Scientific Study of Flock Materials and the Flocking Process

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ABSTRACT

Flocking involves the application of fine particles to adhesive coated surfaces. The majority of flocking is done using finely cut natural or synthetic fibers. Flocked finishes impart a decorative and/or required characteristics to functional surfaces such as fabrics, plastic films and sheet metals. Flock fibers are usually applied to adhesive coated surfaces mechanically, electrostatically, or by a combination of both techniques. The focal points of this year investigation are: (1) experimental verification of a mathematical model for flock fiber motion in an electric field and (2) objective color measurement of loose flock fibers and flocked surfaces. Flock motion in an DC flocking zone was investigated using a high speed digital CCD camera and an image analysis software package. The experimental evidences show that flock motion is influenced by the net charge on a flock fiber, relative humidity conditioning of flock fibers, and applied electric field strength. A color measurement protocol for loose flock fiber was also developed.

PROJECT OBJECTIVE

1. Develop a fundamental understanding of flock motion in electrostatic, gravitational and pneumatic force field during the flocking process.
2. Establish an understanding of textile based flock materials and processes from the standpoint of test procedures as they pertain to materials processing properties such as electrical conductivity, fiber motion.
3. Develop a fundamental understanding of some of the functional properties of flocked materials such as surface durability, coloration and color measurement.
4. Understand fundamentals of controlling transport phenomena through flocked surfaces and assemblies.

INTRODUCTION

Flocking involves orienting fine particles to adhesive coated surfaces. Various particle-like materials including flock fibers can be applied to surfaces by different flocking methods to create a wide range of end products. Flock fibers are usually applied to adhesive coated surfaces mechanically, electrostatically, or by a combination of both techniques. Mechanical flocking can be further divided into windblown and beater-bar methods. Electrostatic flocking sometimes incorporates a pneumatic process to propel fibers toward a surface in an air-stream. The flocking process is used on items ranging from retail consumer goods to products for electronic, industrial and military applications.

This year, the focal points of investigation are experimental verification of a mathematical model describing flock fiber motion in an electrostatic field and developing objective color measurement methods for flock fibers and flocked surfaces.

FLOCK MOTION IN ELECTROSTATIC FIELDS

Quality of the flock is strongly influenced by the flock density on a finished flock surface. Flock density depends on flock motion in an electric field. The flock motion analyses found in the literature are based on simplified physical constraints in the flocking zone and charges on flock fibers. For example, Bershev derived the velocity profile of flock fibers under the assumption of a constant electrostatic field E without an air drag force acting on fibers.[Bershev 1977] Other researchers relaxed the electrostatic field restriction by including the disturbance induced by a space charge on flock surfaces.[Kleber and Schmidt 1992]. A more generalized model for flock motion influenced by electrostatic, gravitational and pneumatic field was recently derived. [Kim and Lewis 1998]

While there are many theoretical flock motion models found in the literature, few experimental results are reported to verify these models. In this present research, experimental investigations were conducted to characterize flock motion in electrostatic field using a high speed digital CCD camera. The experimental fit of these data with the proposed theoretical model is anticipated.

Materials and Method

Two types of nylon flock (1.5 d / 1.25 mm, 3 d /2.5 mm) were used to create flock clouds in flocking zone. A DC flocking device (Model FT 1000 manufactured by Maag Flockmachinen, GmbH) was set up in a flocking booth. Distance between the fiber containing hopper screen and the grounded substrate was maintained at 100 mm. Fibers are charged by ions produced by corona discharge from the mesh electrode inside of the flock fiber hopper. This charging electrode is maintained at two potential levels, –40 kV and –70 kV, respectively.
Moving flock fibers in three (upper, middle, and lower) regions of flocking zone were photographed for a given processing condition with a high speed digital CCD camera supplied by Cooke Camera Co. Processing conditions for this study were: (a) 2 flock types (1.5d-1.25mm / 3d-2.5mm), (b) 2 charging potentials (40 kV / 70 kV), (c) 2 relative humidity levels (40% / 60 %). Replicated pictures were taken to have a reasonable number of fibers in double exposed pictures in the sequence of 15 microseconds initial exposure / 800 microseconds delay / 15 microseconds second exposure. These photographs show double exposed fibers in the region of interest, which show the flight displacements of these fibers for 800 microseconds. These photographs were analyzed with image analysis software (Image Pro V4) to measure coordinates and velocities of these flock fibers. The schematic of flock fiber motion analyzer based on ultra-high speed digital CCD (cooled) camera is shown in Figure 1.

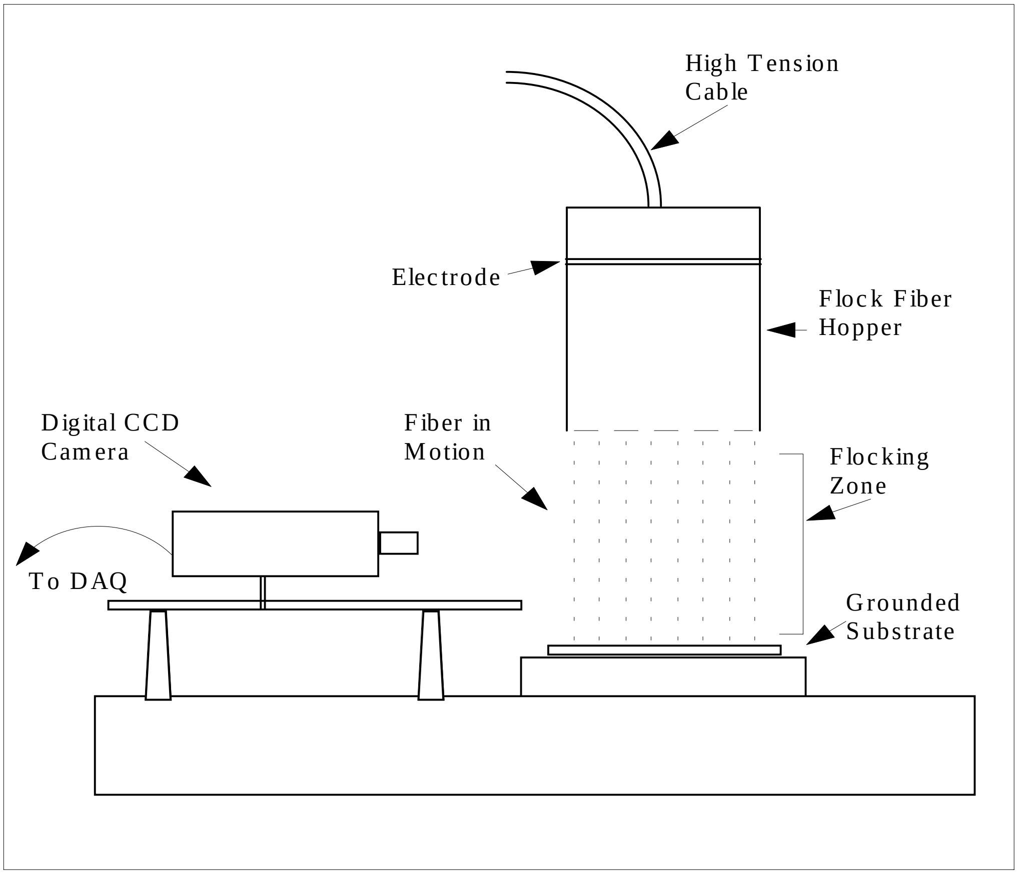


Figure 1. High Speed Digital CCD Camera Flock Motion Analyzer

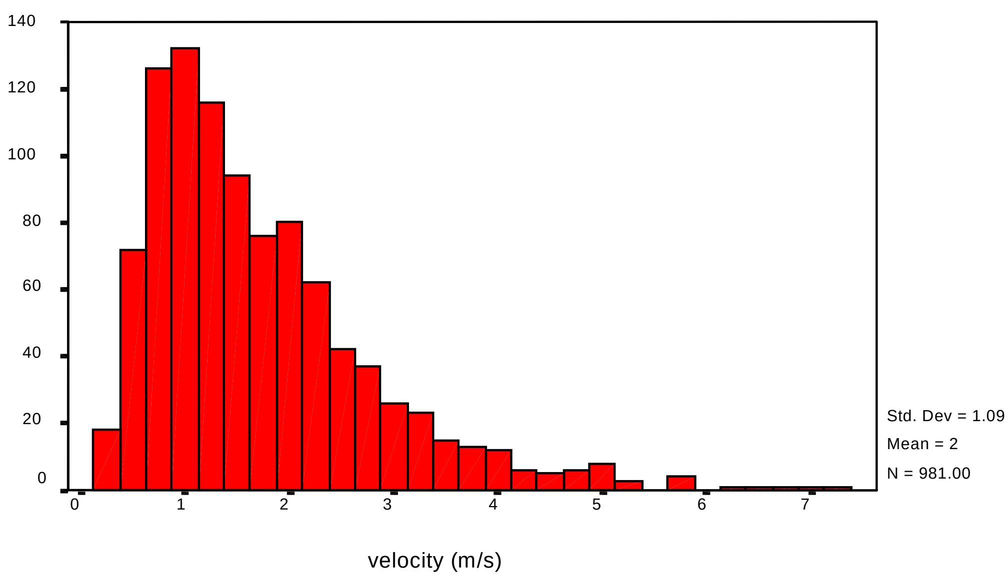


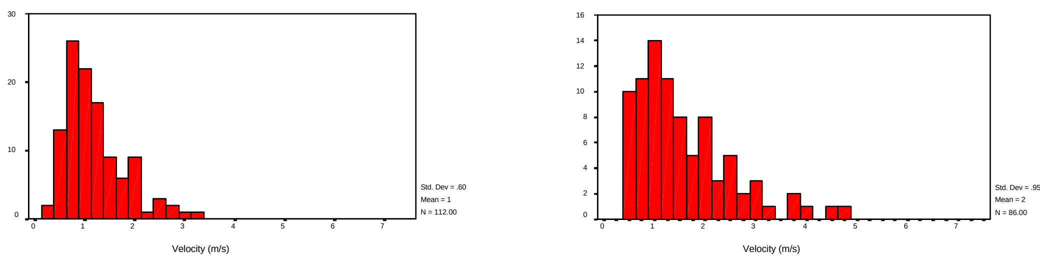
Figure 2. Velocity Distribution of Flock Fibers under Various Processing Variables.

Results and Discussion

Velocity distribution of flock fibers moving under all the processing conditions employed in the study shows that the flock particles can attain the maximum speed of 5 to 7 m /sec under most favorable circumstances. The majority of flocks in the flocking zone moves at speed of 1 to 2 m/sec as shown in Figure 2. The measured speed distribution and its order are comparable to the earlier study of flock motion in an electrostatic field using a flock activity tester. [Gabler 1980]

Effects of fiber linear density and fiber length on flock motion

It is found that fibers with larger surface areas are charged more. Total net charge on the fiber is the major driving force (qE) in the electrostatic field. This qE force effect is observable in Figures 3. The average velocity for 3denier-2.5 mm flocks is twice that of 1.5denier-1.25 mm ones.

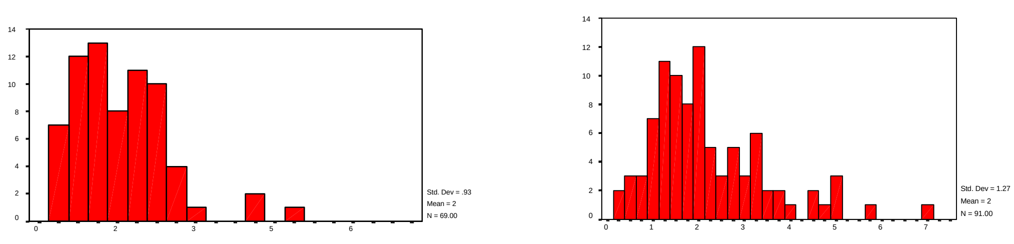


(a) **(b)**

Figure 3. Velocity Distribution at 40kv, RH40%. (a) 1.5d, 0.05" Nylon Flocks, (b) 3.0d, 0.1" Nylon Flocks

Effects of electric potential on flock motion

The velocity histograms for 40 and 70 kV electric potentials are shown in Figure 4. Here, the fiber geometry and RH level are kept constant. It can be observed that at lower potential flocks move in relatively well-defined speed ranges. At higher potential flock fiber speeds are widely distributed. The long tail of high velocity in Figure 4 (b) tells that there is an uneven corona charging of flock fibers in the hopper. This may be due to uneven surface finish distribution.

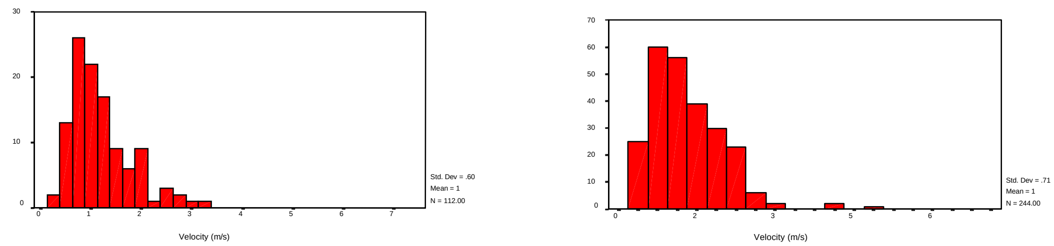


(a) **(b)**

Figure 4. Velocity Distribution of 3.0 denier – 2.5 mm Nylon Fibers at RH 60%. (a) 40 kV, (b) 70 KV

Effects of relative humidity on flock motion

Velocity distributions for 40% and 60 % RH in Figure 5 show the similarity in shape and statistics. This is expected because the fiber charging by corona discharge is not critically dependent on the surface conductivity, which is controlled by RH. This finding contrasts the flock motion study results reported by the authors. [Kim and Lewis 1998] In DC flocking or flock motion testing, the charging method employed is direct charging. Here surface finish and RH of flock fiber conditioning determine the flock fibers' surface conductivity. This surface conductivity controls the effectiveness of charge transfer from high-tension electrode to flock fibers in direct charging.

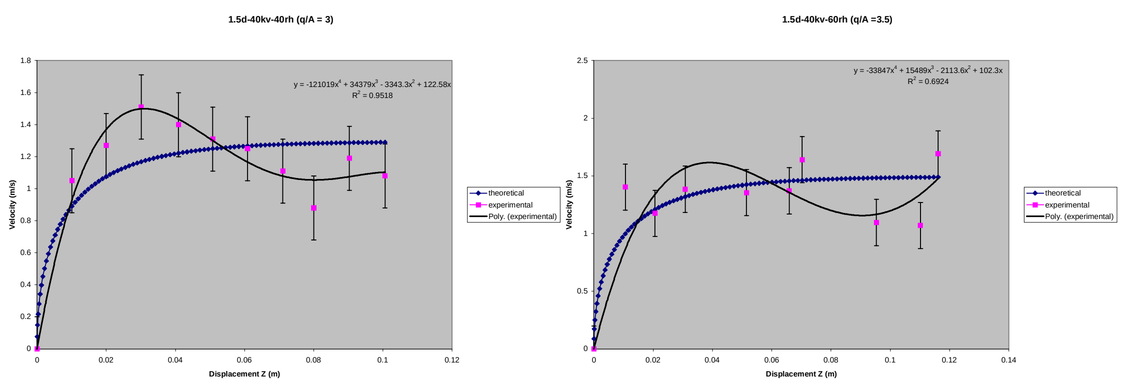


(a) **(b)**

Figure 5. Velocity distribution of 1.5denier - 0.05" Nylon Flocks at 40kV. (a) RH = 40%, (b) RH = 60%

Effect of relative humidity on fiber velocity profile

Surface conductivity of flock fibers depends on finish type, loading, uniformity of finish application, and more strongly on relative humidity. The flock fibers used in the experiment are commercial DC finish on it. Received flock fibers were conditioned in desiccaters held at 40% and 60 % RH, respectively.



(a) **(b)**

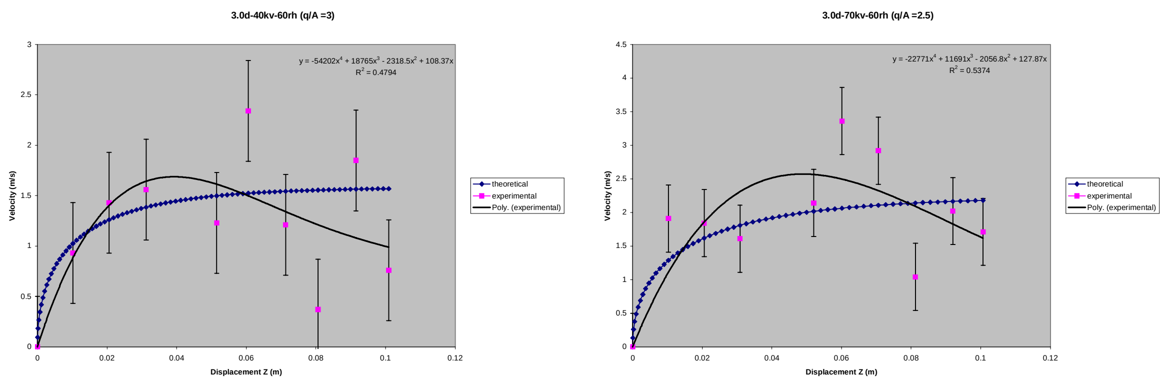
Figure 6. Velocity Profile for 1.5d-1.25mm Flocks at 40 kV. (a) RH = 40%, (b) RH = 60 %

These conditioned flock fibers were used for this motion study. The flock fibers were exposed less than 5 minutes in the flocking laboratory condition (25°C, 50 –70 %RH) during the motion study.

It is expected that surface charge density on the flock fibers are not uniform as assumed in the theory. This is observable in Figure 6. Average surface charge density estimated was 3.5 $\mu C/m^2$ for 60 % and 3 $\mu C/m^2$, respectively based on the model of Kleber and Marton. The velocity profiles follow generally the predicted theoretical trends. [Kim and Lewis 1998, Kleber and Marton 1994] Flock fibers from dispensing unit gain terminal velocity after traveling down about 10 mm toward ground electrode as seen in Figure 6.

Effects of electric potential on velocity profile

An electrode at higher potential will generate more ionic stream for charging fibers. It is evident as seen in Figure 7 that higher terminal velocity is achieved for 70 kV than for 40 kV. This is due to the fact that terminal velocity of a flock fiber depends on net charge (q) and electric field strength (E).



(a) **(b)**

Figure 7. Velocity Profile for 3d-2.5mm Flocks at 60 % RH. (a) 40 kV, (b) 70 kV.

Effects of fiber linear density and length on velocity profile

Fibers with longer and larger diameter have higher surface areas. Thus, higher denier and longer fiber length flocks can accumulate more charges on the fiber. The terminal velocity depends on charges on the fibers and electric field strength. This is shown in Figure 8.

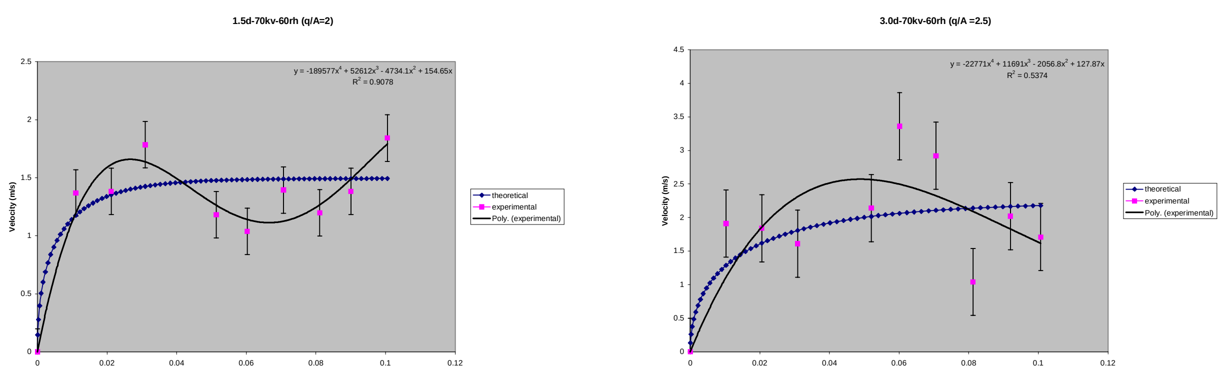


Figure 8. Velocity Profile at 60 % RH70 kV. (a) 1.5d –1.25 mm (b) 3d-2.5mm Flocks.

OBJECTIVE COLOR MEASUREMENT OF FLOCK FIBERS

Color measurement and control of loose flock fibers and flocked surfaces are not well-established areas compared to the well-developed practices in fabric dyeing. The focus of this study is the development of reproducible color measurement protocols for these textured surfaces. Sample preparation and presentation methods to the color spectrophotometer were reexamined and standardized. This reproducible method will be employed in setting up a database for computer color matching of loose flock fiber stocks and flocked fabrics.

Sample Preparation and Presentation

Fabric:
Commercial nylon taffeta fabrics were calibration dyed in a Ahiba Lab Dyeing machine using acid dyes. Care was exercised for consistent degree of exhaustion to have precise dye concentrations on the weight of fabric. The prepared samples were used as control base-line for color measurement.

Mounting a fabric swatch on a hoop was recommended in the literature as a sample presentation method in fabric color measurement. [Hunter and Harold 1987] In our work, it was found that this hooping method does not give consistent and significant changes in reflectance values. Thus, traditional folded fabric layers were presented to the reflectance measuring port of spectrophotometer. The number of fabric layers required to satisfy Kubelka-Munk assumption on sample thickness has never been quantified in the literature. In fact, a different number of layers of fabric are required for the model depending upon the % shade for consistent reflectance reading. As shown in Figure 9, a minimum of 8 layers of blank dyed fabric is needed for consistent reflectance. As the % shade goes up, fewer layers are required. For the higher % shade used, say 2% shade, even 2-3 layers is sufficient. For reproducible color measurements, 8 folded fabric samples are used for reflectance measurement.
Based on the above finding, a color matching database consisting of 72 acid dye shades (12 dyes x 6 concentration) has been established on a color computer.

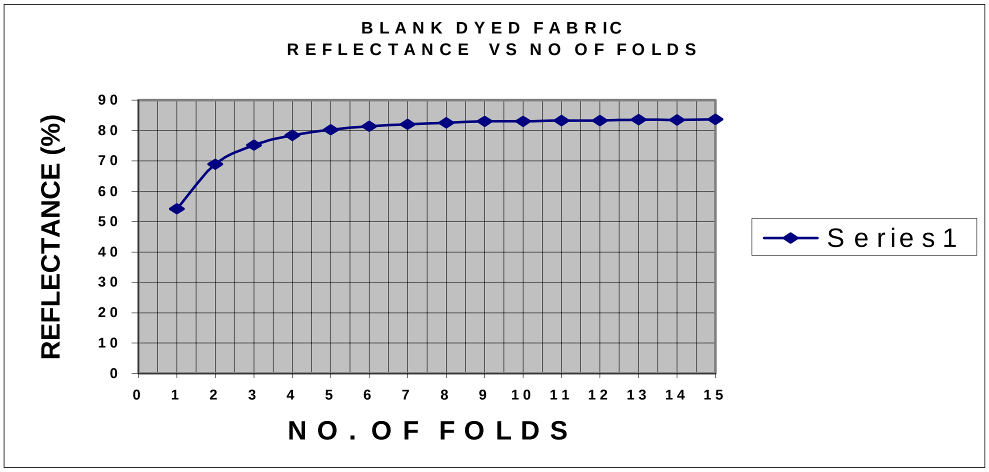


Figure 9. Reflectance dependence on the number of blank-dyed fabric folding presented to measuring port.

Flock Fibers:

Traditionally, fiber stocks are packed in a quartz cell and the fiber filled measuring cell is presented to the spectrophotometer port. [Connelly 1997] This method can not provide a controlled fiber packing density and fiber contact pressure on a quartz window in the cell. To overcome these drawbacks, a novel color measuring cell has been designed for loose flock fiber sample presentation. It consists of a black rubber o-ring (i.d. =31.35mm, thickness = 4.83mm) for holding the specified amount of flock fibers. The o-ring is backed with a white PVC plate. In the front, an optical glass plate (51mm x 51mm x 1.5 mm thick) covers the ring. With this arrangement, the porosity of the fiber assembly in the ring and contact pressure are controlled. To determine the optimum porosity for reproducible reflectance readings, flock fibers were packed in the developed measuring cell at three levels of porosity; 70, 80, 90 %. One of these trials (CI Acid Blue 62) is depicted in Figure 10. It shows that there is a marginal increase (0.87 %) in average relative reflectance for 70% porosity sample from 80% one. However, there is 1.25% increase in average relative reflectance from 90% to 80% porosity. Based on these experimental results, the reflectance measurement protocol for loose flock fibers was decided upon: 1) Pack the cell with a given mass of fibers to make 80 % porosity. 2) Present the prepared cell to the reflectance measuring port. 3) Average three measurements at 0, 45, and 90 degree rotation of measuring cell. Using the developed protocol, a database consisting of 72 shades for color matching in flock fiber dyeing was established.

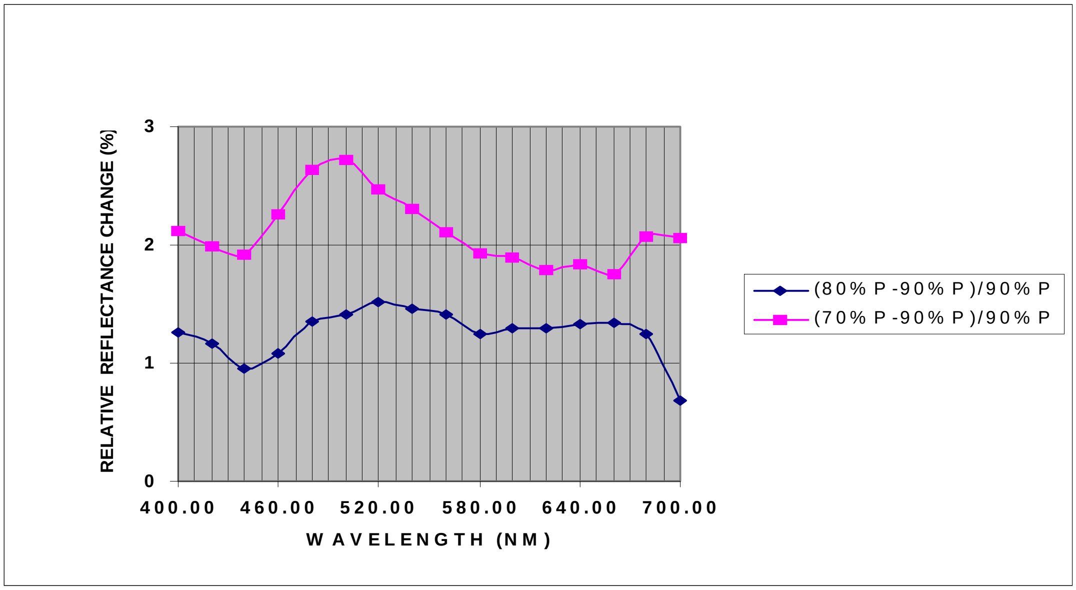


Figure 10. Changes in Reflectance for Various Porosity of Flock Fibers Packed in the Developed Measuring Cell.

CONCLUSION

Flock motion in an DC flocking zone was investigated using a high speed digital CCD camera and an image analysis software package. The experimental evidences show that flock motion is influenced by a net charge on a flock fiber, relative humidity conditioning of the flock fibers, and applied electric field strength. Collected data will be fully analyzed to establish a fundamental understanding of flocking process. Furthermore, an optical method for measuring flock pile density on a flocked surface will be completed using the developed instrumentation.

Color measurement of flocked fabrics is a challenging problem. The color measurement protocol for loose flock fiber was developed. It is planned that sample presentation methods will be investigated further and flocked surface color measurement protocol will be delineated. A dye-bath formula prediction database for flocked fabric will be developed using the delineated measurement protocols for the textured surfaces. Samples of acid dyed nylon fabric, loose flock and nylon flocked fabrics will be color matched using the match prediction generated from the database established. A complete study of the correlation among these different textured or particulate materials will also be conducted. These investigations will provide the rudimentary approaches to the color measurement and match prediction methodology in flock fiber and flocked fabric coloration industry.

REFERENCES

Bershev, E. N., “Developing the Physical Principles of Electrostatic Flocking Procedures,” anonymous English translation of original Russian publication of the author, Moscow, 1977

Connelly, R., “ Good Sample presentation: How to get color measurement results that make sense”, Color Technology in the Textile Industry, RA 36 Committee, AATCC, Research Triangle Park, NC (1997)

Gabler, K., “Investiation of Flight characteristics of Flock by Means of High-Speed Photographic Camera”, proceedings of 6th International flock Seminar” Paper No. 8, Sept 10 (1980)

Hunter, R. S. and R. W. Harold, “The Measurement of Appearance”, 2nd ed., p323,Wiley-Interscience, NY (1987)

Kleber, W. and H-J Schmidt, “Computer Aided Optimizing of Electrical Fields for Flocking Operation”, Proceedings of 11th International Flock Seminar, pp 10-1 to 10-24, Buedingen, Germany (1992)

Kleber,W. and K. Marton, “Comparison of Flocking Methods with Various Current Types” Proceedings of 14th International Flock Seminar, pp 1-1 to 1-19, Darmstadt, Germany (1994)

Kim, Y. K., A. F. Lewis, F97-D01:“Scientific Study of Flock Materials and the Flocking Process”, Annual Report 1998, National Textile Center (1998)