# Basic Principles of Vacuum Slot Extraction

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Vacuum extraction removes excess liquid from open width textile material as it passes over a narrow slot in a tube connected to a vacuum pump. It has been used for this purpose since the beginning of the present century. The pressure differential across the fabric forces mobile liquid from the interyarn spaces into the slot, and then the resulting airflow penetrates into the yarns and removes much of the liquid adhering to the surface of the fibers.

Although mechanical removal of water from textiles is much cheaper than thermal drying, the vacuum technique was not widely used in the past because of poor reproducibility of the final water content. Little thought was given to understanding basic principles and the factors influencing dewatering. When energy costs soared after 1973, however, interest in vacuum extraction was revitalized. Modern extractors are supplied with appropriately sized pumps, vacuum level controls, slots with low friciton shaped to minimize retention of lint, and systems for effective separation, filtration and recycling of extracted chemical solutions. The chemical nature of the fibers present in the fabric and its air permeability are also considered in prediciting performance.

Process optimization is vital to remaining competitive in both domestic and international markets. The vacuum extraction technique aids in process optimization. It gives effective liquid removal from many textiles and yields excellent uniformity of the residual liquid from side-to-side and end-to-end of the piece.

The purpose of this paper is to review the basic principles of textile vacuum extraction. It serves as background for subsequent papers dealing with research on the specific applications and problems encountered in the use of this technique.


### ABSTRACT

**Vacuum slot extraction is becoming more popular in textile wet processing because of its energy efficiency and other economic benefits. The basic principles of vacuum slot extraction are reviewed. The function of the components of a vacuum extractor and the mechanism of liquid removal from the fabric are discussed. The effects of the most important variables controlling the final water content are illustrated using data obtained with a laboratory vacuum extraction unit. Areas requiring further research to improve the vacuum finishing technique are described.**



### KEY TERMS

**Airflow**
**Air Permeability**
**Extraction Equipment**
**Finishing Techniques**
**Vacuum Extraction**


### Equipment

A simple vacuum extractor can be made by cutting a narrow slot along the length of a steel pipe connected to a vacuum pump. The orifice, however, is preferably formed from two parallel plates, mounted on top of the slot in the vacuum tube. The use of a material with low friciton and the actual shape of the orifice formed between the two plates are important factors for minimizing accumulation of lint sucked from the cloth surface and for ensuring good contact and fit of the fabric with the slot. The vacuum tube should have a diameter large enough to avoid any pressure drop in the air flowing through it. The tube may have a plastic lining to avoid adhesion of lint.

If delicate fabrics are vacuumed, more support may be required. In place of a linear orifice, a series of holes or narrow slots arranged obliquely or in a herringbone pattern can be used.

Comparison of the different types of orifices is difficult because of the many variables involved in effective dewatering. Herringbone slots, for example, give improved fabric support but tend to cause greater accumulation of lint which can cause streakiness. Under some conditions they may be somewhat more efficient than a linear slot because they give longer exposure to the vacuum and less deformation and opening of the fabric.

The exposure time to the pressure differential is a key factor determining the efficiency of water removal. It is determined by the slot width, geometry and the fabric speed. The use of a slot of variable gap along its length has been recommended for controlling side-to-side variations in the pickup of dyes and chemicals *(1,2)*. This may be useful for producing or correcting transverse shading effects but a linear orifice of fixed width usually gives

**Table I. Water Retention of Different Textiles After Optimal Vacuum Extraction**

| Fibers | Water[a] |
|---|---|
| Cotton | 51 ± 3% |
| Polyester staple | 12 ± 2 |
| 50/50 Polyester/Cotton | 32 ± 2 |
| 65/35 Polyester/Cotton | 25 ± 2 |
| Polyester filament | 5 ± 1 |
| Viscose staple | 72 ± 4 |
| Wool | 42 ± 5 |
| Nylon staple | 22 ± 2 |
| Acetate filament | 16 ± 1 |
| Polypropylene filament | 2 ± 1 |

[a]Percent water on a bone dry basis. Vacuum level: 38 cm Hg. Fabric speed: 4.6 m/min.

excellent side-to-side uniformity of residual liquid even when the initial distribution is uneven.

A woven fabric passing over the vacuum slot is usually held between the pad rollers and a set of drive rollers running at slightly higher speed (Fig. 1). This ensures that the cloth is under appropriate tension and correctly aligned with the slot. Vacuum extraction is not limited to woven fabrics. Some knitted materials can be handled with appropriate tension and decurling controls. If tension induced deformation of the knitted structure is a problem, the fabric can be supported on a mesh conveyor and vacuumed in a relaxed state through the mesh *(3)*.

In order to control the vacuum level and ensure high speed airflow through the fabric, the slot beyond the selvages must be sealed. This can be achieved simply by using tape or a spring activated strip or tube. Pneumatic or photoelectric devices can be used to automatically detect the selvages and activate movement of sealing strips but require frequent maintenance to avoid problems caused by accumulation of condensation or lint.

Once the liquid has been removed from the web, it is swept down the vacuum tube by the air flux along with any lint. In simple vacuum dewatering, lint should be filtered from the airstream before it passes into the pump. If the liquid extracted contains valuable chemicals, it can be separated from the airstream, along with any lint, by decreasing the air speed. A box type separator, possibly with internal baffles, provides a simple means of doing this. Excellent pump protection and chemical recovery yields of higher than 97% are feasible using a cyclone separator whose design prevents re-entrainment of the liquid *(4)*.

### The Advantage of Recycling

One of the advantages of vacuum slot extraction is the ability to recycle any chemical solution separated from the airflow. Liquid can be drained continuously from the cyclone by means of a barometer leg, if space permits *(5)*. Alternatively, a pump capable of working against the vacuum in the cyclone separator can be used to recirculate the extracted solution back to the reservoir or pad bath on an intermittent or continuous basis. To avoid excessive accumulation of lint in the system, recirculated solution is usually filtered. To clean the filter during continuous operation, the solution may be diverted through a bypass or a parallel filter. If a cyclone separator is used for lint removal, it is possible to have automatic ejection of lint and liquid without releasing the vacuum.

### Three Types of Pumps

Three types of vacuum pumps are commonly used: rotary lobe positive displacement (PD), liquid ring (LR) and centrifugal exhaust (CE) pumps. The choice depends on the required airflow, the level of its contamination, the cost of the pump and its operation and maintenance, the number of slots to be operated in parallel and the water consumption *(6)*.

The LR and PD pumps are constant volume, variable vacuum pumps. They require water injection for cooling, effective sealing and flushing. PD pumps have lower clearance than LR pumps and are more efficient. They also have much lower water consumption, which can have a definite impact on operating costs. In simple dewatering or extraction of soluble waste chemicals, as in washing, extracted liquid may pass through an LR pump operated without a filter. The high flow rate of water necessary to maintain an effective ring of liquid may be sufficient to continuously flush lint and chemicals from the pump *(5,7)* but this should be carefully checked for textile applications. Centrifugal pumps are the most efficient. They run at constant vacuum, with variable power and airflow, and do not require water injection. A CE pump should not be used for textile vacuum extraction unless all liquid and lint have been effectively removed from the airflow.

### Vacuum Control

For most applications, the vacuum must be controlled within reasonable limits (± 1 centimeter Hg) to ensure uniformity of residual liquid along the web. This is more critical for the extraction of chemical solutions to ensure even distribution of the chemical remaining in the fabric. The vacuum level may be controlled in a variety of ways. One of the simplest and most effective methods is by means of a butterfly or ball valve controlling the bleeding of air into the system via a chimney, which also serves as a muffler and drain. The movement of the valve may be activated by feedback from a pressure or humidity measuring system (electric signal from a pressure gauge, transducer or radiation gauge).

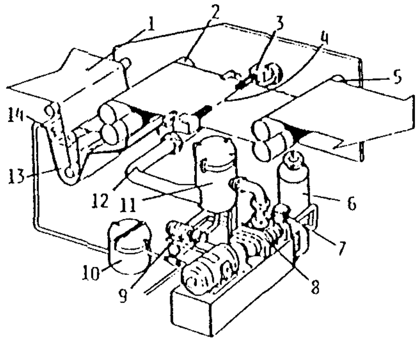


Fig. 1. A typical industrial pad/vacuum unit with filtration and recirculation of the extracted solution. (1) fabric; (2) pad rollers; (3) automatic slot sealer; (4) vacuum slot; (5) drive rollers; (6) chimney, muffler and drain; (7) butterfly valve; (8) vacuum pump; (9) recycling pump; (10) filter; (11) cyclone separator; (12) vacuum tube; (13) pad bath; (14) recycled solution. *Note*: This figure of a commercial unit was selected solely for illustrative and not promotional purposes.

### Mechanism of Vacuum Extraction

In discussing vacuum extraction, it is important to distinguish between bound and unbound water. Bound water is that absorbed by the fiber and held between the polymer chains in the amorphous zones by intermolecular forces such as hydrogen bonds. The amount of bound water depends on the hydrophilic or hydrophobic nature of the particular fiber. Many textile materials can be vacuum extracted down to moisture levels close to the water retention values determined by centrifugation *(8)*.

Table I shows some typical residual water contents of fabrics after efficient vacuum extraction using a laboratory scale unit. These values represent the bound water content of the fibers plus a small contribution from residual interfacial water accumulated at fiber intersections. Comparable results can be obtained under production conditions with industrial extraction systems provided the fabric has adequate residence time at the vacuum slot.

Unbound water is held by surface tension in the interyarn and interfiber spaces. Such water can migrate easily and the bulk of it can be removed by vacuum extraction. This involves two steps: suction of water from the yarn interstices because

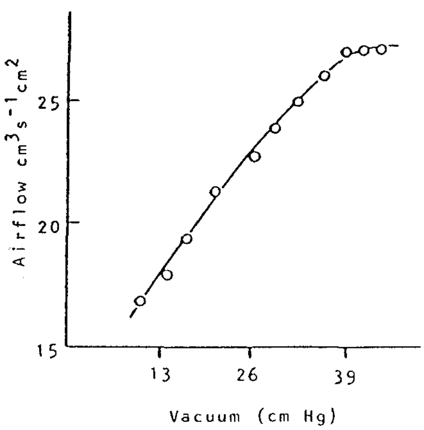


Fig. 2. Airflow through the fabric as a function of the pressure differential. Fabric: 50/50 polyester/cotton, 2/2 twill, 189 g/m$^2$. Fabric speed: 3.7 m/min. Fabric width: 25 cm. Air permeability of the conditioned fabric: 24.6 cm$^3$s$^{-1}$cm$^{-2}$*(18)*. Airflow determined at the pressure in the vacuum manifold from velocity measurement using a Pitot tube.

of the pressure differential between the two faces of the fabric, and subsequent elimination of most of the interfacial water by the high velocity airflow through the yarns. The viscous drag of the air creates shear forces sufficiently powerful to overcome the interfacial tension holding water to the fiber surfaces. There will be some migration of water to fiber intersections during this phase to minimize surface tension. When the pressure drop decreases as the fabric leaves the vacuum slot, relaxation of residual distorted water drops results in retention of a small amount of unbound interfacial water, held predominantly at fiber intersections *(9)*.

Effective liquid removal depends on generating the maximum shear force by having the highest possible air speed through the yarns and ensuring an adequate exposure to the vacuum. There is little evaporative drying caused by the airflow at ambient temperatures. Well extracted fabrics do not demonstrate any significant decrease in moisture content on repeated extraction.

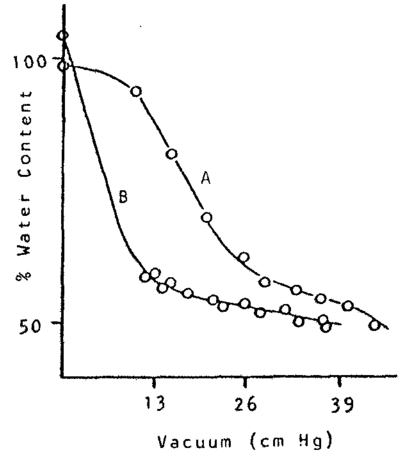


Fig. 3. Residual water retention as a function of pressure differential for two fabrics of differing air permeability. Fabric speed: 3.7 m/min. Fabric A: 18/82 polyester/cotton, 1/1 plain weave, 200 g/m$^2$, 50/50 polyester/cotton warp, 10/90 polyester/cotton filling, air permeability: 64.3 cm$^3$s$^{-1}$cm$^{-2}$ *(18)*. Fabric B: 100% cotton, 1/1 plain weave, 217 g/m$^2$, air permeability: 19.5 cm$^3$s$^{-1}$cm$^{-2}$ *(18)*.

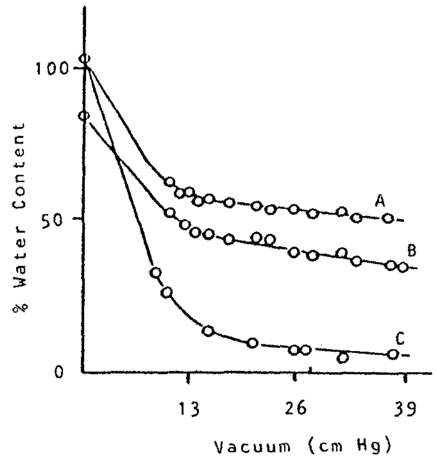


Fig. 4. Water retention of various fabrics as a function of pressure differential on vacuum extraction. Fabric speed: 3.7 m/min. Fabric A: 100% cotton, 2/2 twill, 253 g/m$^2$. Fabric B: 50/50 polyester/cotton, 2/2 twill, 197 g/m$^2$. Fabric C: 100% polyester, texturized filament, 2/2 twill, 230 g/m$^2$.

#### Airflow Is The Key

Vacuum extraction can be considered in terms of airflow through a mesh screen or thin porous sheet as a consequence of the pressure differential across the layer. Fluid flow through such materials follows irregular patterns precluding exact solutions of the equations of motion used in fluid dynamics. Correlations of experimental data based on theoretical models for flow through screens or thin porous layers have been published *(4,10-12)*. These are generally based on equations including both laminar (viscous) and turbulent (inertial) flow for idealized structures, and they could be useful for correlation of air flow data in vacuum slot extraction.

These correlations are based on Eq. 1 relating the pressure drop, $\Delta P$, and the fluid approach velocity, $v$. The two constants, $\alpha$ and $\beta$, depend on the characteristics of the layer material (thickness, porosity) and the moving fluid (viscosity, density). Equations of this form can also be expressed in terms of the two dimensionless parameters, the friction factor, $f$ (proportional to $\Delta P/v^2$) and the Reynolds Number, $R_e$ (proportional to $v$) and two constants, $A$ and $B$ (Eq. 2), related to the viscous and inertial resistance to flow, respectively.

$$\Delta P/v = \alpha + \beta v \quad \text{Eq. 1}$$

$$f = A/R_e + B \quad \text{Eq. 2}$$

As the flow rate increases, the value of $R_e$ increases and the friction factor approaches a constant value of $B$ as the inertial resistance to flow becomes dominant. The actual values of the constants $A$ and $B$ depend on the theoretical model used to represent the structure of the fibrous web.

An empirical relationship describing the airflow through a textile web as a function of the vacuum level, the orifice area and the permeability of the fabric has been published *(13,14)*. It has been called the Albany airflow equation. Its application is difficult because of uncertainties in the mathematical signs and the units of some of the variables. As with all the existing airflow correlations, it is not of general validity but limited to the materials and conditions used in developing it.

The flow of air through a textile fabric is through a series of small orifices in parallel. Consideration of a simple orifice meter *(4)* allows development of some important basic principles applicable to vacuum slot extraction. As the pressure differential is increased, the airflow through the fabric increases, as does the velocity of the air in the channels. Once the air reaches a velocity equal to that of sound in air, its flow rate and velocity through the channels cannot be increased further. This is the critical flow condition. Even if the pressure downstream can be decreased further, this will not be registered in the actual channels because the pressure wave in a compressible fluid can only travel at sonic velocity and the pressure drop cannot be transmitted upstream.

For passage of air from an open face through a narrow section of fabric over a vacuum slot, the critical pressure ratio, $r_C$ (i.e., the ratio of the absolute pressure in the orifices in the fabric and of the entering air) is given by Eg. 3, with a value of 0.528 for air, which has a specific heat ratio, $k$, of 1.40 at 25C.

$$r_C = [2/(1 + k)]^{k/(k-1)} \quad \text{Eq. 3}$$

Thus, ideally, maximum air velocity through a fabric should be reached at a vacuum level of about 36 centimeters Hg as shown in Fig. 2. Results from Clemson University have also demonstrated such critical airflow for a large number of fabrics at about the predicted vacuum level *(15)*.

#### Fabric Permeability

The permeability of the fabric plays a decisive role in determining the amount of water remaining in the cloth after vacuum extraction. The airflow rate through the material can be considered to be the product of air velocity and the total area of the available channels. For textiles of relatively compact construction, the maximum air velocity through the fabric is usually easily attained because of the constricted nature of the channels. Considerable quantities of water can be removed at modest vacuum levels and a relatively constant residual humidity is established at higher levels (Figs. 3B and 4). The optimal vacuum extraction will be obtained when the airflow reaches acoustic velocity in the fabric channels, as this creates the maximum shear force for water removal from fiber surfaces.

If the cloth being extracted is more open, the airflow through the channels will be greater but may never attain the critical flow condition. This is because the pumping speed may not be adequate to increase the pressure drop to the required level. Therefore it will be difficult to strip water from the fibers. Residual humidity decreases with increasing vacuum level but more slowly for open than for compact fabrics. With open fabrics, residual humidity may never reach the bound water plateau as in the previous case.

These two behaviors, are illustrated in Fig. 3.

In removing unbound liquid from the material, it is the air speed and not the volumetric flow which counts. To achieve an air flow at sonic velocity, and thus with the greatest shear force to remove water from the fibers, the vacuum level can be increased, or the area of fabric exposed to the vacuum can be reduced by decreasing the slot gap.

### Controlling Water Removal

Few publications are available which deal with the factors that influence the final water content of vacuum extracted textiles *(16,17)*. The two most significant variables influencing the quantity of residual water are the vacuum level and the chemical nature of the fibers. Fig. 4 shows data obtained with a laboratory unit. In this case, the slot gap was 3.2 millimeters and the low fabric speeds gave residence times of about 50 milliseconds, resulting in optimal extraction. The overall performance of the process also depends on the pump capacity, the type of slot, the slot gap, the construction of the fabric and line speed.

Many factors involved in fabric construction influence its air permeability, which determines whether critical flow conditions can be achieved (Fig. 3). Correlations of airflow in vacuum extraction and fabric air permeability have been established *(13,15)*. It should be pointed out, however, that the air permeability measurements in such correlations refer to airflow at a pressure differential of 0.5 inches of water for conditioned fabrics *(18)*, whereas in vacuum extraction the airflow is through the wet fabric with a much higher pressure drop.

### Fiber Swelling

Recent work *(12)* has clearly demonstrated that fiber swelling on water absorption decreases the air permeability of a material. This can be quite pronounced. For example, a conditioned cotton fabric (1/1 plain weave, 167 $g/m^2$) with an air permeability of 45 $cm^3s^{-1}cm^{-2}$ *(18)* gave a value of only 17 $cm^3s^{-1}cm^{-2}$ after padding with water to a final retention of 74% $H_2O$. There is little data on air permeabilities either at high pressure differentials or when the fibers are in a swollen condition. Airflow through textile fabrics tends to produce much larger pressure drops than their relatively high porosities would suggest. It would be useful to develop further a mathematical model for high speed airflow through a fibrous web including the effects of the real volume available for the flow and of energy absorption by displacement of individual fibers *(19)*. Such information and modeling will be valuable to correlate data on vacuum extraction and to develop the capability of predicting the dependence of water content on vacuum level and airflow.

**Table II. Water Content of a Vacuum Extracted Fabric as a Function of its Speed**

| Fabric Speed | Residence Time at Slot | Water |
|---|---|---|
| 1.8 m/min | 87 ms | 41.6% |
| 3.6 | 43 | 44.3 |
| 5.5 | 28 | 45.5 |
| 7.3 | 21 | 46.6 |
| 9.1 | 17 | 47.6 |

Fabric: 50/50 polyester/cotton, 2/2 twill, 225 $g/m^2$. Vacuum level: 28 cm Hg. Slot gap: 2.6 mm. Initial humidity of fabric: 93 ± 2%.

### Residence Time

The quantity of liquid removed from a fabric during extraction depends on the residence time at the slot. For a linear orifice the quantity of liquid removed is governed by the fabric speed and the slot gap. A minimum residence time of about 10 milliseconds (longer with heavy fabrics) is usually required for effective dewatering. Complete equilibrium is not generally attained in vacuum extraction and the water retention after extraction decreases with decrease in fabric speed (Table II). The effect is not usually very pronounced. Wider slots expose a greater area of fabric to the vacuum and increase the residence time but result in decreased air velocity unless a higher capacity pump is used.

Provided that a minimum dwell time is exceeded, the fabric speed and slot gap do not greatly influence the final humidity, provided that sonic air speed can be attained. Under industrial conditions, with production speeds approaching 100 meters per minute, optimal extraction down to the bound water level may not always be possible because residence times are shorter (two to five milliseconds). In such cases, a combination of two slots can improve efficiency provided the pumping capacity is adequate. In many cases, the final humidity after extraction decreases only slightly on increasing the vacuum level above 20 centimeters Hg (Fig. 4), and it may often be more economical to extract slightly less water at this lower vacuum level than at a higher vacuum requiring a more powerful pump.

For given conditions, the residual moisture is a minimum at an intermediate fabric tension allowing good contact with the vacuum slot, minimal deformation and maximum air speed. Too high a tension may distort the material and thus decrease the air speed through it. This is particularly true for some knitted materials. The fabric may lose contact with the slot if the alignment is not exact. Too low a tension causes more fabric to be sucked into the slot, increasing the exposed area and reducing the air speed.

The initial water content of the fabric before extraction does not significantly influence the quantity of water remaining after extraction provided the residence time of the fabric at the slot is adequate. At high fabric speeds or low vacuum levels, the retention of water after extraction increases slightly with an increase in the initial retention (Fig. 5).

### The Influence of Viscosity

Little work has been published on the influence of viscosity on the efficiency of vacuum extraction. Extraction of dilute xanthan gum solutions of viscosity from 0.025 to 0.915 kg $m^{-1}s^{-1}$ caused little variation in residual pickup of a 100% cotton fabric, indicating that viscosity may not have a pronounced effect on extraction in the absence of other influences *(15)*.

Extraction of NaOH solution is quite difficult and more complex. The chemical combination of the alkali with the cellulose results in a much higher retention of liquid, both before and after the vacuum slot, and the extracted NaOH solution is more dilute than either that initially applied from the bath or that remaining on the cotton. Although NaOH solutions increase in viscosity with increasing concentration, the influence of viscosity on their vacuum extraction is probably not very significant.

### Applications

The major applications of vacuum extraction during textile finishing are:

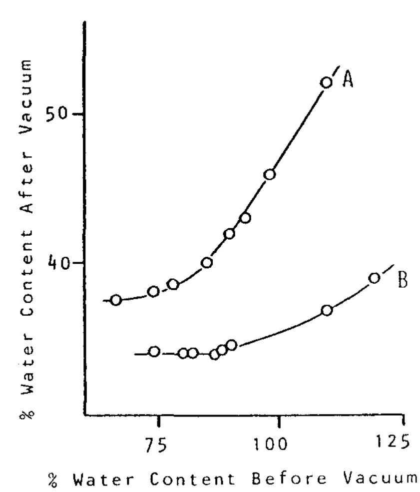


Fig. 5. Influence on the initial water content of the fabric on the water content after vacuum extraction. Fabric: 50/50 polyester/cotton, 2/2 twill, 225 $g/m^2$. Fabric speed: 4.6 m/min. Vacuum level: curve A: 26 cm Hg; curve B: 39 cm Hg.

- Dewatering of fabrics before drying.
- Dewatering before wet-on-wet pad application of chemicals, to eliminate exchange of the water in the incoming fabric with the bath solution.
- Removal of unwanted chemicals in washing during preparation and after dyeing.
- Low add-on finishing with good penetration.
- Lint removal.

The pad/vacuum technique is widely used as a low leave-on chemical application method in textile finishing. Vacuum extraction is also recognized as a useful means of improving the efficiency of continuous washing processes in preparation and after dyeing. Despite its wide use there is little published information on the influence of vacuum extraction on the amounts of chemicals retained by or removed from the textile in relation to the chemical's substantivity for the fibers or its physical form. The further development of the vacuum technique will depend on research of these aspects.

Vacuum extraction is not of universal application and has some specific limitations. It is not suitable for removal of liquid from fabrics with very compact or very open constructions. Neither type of material permits high speed airflow. Knitted fabrics require special handling, with appropriate tension control and decurlers. In many cases, they are preferably vacuumed through a mesh support in a tensionless condition. There may be occasional difficulties with excessive accumulation of lint in the separator or filters, and, with some finishing mixes, foaming or cracking of dispersions may occur on extraction. The applications and problems of vacuum extraction in textile finishing will be discussed in a subsequent paper.

### Conclusions

Vacuum extraction is a technique with considerable merit. This paper has dealt with the basic principles of the technique. Its use results in considerable savings in drying and in recovered chemicals. It can play a key role in improving the efficiency of washing operations. The success of the vacuum technique in dewatering and in finishing has led to its almost universal use in North American finishing mills. More research is required to fully evaluate the following relationships: fabric permeability and air velocity; the removal of unfixed chemicals and of improved mass transfer in washing; and the effects of the various perturbations such as affinity and evaporation which can cause changes of the concentrations of solutions recycled to the pad bath.


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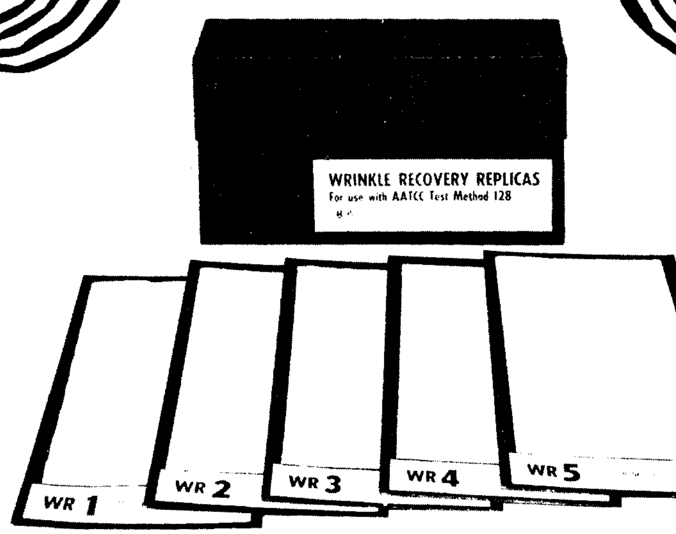

Clemson Conference

# Color Measurement: Visual and Instrumental

Clemson University's annual conference on textile color measurement in April featured 16 papers on topics ranging from human visual perception to closed loop color control. The following is a summary of each paper.

### Vision and Color

Joy Turner Luke of Studio 231 examined the factors that affect human color perception. Her lecture included a slide presentation demonstrating how perception of colors are modified by the influences of background, adjacent colors and lighting. She defined the following terms for the phenomena shown:

- Color Constancy. Colors whose appearance remains relatively constant when viewed under different light sources. In a broader sense, color constancy also refers to colors which continue to be recognized even when changes in illumination radically alter the pattern of wavelengths reflected to the observer. Luke said that just as there is observer metamerism, there also is variation in individual perception of color constancy.
- Reflection Color. Refers to colors of objects which are perceived through light reflected back to the observer after absorption of selected wavelengths by the object.
- Induced Color. Color whose appearance is due to the presence of surrounding colors, not to the pattern of reflected wavelength. The term is generally used with reference to emitted light rather than reflection color.
- Simultaneous Contrast. The contrast effect in hue, lightness and saturation induced in a color by a surrounding or neighboring color. The term generally refers to reflection color.
- Additive Color Mixture. Mixtures of beams of colored lights. When the energy of two lights are added together, the mixture color is lighter than either parent color. The additive primaries are red, green and blue.
- Partitive Color Mixture. When color areas are either too small for one parent color to be distinguished from the other or when colors are spun on Maxwell disks so rapidly that the individual parent colors cannot be perceived.
- Subtractive Color Mixture. Mixtures of paints or dyes, overlapping of ink films or any other combination of colors where light must pass through both colorants before being reflected to the observer. A printing process results in subtractive colon if the dots overlap but in additive color if the dots are side by side. Subtractive mixture color is darker than either parent color since each colorant has absorbed some wavelengths from the light. The subtractive primaries are each of the sum of two additive primaries: yellow is red plus green; cyan is blue plus green; and magenta is blue plus red.

### Conditions Affecting Sample Color

Susan H. Keesee of AATCC reported on results generated from studies conducted at Clemson and within AATCC Research Committee RA36 on color measurement. Her presentation stressed the importance of quantifying color changes than can occur due to heat, moisture content, aftertreatments and ageing of textiles and standards. Techniques for determining such color changes were offered.

Changes in heat and moisture content occur during dyeing and finishing which will cause the color measured in-process to differ from the color measured after standard conditioning practices. Aftertreatments applied on the finishing range can change the measured color of the sample either temporarily (due to the process conditions) or permanently (due to the nature of the finish applied). In-process color changes must be quantified and controlled if techniques such as on-line color measurement are employed.

The need to know the color measured within a process as opposed to after conditioning also has implications for users of endpoint indicator fabrics during high humidity light or atmospheric contaminant tests. A color measurement needed to make the decision to continue or end a test cycle often cannot wait for a four-hour conditioning period. Methods to measure indicator fabrics immediately after removal from a humid test chamber require an understanding of that shade's color difference when conditioned versus heated.

Keesee cautioned users of instrumental color data that when there is no knowledge of the potential for shade changes during the measurement phase, decisions to pass a shade can be made erroneously or the color instrument wrongly blamed for the misinformation.

Color standards will shift over time due to storage conditions and dye degradation. As a result, production runs can drift from the original target shade to a faded shade. Measuring the perishability of the colors instrumentally to determine the point at which physical standards need to be replaced should be part of a quality control program to protect the integrity of visual shade comparisons. Keesee said that with a well calibrated instrumental system, it can be more practical to store the instrumental color values for comparison to new production runs rather than rely on physical standards.

### Solution Measurement

A laboratory technique to measure the color of dye solutions was discussed by Donna D. Faber of C. H. Patrick & Co. She said that solution transmittance measurement correlates well to dyeings run for strength evaluation. An additional advantage to measuring solutions is the opportunity to get results in 15 minutes in contrast to about two hours required to obtain the results from a dyeing. The technique is primarily used by the manufacturer of dyes or for quality of control of incoming dyes. It can be used for single dyes or mixtures.

The equipment required to measure solution transmittance is readily available in many dyeing laboratories. Faber said that a lab with a spectrophotometer, hot plate, ultrasonic cleaner, analytical balance and volumetric glassware can test the color of solutions. She recommended that the spectrophotometer have a bandwidth of 10 nanometers or less, be dual beam and have monochromatic illumination. The balance should be accurate to four places. Volumetric glassware should be the Class A type and calibrated to deliver. Users should leave solution in the tip after delivery as opposed to blowing it out. A flow-through cell makes the measurements easier by eliminating the need to handle cuvettes and risk placing fingerprints on them.

According to Faber, accurate solution procedures must meet the following criteria: adherence to Beer's Law, reproducibility and conformance as closely as possible to dyeing results. To develop accurate solution procedures, the solution variables must be indentified and controlled or eliminated. Some solution effects which affect accuracy are plating, concentration, light, ageing, temperature, pH, solvent effects and metal ions. She offered techniques to determine these effects.

The optimum absorbance to analyze dyes is 0.6. It is often necessary to dilute a stock solution of dyes to allow the maximum absorbance at the analytical wave-