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## 1970 Olney Medal Address

# Meeting The Challenges of the Textile Industry Through Application Research and Technology

By PAUL L. MEUNIER, The Du Pont Co., Wilmington, Delaware

**I**N speaking of challenges of the textile industry, I refer to those occasions when the industry has been confronted with serious problems brought on by war, depression, new discoveries and the like. Needless to say, it has accepted these challenges and continues to advance along with other industries in our "exploding" technical age.

How has this been accomplished? By applying the fruits of research and technology! Whatever one's position might be on the question as to whether our industry, particularly the dyeing and finishing part of it, is as progressive as it should be, the fact remains that remarkable improvements have been made in a relatively short time.

U.S. mill production of man-made fibers — polyester, nylon, acrylic, rayon and acetate — in 1969 totaled 4,740 million pounds. Cotton mill production was 3,925 million pounds, wool was 355 million and silk was 3 million pounds in 1969. In contrast to this, for the year 1939, man-made fiber production was only 459 million pounds, silk was 47 million, wool was 397 million and cotton pro-

duction was 3,630 million pounds.

Although the differences in pounds of wool and cotton are relatively small, the percentage change from 1939 to 1969 is revealing. Thirty-one years ago, cotton production in the U.S. was 80.1% of the total whereas in 1969 it was 41.3%. Wool fell from 8.8% to 3.7% and silk from 1.0% to 0.03%. On the other hand, man-made fibers increased from 10.1% of total production in 1939 to 50.0% in 1969! Meanwhile, total fiber production more than doubled during this span.

This picture serves to illustrate the nature of changes that have been taking place in the last few decades and the need for the industry to keep pace with advancing technology. I will discuss a few notable developments in the dyeing and finishing field and then offer some recommendations for future growth.

### Dyeing Of Cotton Piece Goods With Vat Dyes

Traditionally, the best quality dyeing on any type of cotton fabric was obtained with vat dyes by padding, drying and jig development with caus-

#### ABSTRACT

Research and technology have produced some remarkable improvements in dyeing and finishing in a relatively short time. The author, the 1970 recipient of AATCC's Olney Medal for outstanding achievement in textile chemistry, traces several of the more notable advances and offers some recommendations for future growth.

#### KEY WORD INDEX

Carriers  
Dyeing  
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Finishing  
Padding  
Research  
Steaming

## Meeting The Challenges

tic soda and sodium hydrosulfite. This is a batch process in which an average load of 500-1,000 yards can be dyed and finished in about three to four hours. This so-called pad-jig process was originally developed during the first decade of this century (1).

The goal in the coloration of all textile materials is the production of a full range of attractive shades with maximum durability. In the U.S., there had been a strong demand for a continuous process to satisfy large volume production of goods at lower costs. During the 1920's and 1930's, partial success was attained by two continuous methods known as the reduced pad-booster (2) and the pigment-pad-booster (3) systems which produced acceptable dyeings on certain types of unmercerized goods for work clothing and other limited uses. In the 1940's, however, projected requirements of the U.S. military for vat-dyed combat uniforms were so great that research efforts were renewed and intensified. The pad-steam continuous dyeing process (4), introduced in 1944, proved to be the answer to that particular challenge. It is still used worldwide for high quality dyeings on cotton and blends of cotton with synthetic fibers. At the same time, in the 1940's, the Williams Unit (5) was introduced. This provided a short volume development chamber for economical dyeing of certain types of fabrics. Later on, the Standfast

Machine (6), utilizing molten metal for the development of the dyes, was brought out in England.

The success of the pad-steam process was based on the appreciation of a simple scientific fact — that the rate of reaction increases by about 100% for every 10C rise in temperature. Thus, when vat dyes in their pigment form and caustic and hydrosulfite are brought together in a steam atmosphere, reduction and fixation of the dye in the cotton fiber occurs instantaneously. Another vital consideration was that the stability of hydrosulfite in a steam atmosphere without air is remarkably good. At speeds of about 100 yards per minute each pad-steam range can produce the equivalent of about 24 jigs in a given period of time.

### Dyeing Of Synthetic Fibers

I shall define synthetic fibers as those manufactured from man-made intermediates. This excludes the man-made fibers derived from natural sources such as cellulose acetate, rayon (regenerated cellulose) and nitrocellulose.

The first truly synthetic fiber was nylon, invented by Carothers and introduced as a textile fiber in 1938. The impact of this fiber and those that followed closely on its heels (i.e., acrylic, polyester, spandex, olefin, etc.) on the textile industry and the whole economy in general has been tremendous. The textile industry has never been so dynamic as during these last three decades. Evidence of this is seen in the drastic changes which have occurred in the fiber content of wearing apparel, floor covering, upholstery fabrics and others.

Nylon filament yarn was first used for hosiery. Then, during World War II, it was reserved chiefly for military uses such as in parachutes, ponchos and uniform fabrics. Nylon staple fiber was employed in jungle boot cloth.

To the dyer and finisher, nylon represented new and somewhat perplexing challenges. Although it possessed affinity for nearly all classes of dyes, their behavior on nylon was often much different from that exhibited on other fibers. For example:

- Certain disperse dyes which had excellent lightfastness on cellulose acetate were very fugitive on nylon;
- The washfastness of acid and direct dyes on nylon was appreciably better than on wool and cotton; and
- Certain vat dyes which exhibited very good lightfastness on cot-

ton, rayon or wool were very poor on nylon.

Nevertheless, broadwoven and knit fabrics, as well as hosiery and yarns of nylon, were dyed in the beginning and are still being dyed with disperse or acid dyes, depending upon end-use requirements. Demand for the superior wash and lightfastness of acid type dyes is increasing because of widespread use of nylon in automotive upholstery, carpeting and outerwear fabrics.

### Meeting A Need

Here is one example of the role of research and technology in supplying a need during World War II. It will serve to demonstrate the type of cooperation between research groups and industry that is needed to meet our challenges. The U.S. Armed Forces had designed a jungle boot for combat soldiers fighting in the tropical areas of the Pacific. The boot consisted of a spun nylon fabric bonded to the rubber sole. Substantial yardages of the nylon fabric, dyed in an Olive Drab #7 shade, were needed quickly for mass production of the boot. The War Production Board established a committee composed of industry representatives from chemical manufacturing and dyeing and finishing groups to study the problem. As a result, several successful processes were developed for continuously dyeing the spun nylon fabric with acid and chrome dyes and the needs of the Armed Forces were supplied (7).

One of the processes consisted of padding nylon fabric with a solution containing dyes and a highly effective dispersing and wetting agent, followed by steaming at atmospheric pressure for about ten minutes. We knew then that steaming under pressure at elevated temperatures would have been better because of time saving and improved dye utilization, but suitable equipment for pressure steaming was not available. The wonder chemical, that is, the dispersing and wetting agent, was — would you believe? ammoniacal shellac! There has not been anything before or since to surpass it for nylon dyeing but, of course, we now have many good synthetic chemicals for this purpose.

In dyeing nylon filament yarn or fabric, irregularities are often accentuated, particularly by acid dyes, in the dyed fabric. These irregularities may be of one or more of the following types:

(1) Luster differences in yarn which lead to streaky appearance, even when the yarn bundles are uniformly dyed.

PAUL L. MEUNIER, the 1970 recipient of AATCC's Olney Medal, the association's highest recognition for technical and scientific contributions to the advancement of textile chemistry, is director of The Du Pont Co.'s dyes and chemicals technical laboratory at Wilmington, Del. A native of Indianapolis, he holds a BS in organic chemistry from Butler University and MS and PhD degrees in organic chemistry from Pennsylvania State University. Since joining Du Pont as a chemist in 1936, he has served in a wide variety of assignments (TCC, Vol. 2, No. 14, July 15, 1970, p10). His broad experience and knowledge in textile dyeing, printing and finishing have earned him wide acclaim in governmental, institutional and commercial circles.



(2) Physical variations in adjacent yarns of the fabric, such as might be introduced during processing of yarn to fabrics.

(3) Chemical differences typified by variations in the basicity of individual yarns.

Disperse dyes cover both physical and chemical irregularities because they transfer readily during dyeing, but luster differences can result in streaky goods. On the other hand, at temperatures under the boil most acid dyes migrate or transfer very little and not only fail to cover but actually accentuate physical and chemical variations in conventional dyeing processes.

Methods have been developed to improve the levelness of acid dye application to nylon through the use of: elevated dyeing temperatures (8), swelling agents, anionic dyeing assistants, cationic dyeing assistants (9) and the development of new acid dyes having good transfer properties (10).

Just as nylon responded to scientific study and adoption of new techniques to overcome serious commercial obstacles, so have the acrylics and polyesters. Complete lines of cationic and disperse dyes in powder, solution and paste forms have been developed. For the acrylic fibers, cationic dye application is controlled by the use of cationic or anionic retarding agents (11). For the polyester fibers, carriers are used to improve the rate of dyeing of the disperse and cationic dyes. The development of dyeing methods utilizing carriers is a separate story in itself and deserves special treatment elsewhere. In fact, the market for carriers used in these dyeing procedures is large and very attractive.

#### New Techniques Of Coloration

Now, I should like to beg your indulgence while I reminisce that period of our recent history which is probably the most important. These were the years just after World War II when the industry was trying to utilize to the fullest extent the nylon fibers released from military priorities. At the same time, many of us were carrying out research on the dyeing of new fibers; e.g., the forerunners of Orlon and Dacron. We were convinced that (1) all the new synthetic fibers required the highest possible temperature for reasonable diffusion rates of dyes into fiber, (2) dyeing at elevated temperatures under pressure was a "must" under certain conditions, and (3) other means of "opening-up" these intractable fibers must be found. In these studies, we borrowed from textile

printing technology by studying the effects of pressure steaming of padded fabrics in autoclaves using varieties of assistants or potential swelling agents. Also, a small, pressurized reel machine was built for dyeing from aqueous dyebaths at high temperatures.

Finally, the day came when we gathered around a laboratory scale one-pound package dyeing machine on which our safety engineers had installed a pop-off valve set to go off if the pressure exceeded 15 psi above atmospheric pressure. The temperature at this pressure is 121C or 250F. To operate under pressure, we had simply closed off the expansion tank or overflow kier. This first pressure dyeing experiment was a complete success (12) not only because the dyeing was good and the equipment did not rupture or blow up, but it gave us confidence that commercial mill equipment, represented in this experiment, would probably be operable. Later events proved this to be the case. It is true that earlier workers at Uxbridge Worsted Co. had demonstrated the advantages of pressure dyeing of wool but they had built a "submarine" to house a dye box or booster bath of conventional design (13, 14).

By the time significant quantities of Orlon acrylic and Dacron polyester fibers were available in the market, the industry had met several challenges, namely:

(1) It had learned how conventional becks and jigs could be covered tightly so that temperatures very close to the boil, 208-210F, could be obtained. Engineers learned how to pump hot liquors without cavitation in the lines,

(2) Carrier dyeing of polyester fibers was practiced widely, and

(3) Pressure dyeing was firmly established for dyeing yarns, sewing thread, rawstock and certain types of piece goods in beam machines.

#### Not As Simple As It Sounds

Lest we have the impression that such things just happen, let me assure you that they do not. For example, many thought that an active boiling bath meant that its temperature must be at or near the boil. In equipment open or partially open to the atmosphere, however, heat losses from convection and radiation are so great that the temperature of the liquor was often found to be as low as 180-190F.

Carrier dyeing sounds simple, too, but intensified application research effort was expended in developing the

necessary basic information and practical processes for dyeing the first polyester fibers. Research teams explored the chemistry of carriers and evaluated literally hundreds of compounds as additives to the dyebath, pre-padded on the goods to be dyed or as pretreatments of the fabrics in so-called "standing baths." This work preceded the announcement of Dacron by several years. It was evident that carriers must be aromatic rather than aliphatic and to be highly effective they should have solubility in the polyester fiber, thus being able to disrupt the ordered arrangement of fiber molecule chains and allow dyes to penetrate. Schuler and Remington (15) published one of the most widely recognized early papers on the mechanism of dyeing Dacron polyester fiber with disperse dyes. They showed that the fiber is dyed by a reversible process involving solution of dye in fiber. The dyes are very slightly soluble in water and enter the fiber from the solution in the aqueous dyebath. Invaluable assistance and guidance was given by industry people who participated in mill trials. Equipment modifications were made to increase the effectiveness of carriers, e.g., the insertion of top steam coils to maintain high temperatures in becks and jigs.

The huge market for carriers in this country alone is a strong indication of the progress of the industry in this field. Whereas assistants of various types had been employed previously in the dyeing and printing of acetate, rayon, cotton and nylon, never before had there been such dependence on specific organic chemicals for carrier activity in dyebaths or in printing pastes.

#### Pressure Dyeing

Of all the challenges to the so-called "backward" dyeing and finishing textile industry, that posed by the need for pressure dyeing was perhaps the most severe. On the other hand, it is an excellent example of technical progress and we should all feel proud to be part of it.

I have already described an incident in one of the first applications of pressure dyeing. Economical and technical advantages of pressure dyeing were pointed out soon after polyester and acrylic fibers appeared on the market. As the volume of these new fibers increased, the demand for pressure equipment and processes increased also. Adaptation of existing circulating machines to pressure dyeing was accomplished quickly and new

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equipment was also designed for raw-stock, yarns and hosiery. Also, the Burlington beam machine was redesigned for pressure to dye light and medium weight fabrics at elevated temperatures. It has been widely used for dyeing polyester/wool suitings as well as nylon and nylon/wool ski-wear fabrics.

The Barotor, an ingenious idea for handling light weight, delicate fabrics without tension and dyeing at high temperatures under pressure, was announced in 1952. While it produced excellent results, the expense of loading and unloading on the movable bars relegated the machine to operations where it was used solely to correct unlevel dye lots. No machine of this type is in use today.

Early in the 1960's, Burlington Engineering introduced their low pressure (LP) and high pressure (HP) becks. The LP machine, designed for operation up to 220F, was recommended for fabrics of nylon, triacetate, acrylic fibers, wool and blends. The HP unit could be operated at temperatures up to 300F and used for polyester/wool, rayon or cotton blends in a broad range of fabric weights including knit goods. Although the investment is high, the pressure beck is widely used. There are approximately 290 pressure beck machines in the U.S.

Burlington Industries designed the pressure jet machine and Gaston County is building it. Operating up to 300F, the pressure jet is based on the principle of introducing cloth in rope form in a liquid stream enclosed in a pipe. The cloth is propelled by a specially designed Venturi jet, deriving liquid power from a circulating pump. Absence of moving parts makes it feasible to enclose the jet device in a pressure chamber. The rapid movement of dye liquor in the overhead tube and the controlled movement of cloth facilitate good dye distribution through the goods and rapid, even dyeing. The pressure jet is immensely successful because it is used for dyeing polyester double knits. About 240 of these machines are in use in the U.S.

Pressure jigs have also been designed and built in Europe. They are used for dyeing filament nylon and polyester fabrics. To my knowledge, the pressure jig has had very limited application chiefly because of difficulty in sampling and competing processes have been developed, utilizing

new, level dyeing acid colors and improved leveling agents at the boil (10).

### The Thermosol Process

In the search for other means of "opening up" the new synthetic fibers so that dyes could penetrate readily, we discovered the thermosol process (16). The principle is very simple. Nonionic dyes — a grouping that includes disperse dyes, vat dye pigments, azoic pigments, or any other coloring matter without pronounced ionic properties — can penetrate and dye any thermoplastic fiber in which they are soluble. For example, in addition to the most widely known application of disperse dyes on Dacron polyester fiber, the 2:1 premetallized acid dyes can be dyed on nylon, special cationic dyes on Orlon acrylic fiber and soluble vat dyes which are leuco esters, can be dyed on Dacron. Dyes are padded on the fabric which is then dried and exposed to a short heat treatment at a temperature below the softening point of the fiber. On Dacron, using disperse dyes, dyeing is complete in only 60 seconds in dry air, 10 seconds in contact with hot surfaces or about 3 seconds in a very hot infrared heating zone. The diffusion rates of dyes vary in the different substrates such as nylon, polyester, acrylic; also, dyes within any given group will vary in this respect. It was apparent, however, that the process would be most useful for dyeing Dacron polyester fiber because disperse dyes have a high degree of solubility in the fiber and their wetfastness and lightfastness properties in general are very good on this fiber. Likewise, other colorants applied by the thermosol process, such as vat pigments and soluble vat dyes, possess outstanding fastness properties.

In one sense, the thermosol process was developed and demonstrated commercially long before its time. The early laboratory work was carried out by Joseph Gibson (17) during the late 1940's and mill trials were conducted in 1949-1950 on fabrics of filament and spun Dacron and nylon. The real challenge came later when fabric development and market studies of blends containing Dacron and cotton clearly showed that an economical, continuous process for these blends was a "must" if Dacron was to penetrate the huge cotton market.

The tools to accomplish this goal were available — the thermosol method for dyeing the Dacron with disperse dyes and the pad-steam process for dyeing the cotton portion of the blend with vat dyes. Nevertheless, application research and engineering

studies were needed to bring about the final marriage of the two processes in the smooth running operations that we all know today. This was a joint effort of the dyeing and finishing industry and dyes and chemicals manufacturers. Among the problems solved and needs met in this enterprise were the following:

(1) Speck-free vat dye pastes and disperse dye pastes.

(2) Techniques for controlling migration through the use of pad bath additives and infrared predrying.

(3) Development of new disperse dyes having high resistance to sublimation.

(4) Chemical finishing, including durable press, water and oil-repellent finishes, etc.

At the latest count, there are about 70 completely continuous thermosol-pad steam ranges in this country. Additional semi-continuous arrangements involving the two basic elements of the process are utilized.

### Other Important Advances

While we have selected these few areas of activity to illustrate the importance of research and technology to the progress of our industry, recognition must be given to other developments, many of which are perhaps equally important. Some of these are:

- Resin-bonded pigment printing and dyeing systems
- Flash-age printing of vat dyes on drapery and slip cover fabrics
- New sulfur dyes, including the vat-table types
- Fiber-reactive dyes
- Continuous dyeing processes for wool rawstock in the scouring train and in special steamers
- Printing of synthetics by heat transfer from paper
- Continuous dyeing and printing of carpets
- Continuous dyeing of polyester fabrics and film from hot, non-aqueous solutions of dyes
- Chelatable dyes for modified polypropylene
- Pad-steam continuous methods for acrylic fiber tow and stock
- Computer shade matching and instrumental measurement of color
- Polychromatic dyeing process
- Resin finishes for "wash-wear," durable press
- Fluorochemical finishes for stain resistance, oil and water repellency

### Many Challenges Remain

The list is long but still incomplete. There remain, however, several areas where the challenges have been hurled,

and they are waiting for our answers.

The question of solvent dyeing, for instance, brings forth comments running the gamut from "bullish" to "bearish." Many organizations are working on various aspects of solvent dyeing, hoping to convert from aqueous systems to avoid pollution problems as well as to take advantage of possible savings in overall cost. It will take a long time to resolve problems of dye-solvent-fiber relationships, exhaustion properties of dyes and relative costs of solvent versus aqueous dyeing. It is difficult, however, to see how such a goal can be reached without considerably more fundamental research on these problems than is being done at present. In this country, two research programs have been initiated to develop the information vital to this issue. One is at Textile Research Institute and the other at North Carolina State University.

Another challenge is that of satisfying increasing demands for durable fire retardants on all types of wearing apparel, home and public transportation fabrics, etc. Industrial research laboratories are active on this problem but answers are needed urgently. Some progress has been made but performance levels and economics must be improved to satisfy projected needs. Here, again, fundamental research on the basic issues — e.g., the effect of combustion products on the human system — by independent research organizations, such as university doctoral programs, would be most welcome.

Our industry, through the AATCC or independently, should be able to support more research programs in colleges and universities as is done in many European countries. Whereas large textile firms in the U.S. have their own research organizations and modern facilities, many small businesses do not and cannot afford them. Even so, I doubt that fundamental research is carried out even in those large organizations. Our need is for more young people, doctoral candidates and engineers, to become interested in research for the sake of "pushing back the frontiers of science." The place for this is in our graduate degree programs in the colleges and universities.

Obviously I am not the first to suggest this but the challenges of our future are going to be tougher and tougher, so, it seems to me, our best preparation for meeting them is through the research efforts of our new, younger generations. ☺

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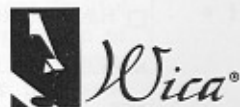
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