton trash particles causes the edges of high contrast particles to be measured at a point outside of their actual boundaries. This inability to properly define the high contrast particle's edge may be caused by something such as a lack of sharpness in the focusing of the HVI camera. Since pixel resolution in the measured area is about the same for the HVI and the master instrument, resolution is probably not a significant contributing factor to HVI small particle inflation.

Correcting for the Inflation Effect

Since Figures 1 and 2 demonstrated that inflation occurred as particle size decreased, corrections were developed based on particle size. The purpose of the corrections was to bring the HVI total particle area measurement level closer to that of the master instrument.

Average particle size can be obtained by dividing the overall measured percent particle area by the number of counted particles. In addition, the overall area being measured must be factored into the equation. The conversion of instrument measured area and count into an average single particle area measurement can be calculated by

$$ASPA = [(PPA)(TRIA)] / [(TPC)(100)] \quad (1)$$

where

ASPA = Average Single Particle Area (in.^{2}),
PPA = Percent Particle Area (%),
TRIA = Total Region of Interest Area (in.^{2}) = 9 in.^{2},
TPC = Total Particle Count.

ASPAs were calculated for the master instrument and the HVI. A quadratic model was fitted to the data. The form of the model in terms of the appropriate ASPAs is

$$CHASPA = a(HASPA)^b \quad (2)$$

where

CHASPA = Corrected HVI Average Single Particle Area (in.^{2}),
HASPA = HVI Average Single Particle Area (in.^{2}),
a = $e^{intercept}$ = constant from quadratic model,
b = exponent from quadratic model.

Table 1 gives the correction constants and R^2 values for both tile sets on all three HVIs. The exponent values and more so the intercept values were consistently higher for the circular tile set than for the square tile set. This demonstrated that the circular particles were more sensitive to particle size inflation.

Solving equation (1) in terms of percent particle area and presenting it in terms of a corrected HVI measurement results in

$$CHPPA = (CHASPA)(HTPC)(100) / TRIA \quad (3)$$

where

CHPPA = Corrected HVI Percent Particle Area (%),
HTPC = HVI Total Particle Count.

Substituting equation (2) into equation (3) results in

$$CHPPA = a(HASPA)^b (HTPC)(100) / 9 \quad (4a)$$
$$= a(HASPA)^b (HTPC) / 0.09 \quad (4b)$$

In order to complete the change of variables from single particle area to percent particle area, the pattern form of equation (1) can be used in equation (4) to replace HVI average single particle area with percent particle area to give

$$CHPPA = a[\{(HPPA)(TRIA)\} / \{(HTPC)(100)\}]^b [HTPC] / 0.09 \quad (5a)$$
$$= a[\{(HPPA)(9)\} / \{(HTPC)(100)\}]^b [HTPC] / 0.09 \quad (5b)$$
$$= a[\{(HPPA)(0.09)\} / \{HTPC\}]^b [HTPC] / 0.09 \quad (5c)$$

where

HPPA = Raw HVI Percent Particle Area (%).

Looking again at Figures 1 and 2, the lines just above the graphed bars show the original raw HVI results corrected for particle size. As can be seen, particle size corrections were effective in bringing HVI total particle area to a level comparable to the master instrument and visual measurements.

Mixing Particle Shapes and Sizes

Analysis of the mixed particle tile (tile set No. 3) involved a combined particle analysis followed by a particle separation analysis. The combined particle analysis was performed by applying corrections derived in the previous circular and square tile analyses to the HVI measurements of the mixed particles tile. Separated particle analyses had to be simulated since the instruments used were not capable of providing measurement on individual or grouped particles. Data used in the particle separation analyses was taken from the analyses of tile sets one and two.

Table 2 gives the measured and corrected results for the mixed particle tile on HVI No. 715. Results for the other two HVIs were similar. The separated and combined particle analyses for the master instrument and raw HVI measurements did not indicate much difference in total particle area. Differences were found when corrected HVI combined particle areas were compared to corresponding master instrument areas. These comparisons demonstrated that non-uniform particle sizes in a tile can cause error in the calculated average particle size-based corrections. Data in the tables also indicated that application of the circular particle correction to square particles or vice versa will also decrease the effectiveness of the particle size correction. The best particle size correction results occurred when separated particle analyses were performed on each particle type and the resulting areas were summed.

Particle Size Correction Applied to Cotton Calibration Boxes

Particle size corrections were applied to cotton calibration boxes "B" and "F". In addition, calibration slopes and offsets, based on both the raw and particle size corrected measurements, were calculated using linear regression and then applied back to the respective data.

Table 3 gives the differences in measurements between HVI No. 715 and the master instrument on calibration box B. Unlike the tile sets, there was some variation in particle counts from one instrument to the next. This was normal since cotton trash particles have less particle to background contrast compared to printed particles.

Standard deviations of the measurement differences were a good indication of the level of agreement between various HVI measurement methods and the master instrument. Averages of these measurement differences demonstrated the overall measurement bias between HVI measurement methods and the master instrument. In the calibration applied measurements, there was no measurement bias since it was removed by calibration.

Figure 4 illustrates the comparison of standard deviations of the measurement differences. Standard deviations for the raw HVI measurement differences were not shown since they were a degree of magnitude higher than the other standard deviations. As shown in Figure 4, the highest standard deviations were for normally calibrated measurements and are representative of difference standard deviations that would be obtained from currently established and practiced methods of cotton trash measurement calibration. Among the corrected methods, the square particle correction method without calibration had the highest standard deviations for HVIs 744 and 745. However, once calibration was applied, the square particle correction had the lowest or equal to the lowest standard deviations among all HVIs.

Figure 5 graphically illustrated the averages of the measurement differences and helps explain the reason for the big effect calibration had on square particle corrections. That is, measurement difference averages for square particle corrections on HVIs 744 and 745 were considerably farther from zero than circular particle correction averages. This difference was removed by calibration and resulted in square particle corrections giving the best corrections for the calibration cottons.

Offset values were small and did not influence instrument calibration to any significant degree. However, slopes did vary as illustrated in Figure 6. The slopes were consistently higher for the square corrected method which was not totally unexpected since the calibrations had to remove larger measurement differences as was shown in Figure 5. A large difference between corrected and uncorrected slope values can also be observed in Figure 6. Corrected slope values were all close to unity while uncorrected slope values were significantly lower. This indicated that particle size corrections, especially circular particle corrections, do not require much if any calibration adjustment.

Effects of Different Particle to Background Contrasts

In order to evaluate varying contrasts caused by various color combinations, three tiles (tile set No. 4) were used. The tiles were made to imitate the range of actual cotton grades. Measurements on a cotton colorimeter verified the cotton color grades. The color of tiles 1,2 and 3 appeared visually as off-white, gray and tan, respectively. Cotton color grades on the respective tiles were measured at 21, 51 and 25. Diameters of the plotted brown particles on these tiles were visually measured at 0.032 inches which converts to a total particle area of 1.787% for 200 particles.

Figure 7 shows the results of measurements on these tiles by the master instrument and HVI No. 744. All area measurements decreased as particle to background contrast decreased which indicated that varying color contrasts do have an undesirable effect on particle area measurements. The master instrument was influenced least by decreasing contrast.

The tan colored tile is the same tile used in routine HVI calibration. Figure 7 illustrates the consequences of both the effects of HVI particle inflation and particle to background contrast. The HVI normal calibration line in Figure 7 is based on a cotton calibration. The line reveals the difference in HVI and master instrument area measurements on tiles whenever the HVI is calibrated to the cotton standards. When the circular particle correction was applied, the differences were reduced, especially for the lighter background tiles. However, the particle size correction over-corrected the tan calibration tile because of the contrast effect.

Conclusion

This study revealed two major causes for measurement differences in particle area that have always existed between the HVI and the master instrument. The first cause that was studied was the HVI area measurement inflation effect on small particles. The second studied cause was the under-estimation of the area measurement caused by decreased particle to background contrast.

Although particle size corrections were successful at reducing measurement differences, they are ideal only when the measured particles are uniform in size and shape. Since the only measurements obtained from the HVI are total particle area and total particle count, the calculated single particle area is an average which may not be very representative if the particles are non-uniform. If the HVI was capable of categorizing the measured particles and then applying appropriate corrections to each category, then the effectiveness of the corrections would be improved. The best solution to the particle inflation problem would be a hardware fix rather than a software correction fix.

The effect of particle to background contrast differences is a significant problem in the area measurement. Utilization of the color measurement to correct for this effect may be a possible solution. The problem of particle to background contrasts does not have a significant effect on HVI and master instrument agreement since both instruments are effected in the same way. However, an overall reduction in particle measurement accuracy is occurring due to the error caused by the various contrasts that are found in cotton.

References

Randle, J.A. 1992. Cotton Trashmeter Evaluation and Calibration. ASAE 92-1539. ASAE Headquarters, 2950 Niles Road, St. Joseph, MI 49085.

Taylor, R.A. 1985. Using High-Speed Image Analysis to Estimate Trash in Cotton. Journal of Engineering for Industry, Vol. 107.

Table 1. Table of correction constants and R^2 Values derived from quadratic analyses of single particle area measurement data from the circular and square particle tile sets.

Circular Particles (Set#1)

HVI No.	715	714	745
Intercept	0.957	0.960	1.284
Exponent	1.287	1.273	1.334
R^2 (%)	99.94	99.91	99.85

Square Particles (Set #2)

HVI No.	715	714	745
Intercept	0.898	0.822	1.131
Exponent	1.282	1.254	1.315
R^2 (%)	99.98	99.89	99.80

Table 2. Measurement and Correction Results for Separated and Combined Particles for Mixed Tile on HVI #715.

Separated Particles	**Particle Diameter or Side Length (in.)**	**Particle Count**	**Visually Measured Total Particle Area(%)**	**Master Instrument Total Particle Area(%)**
circles	0.04	18	0.25	0.26
squares	0.04	18	0.32	0.33
circles	0.08	5	0.28	0.28
squares	0.08	5	0.36	0.36
Sums		**46**	**1.21**	**1.22**
Whole Tile			**1.21**	**1.20**

Separated Particles	**Raw HVI Total Particle Area(%)**	**Circle Corrected HVI Total Particle Area(%)**	**Square Corrected HVI Total Particle Area(%)**	
circles	0.53	.25	----	
squares	0.67	----	0.33	
circles	0.43	0.28	----	
squares	0.54	----	0.35	**Sum:**
Sums	**2.16**	.53	0.68	**1.21**
Whole Tile	**2.11**	**1.14**	**1.10**	

Table 3. **Measurement differences between master instrument and HVI #715 for cotton calibration box B (HVI - master instrument = diff.)**

Biscuit	Raw HVI Particle Count	Raw HVI Total Particle Area (%)	Normal Calibrated HVI Total Particle Area (%)	Circle Corrected HVI Total Particle Area (%)-
1	0	0.13	0.03	0.01
2	0	0.30	-0.02	0.01
3	1	0.52	0.04	0.01
4	-1	0.67	0.03	0.01
5	4	0.96	0.05	0.01
6	-3	1.37	-0.09	0.02
7	0	0.14	-0.03	0.01
8	0	0.25	-0.03	-0.01
9	-3	0.48	0.01	-0.01
10	2	0.64	0.04	0.00
11	0	0.98	0.07	0.03
12	0	0.45	-0.04	-0.04
s.d. >>>	1.87	0.38	0.047	0.020
avg.>>>	-0.333	0.574	0.000	0.006

Biscuit	Circle Corrected & Calibrated HVI Total Particle Area (%)	Square Corrected HVI Total Particle Area (%)	Square Corrected & Calibrated HVI Total Particle Area (%)
1	0.02	0.01	0.01
2	0.00	-0.00	0.00
3	0.01	-0.00	0.01
4	0.00	-0.01	0.00
5	0.00	-0.02	0.00
6	-0.00	-0.04	-0.00
7	0.02	0.01	0.02
8	-0.01	-0.02	-0.01
9	-0.01	-0.02	-0.01
10	-0.00	-0.02	-0.00
11	0.02	0.00	0.02
12	-0.05	-0.06	-0.05
s.d. >>>	0.019	0.021	0.019
avg.>>>	-0.000	-0.015	-0.000

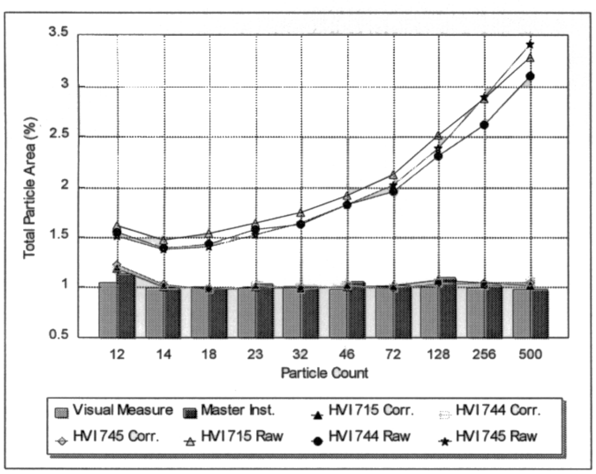

Figure 1. Original and corrected HVI measurements compared to visual and master instrument area measurements for circular tile set #1.

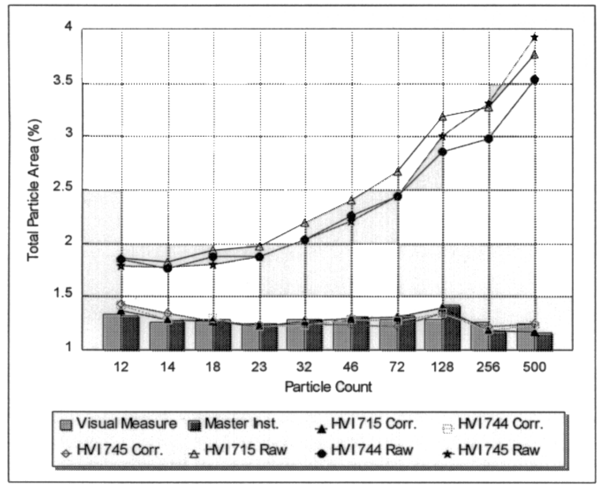

Figure 2. Original corrected HVI measurements compared to visual and master instruments for square tile set #2.

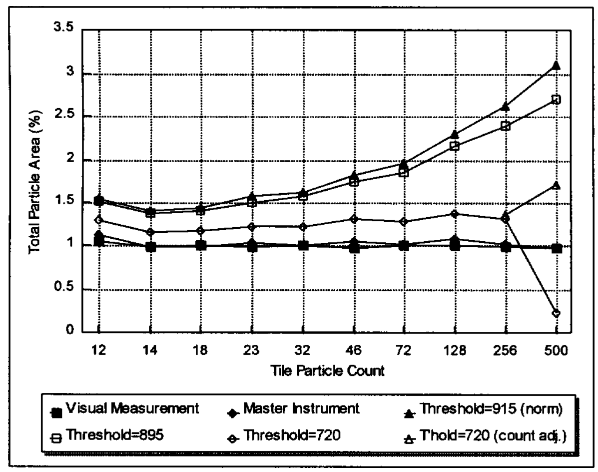

Figure 3. Circular particular tile set measurement results at various thresholds.

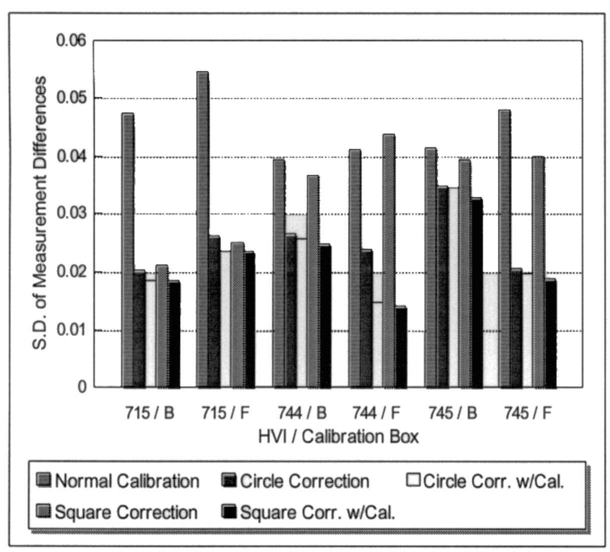

Figure 4. Standard deviations of measurement differences between master instrument and HVIs on cotton calibration boxes.

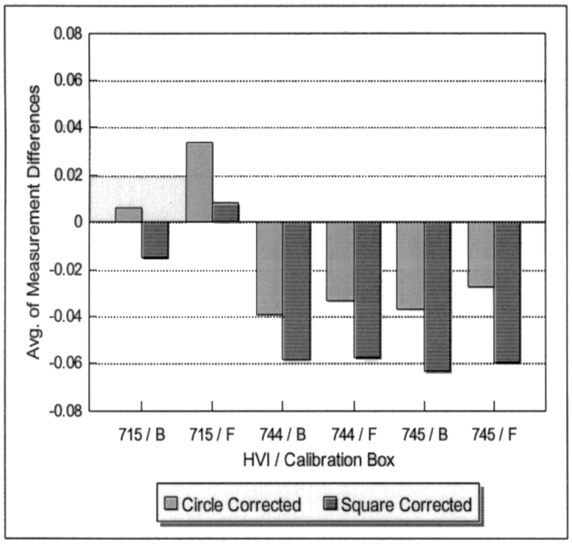

Figure 5. Average of measurement differences between master instrument and HVIs (HVI - master instrument = Diff.) With no calibration applied.

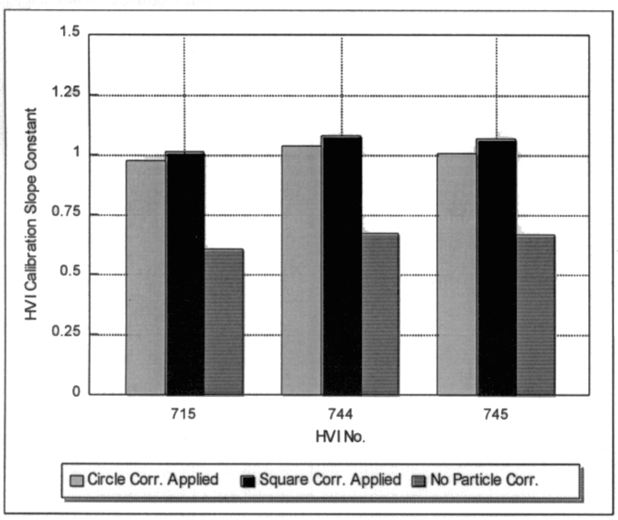

Figure 6. Calibration slope constant levels for calibration box F.

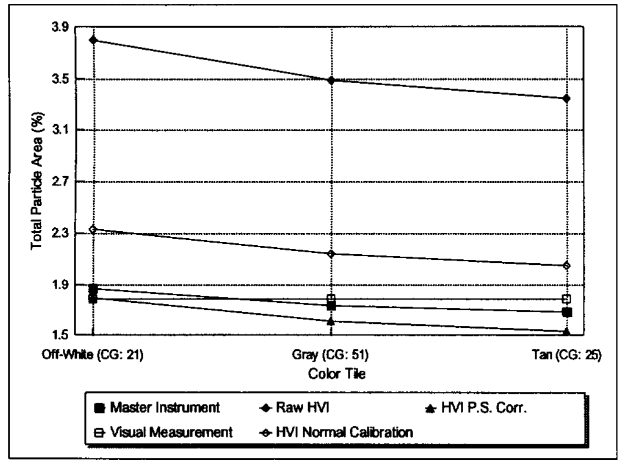

Figure 7. Measurement results between master instrument and HVI #744 on tile set #4 (particle to background contrast tiles)