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Date: May 31, 1979

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Project No: A-1853-002

Project Director: W. W. Carr

Sponsor: US Department of Energy

Effective Termination Date: 11/30/78

Clearance of Accounting Charges: all clear

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  X Final Fiscal Report
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
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TERMINATED

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Other
ENERGY CONSERVATION IN THE TEXTILE INDUSTRY

Phase I

Submitted by
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and
School of Textile Engineering
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Funded Through
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TABLE OF CONTENTS

I. Executive Summary ........................................... 1

II. Introduction ................................................. 5

III. Research Plan ............................................... 17

IV. Process Investigation Results ................................ 32

Batch:

Atmospheric beck dyeing ........................................ 32
Hosiery dyeing .................................................. 43
Jig dyeing ........................................................ 45
Pressure beck dyeing ........................................... 48
Jet dyeing ........................................................ 52
Package/beam dyeing .......................................... 55
Stock dyeing ..................................................... 59

Continuous:

Slashing (sizing) ............................................... 62
Singeing .......................................................... 64
Preparation Range - Desizing/Scouring/Bleaching ............ 65
Mercerizing ....................................................... 68
Fabric dye range ............................................... 70
Finishing range ................................................ 75
Carpet dye range ............................................... 77
Printing .......................................................... 80
Predrying ........................................................ 85
Tenter frames and dryers ..................................... 89

V. Energy Consumption Profile .................................. 97

VI. Energy Conservation Potential (Estimate) ................. 99

VII. Recommended Research Programs ............................ 100

VIII. Bibliography
LIST OF TABLES

I. Energy Consumption and Conservation Potential 4
II. Fiber Consumption 21
III. Process Production Matrix 29
IV. Dryer Energy Consumption Samples 93
V. Energy Consumption Profile 98
VI. Estimated Energy Conservation Potential 99
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System Heat Balance for Atmospheric Becks</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>Atmospheric Dye Beck</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>Atmospheric Beck Flows</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>Energy Balance in Typical Atmospheric Beck</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>Diagram of Jig Dye Machine</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>Pressure Beck</td>
<td>49</td>
</tr>
<tr>
<td>7</td>
<td>Continuous Dye Range</td>
<td>72</td>
</tr>
<tr>
<td>8</td>
<td>Effect of Predrying and Exhaust Controls and Dyers</td>
<td>91</td>
</tr>
<tr>
<td>9</td>
<td>Energy Balance in Drying and Heat Setting</td>
<td>95</td>
</tr>
<tr>
<td>10</td>
<td>Low Energy Predryer</td>
<td>113</td>
</tr>
</tbody>
</table>
## APPENDICES

<table>
<thead>
<tr>
<th></th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Atmospheric Beck</td>
<td>124</td>
</tr>
<tr>
<td>B</td>
<td>Pressure Beck</td>
<td>130</td>
</tr>
<tr>
<td>C</td>
<td>Jet Dyeing</td>
<td>132</td>
</tr>
<tr>
<td>D</td>
<td>Package Dyeing</td>
<td>138</td>
</tr>
<tr>
<td>E</td>
<td>Slashing</td>
<td>148</td>
</tr>
<tr>
<td>F</td>
<td>Continuous Preparation Range</td>
<td>151</td>
</tr>
<tr>
<td>G</td>
<td>Fabric Dye Range</td>
<td>152</td>
</tr>
<tr>
<td>H</td>
<td>Continuous Finishing Range</td>
<td>153</td>
</tr>
<tr>
<td>J</td>
<td>Carpet Dye Range</td>
<td>155</td>
</tr>
<tr>
<td>K</td>
<td>Dryer Calculations</td>
<td>159</td>
</tr>
</tbody>
</table>
I. EXECUTIVE SUMMARY

The textile industry is a major sector of the United States industrial economy. Although one of the oldest industries, textile processing has exhibited drastic technological changes, progressing from an extremely labor-intensive, production oriented industry to one which is primarily capital-intensive. Added machinery and increased production volume has increased fuel consumption considerably, while employment has stabilized at around one million persons. The competing demands for fuels and chemical feedstocks as well as diminishing supplies has focused attention on energy considerations in the textile industry.

The industry consumed over 67 million barrels of oil equivalent energy in 1971 and is ranked in the top ten in U.S. industrial energy use. The Energy Research and Development Administration has funded the enclosed research by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech to study energy consumed by various processes within the industry. The research is concentrated on the wet processing segment of the industry which previous study had indicated used 60% of the total energy consumed. The approach was to gather process energy consumption data from available literature and selected companies and to develop a production matrix by wet process within the industry. Comparison of process energy consumption with the production matrix then identifies major energy intensive processes. Energy conservation potential of each major process is estimated in order to complete Phase I. In Phase II, equipment and procedure modifications are being developed to demonstrate energy savings. This report completes Phase I and identifies the major
energy consuming wet processes within the industry and estimates their conservation potential.

Plant visits indicated that engineering capabilities were considerably better at large facilities than smaller ones. The small plants are mainly dependent upon natural gas and the majority have only recently experienced significant difficulty in obtaining required supplies. Economies of scale and the declining price of natural gas with volume have also hindered economic implementation of energy conservation engineering at small installations.

Many installations have started comprehensive energy conservation programs. All of the companies were interested in any assistance Georgia Tech could provide. Some of the more attractive concepts detailed in this report have already been implemented by various plants and the technology made available through additional channels for others to consider. The approach taken by Georgia Tech to quantify energy consumption by wet process in Phase I was welcomed by the industry. Unfortunately, energy use data by wet process was generally unavailable or in a form such that different systems could not be accurately compared. Sufficient data was obtained by working closely with individual mills to identify relative energy consumption of major wet processes and to estimate their conservation potential.

The major energy consuming equipment in the industry includes boilers, dryers, climate control systems, and textile fabrication and finishing machinery. Climate control systems and textile fabrication equipment are utilized in dry processing (spinning, knitting, weaving, tufting, etc.) and by their nature, require extensive and costly engineering modifications to
significantly reduce energy consumption. Most of the energy required in
dry processing is in the form of electricity, which also limits energy
conservation potential.

Wet processing of textiles (dyeing, finishing, etc.) on the other hand
utilizes predominately thermal energy. Energy is either transformed and
utilized indirectly as steam (e.g., in heating dye liquors) or utilized
directly by fuel combustion (e.g., in drying operations). Textile wet pro­
cessing plants, influenced by the artificial low price of clean-burning
natural gas, have not developed comparable engineering sophistication to
that found in dry processes.

The data shows that approximately 41 million barrels of oil equivalent
energy (BOE) is consumed by the wet processing segment of the Textile
Industry. An estimated 12.5 million barrels of oil equivalent energy can
be eliminated by conservation via procedural and engineering modifications. Thus
approximately 31% of the wet processing energy and 19% of the total industry
consumption of energy can conceivably be saved by the procedural and engineer­
ing modifications. Wet process energy consumption and conservation potential
are shown in Table I.

The results indicate two major areas where conservation research
should be most productive. Drying, curing, heat setting, and fixation
operations waste the largest amount of energy due to the weight processed
and the required repetition. In Table I, drying operations account for
most of the energy consumed by continuous dye ranges, finishing ranges, and
printing ranges. Atmospheric dye becks and related batch atmospheric equip­
ment consume an inordinate amount of energy due to their design and are
therefore especially suited for conservation research. Accordingly, Georgia
Tech will concentrate research and development efforts in these two areas
during Phase II.
<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Consumption:</th>
<th>Energy Per Cent of Total</th>
<th>Estimated Savings, Application, BOE</th>
<th>Conservation Potential, BOE</th>
<th>Per Cent of Total</th>
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<tr>
<td></td>
<td>Thermal BTU/lb.</td>
<td>Electrical BTU/lb.</td>
<td>Fiber lbs. x 10^6</td>
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<td>Batch</td>
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<td>Carpet</td>
<td>13,300</td>
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<td>Hosiery</td>
<td>23,500</td>
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<td>Pressure Beck</td>
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<td>Jet</td>
<td>9,200</td>
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<td>Package/beam</td>
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<td>Stock</td>
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<td>375</td>
<td>857,000</td>
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<tr>
<td></td>
<td>13,360,000</td>
<td></td>
<td></td>
<td>6,435,000</td>
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| Continuous |                     |                          |                                     |                             |                  |
|            | Slashing            |                          |                                     |                             |                  |
|            | 2,900               | -                        | 3,905                               | 1,900,000                   | 6                |
|            | Singe              |                          |                                     |                             |                  |
|            | 200                 | -                        | 3,717                               | 126,000                     | 1                |
|            | Preparation Range  |                          |                                     | 1,478,000                   | 5                |
|            | Mercerize           |                          |                                     | 1,572,000                   | 5                |
|            | Fabric Dye Range   |                          |                                     | 1,929,000                   | 6                |
|            | Finishing Range    |                          |                                     | 4,612,000                   | 12               |
|            | Carpet Dye Range   |                          |                                     | 826,000                     | 2                |
|            | Printer            |                          |                                     | 1,656,000                   | 5                |
|            | Predryer           |                          |                                     | 3,300                       | 28               |
|            | Infra-red          |                          |                                     | 7,528                       | 3                |
|            | Mechanical         |                          |                                     | 4,895                       | 500              |
|            | Steam Cans         |                          |                                     | 1,222,000                   | 3                |
|            | Dryers             |                          |                                     | 6,331,000                   | 19               |

Sub Total: 22,870,000
Continuous Idle time (.2 x 22,870,000) = 4,574,000

Total: 40,804,000
Conservation Potential = 12,545,000 / 40,804,000 = 31%
II. INTRODUCTION

The textile industry is a major industry in Georgia as well as nationwide. This group is comprised of establishments engaged in:

1. Production of fiber, yarn, thread, braids, twine and cord.
3. Dyeing textile structures.
4. Coating, waterproofing or otherwise finishing textile structures.

The textile industry in the United States employs approximately one million persons and is dependent upon petroleum products and natural gas for process energy. Total energy requirement for the industry is equivalent to 67 million barrels of oil annually (1971 data). Reductions in energy supplied to the textile industry will result in production curtailments, increased costs and subsequent unemployment unless innovative methods for conserving and substituting energy can be found and implemented.

Research Projects A-1853 and E-27-642 are being conducted for the Energy Research and Development Administration pursuant to contract E(40-1)-5099 by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. Process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies are identified in Phase I and are being demonstrated in Phase II. Development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements and dissemination of the research results throughout the industry are addressed by the research. Phase I of the project attains the specific objectives of:
1. Identifying major energy intensive wet processes which may be subject to energy conserving modifications and to determining the energy conservation potential for these process modifications, and

2. Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:

1. Developing and demonstrating, on a pilot or full scale basis, energy conserving modifications for selected processes identified in Phase I.

2. Examining cost-benefit relationships of proposed process modifications, and

3. Disseminating the results of the research to industry.

This report describes the identification and conservation potential of manufacturing wet processes used in the textile industry as the culmination of the Phase I research.

Approximately 60% of the total energy presently used by the textile industry is consumed in wet processing. Wet processes are those in which yarn or fabric is prepared, dyed and finished. Wet processes require thermal energy for heating water, fixing and curing chemicals, and dyeing and heat setting. A large portion of the total wet processing energy is used in boilers to produce steam for dyeing and finishing processes, as well as in some ovens. The hot-air systems utilized in drying and heat-setting processes (250° - 425°F) are basically the same in design and operation, and rely mainly on natural gas as the energy source.
Little coordinated, industry-wide research and development has been undertaken in energy conservation by the textile corporations. Most energy conservation technology development has been implemented in-house. Development of process improvements has been slow due to the fragmented nature of the industry and lack of economic incentives. Energy conservation must be applied by a large number of plants to have a significant affect on energy consumption. Due to the variety of products and processes, however, programs too general in nature cannot be applied directly within specific plants.

Energy consumption was found to vary greatly at different plants producing similar products and even within a given plant for particular arrays of process equipment due to the wide range of process variables. Following the Arab oil embargo of 1973, equipment manufacturers began to address the problem of improving the energy efficiency of new machinery lines. A brief review of some of the more promising advancements by wet processing area follows.
Dyeing

Advancements in dyeing from aqueous solutions have concentrated on lowering liquor ratios, shortening cycle times, recovering waste heat, etc., to conserve energy. From a procedural viewpoint, a method for isothermally dyeing fabric has been developed in which the bath with chemicals, excluding dye, is heated to the dyeing temperature while circulating through the material, followed by rapid and uniform injection of the dye from a pressure injector sluice into the bath. Energy savings are connected with shorter dyeing times and heat requirements without peak demands, giving uniform steam consumption. Research has also been directed toward using chemical rather than thermal means to attain desired product quality at considerably lower energy consumption rates. Lowering consumption by matching shades with specific classes of dyes that require less energy has also been proposed. Utilizing increased automation to improve the reliability factor in first-run dyeings and consequently to decrease energy-consuming reshadings, reworkings, and redyeings has been detailed.

Engineering modifications to reduce energy consumption in aqueous dyeings have outnumbered procedural modifications. Rapid dyeing of polyester in package form at high temperature (> 275°F) during short cycles lowers overall energy requirements. New machines are being equipped with water-to-water heat exchangers that also allow dropping the pressurized baths containing the high quality heat to give further energy savings. Radio frequency (RF) heating of dyebaths has been applied to continuous dyeing of raw stock, resulting in decreased water (liquor ratio of 1:1) and energy consumption over conventional processes. Steam generated by the RF heating of
the padded stock is extracted, recycled, and used to boost drying. Recent jet dyeing machines claim an energy savings of 42% over older models, mainly due to a lower required liquor ratio (1:1.5 - 1:4).6,9 By applying dyes with atomizing nozzles or nozzles directed onto the fabric, followed by thermal fixation and atomizing nozzle washing, a liquor ratio of 1:1.5 - 1:4 is possible with considerable energy savings.9,10

Several devices have been developed to recover process heat from waste water. These range from specially designed shell and tube heat exchangers7,11 to hyperfiltration units.9 The hyperfiltration technique, based on reverse osmosis, allows clean up and recycle of the hot waste water without total loss of the latent heat.12 Capital investment and maintenance costs, however, have detracted from the utility of the hyperfiltration process.12 Waste heat recovery heat pumps amplify the temperature of the heat process fluids from textile plants to temperatures as high as 220°F.14

Solvent dyeing has undergone a rejuvenation in the past few years due to the lower energy requirements over aqueous systems. A European system based on solvation of commercially-available acid dyes by a 90% perchloroethylene-10% methanol solution has gained considerable interest in dyeing of nylon carpets.14 The ionic dyestuffs are insoluble in perchloroethylene but soluble in methanol, as well as in the mixture. When approaching the conclusion of the dye cycle, a pseudo-azeotrophic distillation of the methanol drives the dye onto the fiber, assuring total exhaustion. A 60% reduction in energy over becks is claimed.14 A plant utilizing the new system is being planned for the southeastern United States.15 A solvent dyeing process developed in this country, utilizing as yet undisclosed dyes and solvents, is
adaptable to either fabric or carpet, and is said to require approximately 50% less energy than conventional water-based processes. Solvent dyeing systems should be made more attractive by new solvent recovery units that collect, purify, separate, and recycle solvents ordinarily lost in fumes. Fluorocarbons are now being proposed as textile process solvents. Regulations by OSHA and other regulatory agencies on allowable exposure to various solvents, and especially chlorinated hydrocarbons, may slow down the expansion of solvent-based systems.

The major advancement in printing has been processes based on dye sublimation. The initial process, termed heat transfer printing, is applicable only to 100% polyester fabrics using disperse dyes. The desired pattern is printed on paper with inks containing the sublimable disperse dyes. The pattern is then transferred to the fabric by applying heat and pressure to the back of the paper on contact. Although high temperatures (> 210°C) and pressure (0.5 lbs./in.²) are required for transfer, dwell times are relatively short (30 sec.), and energy savings over conventional pad-fix operations are projected. Recently, wet heat transfer printing has expanded the sublimation technique to other conventional textile fibers and dye classes. The fabric is coated (padded) with an emulsion on entering the machine. The fabric is then fed to a steam-heated calender for contact with the printed paper, with transfer effected at 100°C-105°C under high pressure (8-10 lbs./in.²).

Some effort has been made by synthetic fiber producers to alter polymer properties to facilitate lower energy consumption and reduced pollution from wet processing. A new generation polyester, dyeable in all colors with no
added dye carrier on conventional atmospheric equipment, has been intro-
duced. The new fiber also allows increased dyeing speeds, particularly on
continuous dyeing equipment.

Alternate energy sources are also being proposed. A solar heating
system to supply hot water at 190°F to an atmospheric dye beck is being
constructed on a demonstration basis, with operation and evaluation ex-
pected to begin in 1978. Solar energy does not appear to be economically
feasible as a high-temperature process heat source in the near future,
however.

One problem in the industry has been the lack of fast, efficient
methods to monitor the fluid and gas flows and pressures necessary to
derive energy balances and hence provide data for necessary energy manage-
ment. A venturi-portable computing flow monitor system has been developed.
The versatile system provides useful data (total flows, flow rate, peak flow
and time, minimum flow and time, and pressure) for special projects and periodic
checks on fuel consumption of various machines. The system can meter any
liquid or gas.

Preparation

In aqueous, continuous preparation of fabrics, the main energy loss is
in the J-box steamings and in washing. A patent that eliminates one of the
J-box steamings in a typical desize-scour-bleach preparation line by sub-
stituting chemical energy for thermal energy has appeared. The process
involves dampening the fibers with an aqueous alkaline hydrogen peroxide
solution containing a peroxypophosphate followed by a single J-box steaming.
Combination desizing, scouring and bleaching is claimed for the process. A
new generation of aqueous fabric washers, giving fine detail to increases in liquor turbulence and optimizing counterflow, have appeared. Several of these washers have incorporated suction drums and jet spray-suction combinations to increase washing action while decreasing energy consumption. More energy-efficient washers have also been developed for fabrics wound on beams and for carpets.

Due to reasons detailed previously for solvent dyeing, solvent preparation processes have also staged a recovery. A continuous solvent scouring machine based on perchloroethylene guarantees solvent losses not to exceed 3% per year. Solvent slashing, in which all or most of the ingredients and solvents are reclaimed for reuse, has been introduced.

In another new development, radiation energy has been substituted for thermal energy in bleaching. The process, covering both continuous and discontinuous bleaching, entails using chlorite activated by high energy irradiation (2-40 M rad) in the presence of water at pH 9-11 at or below room temperature.

Finishing

Procedural modifications in finishing to conserve energy have mainly been directed toward substituting chemical energy for thermal energy. Acrylic emulsions containing chemical additives that allow cure at room temperature have been introduced. These room temperature cured emulsions are a significant energy improvement over traditional emulsions that require 100°C-120°C for development. Metal-based catalysts have been used to speed up low-temperature curing of permanent press resins on fabrics, allowing complete by-pass of the tenter frames. In a different approach, govern-
ment researchers have developed an improved method of padding on finishes requiring no cure in a continuous operation that results in a 10-60% decrease in water uptake during impregnation, thus lowering drying energy requirements.\textsuperscript{31} Electrochemical grafting of polymers to textiles to provide chemical attachment of a wide variety of fire retardants, water repellants, and other finishes is under investigation.\textsuperscript{22}

Substituting other more energy-efficient types of radiation for thermal energy in curing and fixation processes is being proposed.\textsuperscript{32,33} Electron radiation processes have demonstrated savings in coating applications, and are being researched for other textile finishing processes.\textsuperscript{32,34} Initial capital investment and cost of development of radiation-curable chemicals appear to be the major disadvantages. In a curing process not involving drying, however, energy costs are claimed to be essentially eliminated by a switch to radiation.\textsuperscript{32} Microwaves, long in use for rapid drying of paper print,\textsuperscript{35} have more recently been proposed for rapid, uniform, and efficient heating of textiles.\textsuperscript{33} A closely-related development has been that of dielectric heating of textiles.\textsuperscript{36}

The majority of research in saving energy in finishing has been directed toward improving the performance of predryers and recovering heat from exhaust stacks of ovens and tenter frames. Typical infrared predryers, which require a phase change to eliminate enough water to lower the moisture content of fabrics entering high-temperature ovens to less than the desired 30% level, are only about 10% efficient.\textsuperscript{37} These infrared predryers traditionally operate on natural gas. Improvement has been made by enclosing cup-shaped, ceramic radiant burner assemblies.\textsuperscript{38} Newer systems have been based on electricity rather than gas. High-speed radiant heaters consisting of
broad ribbons of thin metal foil mounted on a panel of refractory board are now being marketed. Current passes through the foil and heats it to a temperature of 1500°F. Radiant heat generated by electricity and emitted through flat quartz plates has offered another potentially effective method of producing textile finishing energy. Ultraviolet dryers have been applied to screen printing of paper, and may be applicable to some forms of textiles. Although vacuum extraction of water from textiles is not a recently developed concept, new vacuum roll extractors offer more efficient predrying than vacuum slot machines or squeeze rolls. Avoiding a phase change, the energy-efficient vacuum roll extractor is claimed to have a short payback period mainly due to energy savings. The process works best on hydrophobic fabrics such as 100% polyester, and to date the moisture removal from cotton/polyester blends at less than typical sheeting mill production speeds is not sufficient for industrial application in this area (approximately 60% moisture remaining). A recent predryer innovation is the application of sonic and supersonic vapor flows to fabrics to create an extremely high flow of steam (usual) or air through the structure. Water and other residuals trapped in the yarns are literally "blown" out of the textile. Residual moisture after treatment is impressive, e.g., 20-40% for polyester/cotton. Mechanical squeezing of water from fabrics via rolls has been improved by introduction of a fiber-filled roll that absorbs moisture and compresses simultaneously, whereas traditional rubber-covered rolls displace but do not absorb. Due to extraction improvements of up to 35%, auxiliary predrying equipment such as steam cans can be reduced or eliminated by incorporation of the filled rolls.
Air-to-air heat exchangers for recovering oven and tenter exhaust energy have been widely employed including fin and tube types and heat wheels. These traditional systems have encountered frequent fouling problems, especially in plants in which an excessive volume of high-boiling volatiles are produced in finishing. Even minor fouling can drastically reduce the efficiency of air-to-air heat exchangers. Several methods have been devised to circumvent the volatiles problem. Incineration systems which burn the exhaust gases and recover the heat as recycled make-up air or as an energy source for heating water or air by exchange have been introduced. Catalytic incineration has been introduced as a method of directly reusing tenter air by chemical oxidation at lower temperatures \((260^\circ C-350^\circ C)\) than the unassisted incineration systems detailed above \((650^\circ C-900^\circ C)\). Supported platinum is the usual catalyst employed. Air-to-water exchangers that incorporate precipitators to minimize fouling have also utilized hot oven exhausts. Incoming water at \(60^\circ F\) has been heated to \(140^\circ F\) by a \(450^\circ F\) oven exhaust stream. A novel innovation makes use of heat pipe technology, developed during the space program, to recover about \(70\%\) of the energy from textile hot air exhausts. One textile firm has adopted an air-to-oil-to-water bi-exchange process from the chemical processing industry to eliminate volatiles. The tenter exhausts are passed through cool, cascading oil, which absorbs most of the heat as well as the high-boiling chemicals. The hot oil passes over exchange coils containing incoming process water, and is then recycled. As the oil volume gradually increases with time due to the absorbed volatiles, the excess is drained off, mixed with fuel oil, and the mixture is burned in the plant's boilers to close the loop of the process.

-15-
Entirely new sources of heat for drying and curing textiles have been recently introduced. Closed thermal fluid systems, in which hot oil (or other heavy fluid) transfers its heat to the textile before being re-heated, is claimed to reduce fuel costs by 300% compared to steam fired ovens in curing of carpet underlay. The thermal fluid avoids the phase change necessary in steam operations, and eliminates the need for water-softening treatments inherent with steam.

One problem in energy management of textile finishing operations has been the inability to monitor moisture content of a moving fabric before and after the oven. A nuclear technique employing a low energy radioactive source which provides photon emission and a detector circuit to measure the quantity of backscatter can measure fabric weight (and hence indirectly moisture content) to ± 1% accuracy. A continuous scanner-computer system also shows promise of alleviating the water-monitoring problem. The fabric is scanned by basic weight and moisture sensors every ten seconds as it traverses the range, the measurements fed to a minicomputer, and the computer calculates the exact weight per unit area based on the dry fabric. The computer makes automatic adjustments to the feed speed mechanism to attain the desired moisture content of the exiting fabric.
III. RESEARCH PLAN

Energy Use Data

The proposed approach was to gather process energy consumption data from available literature and selected companies and to develop a matrix of relative utilization of each process within the industry. Comparison of process consumption with the matrix would then identify major energy intensive processes. Additionally, the energy conservation potential for each process would be estimated.

After an extensive literature search and several plant visits, it became apparent that the proposed approach would not yield the desired results due to the lack of detailed process energy consumption data. Therefore, more plant visits than anticipated were scheduled in an effort to generate original or unpublished data. The number of samples obtained for each process are less than the amount required to be statistically valid. Also, the results are subject to varying error and should be considered less than absolute. However, relative magnitudes are considered valid and were used to identify those processes where research and development could lead to significant energy conservation in Phase II.

Conditions influencing the estimate of conservation potential are stated where applicable. It should also be noted that the estimates are considered technically possible but do not reflect economic considerations.

The processes themselves were defined by the equipment utilized. For example, dyeing in an atmospheric beck was considered one process although several steps may be included such as bleaching, scouring, etc. Also the individual thermal energy consumption per pound of product (BTU/lb.) was
that actually consumed in the equipment and inefficiencies of conversion were not included. For example, the energy input to an atmospheric beck is hot water and steam. The thermal energy contained in the hot water and steam was considered the thermal consumption for the specific beck process. However, when extrapolating to an industry-wide consumption, conversion inefficiency was included in order to obtain raw fuel requirements. For the beck example, including the conversion inefficiency translates into increased requirements to generate steam from a primary fuel and end-use electricity from a primary fuel. The conversion efficiency employed when converting fuel in a boiler to steam was 78%. Where fuel is directly combusted, no conversion efficiency applies. For electrical conversion, a factor of 11000 BTU/KW-HR was employed to account for power plant and distribution efficiencies.

As investigation into the energy intensive and inefficient processes continues, it is anticipated that additional data will become available. This report will be revised to reflect this data as it becomes available.

Fiber Consumption Data

The processes and equipment required in the dyeing and finishing of textile materials depend on the type fiber being processed (its chemical and physical properties), the form of the fiber (staple, tow, continuous filament), yarn and fabric construction, and the color design and end-use properties required of the finished product. Data which relates the amount of each type of fiber finished and those dyeing and finishing processes used is scarce. The purpose of this section is the specification of those processes used in dyeing and finishing, and the poundage of fiber for each process. With a knowledge of the energy requirements per pound of fiber for
each process, it is possible to pinpoint those processes which are most
intensive in the use of energy. Phase II of this program involves the
development of new and modified processes which are less energy intensive
than those currently used. The total impact of this new technology in
terms of savings in energy can be readily calculated if estimates of the
total poundage of fiber by finishing process is available.

In order to arrive at fiber consumption data broken down according to
end use, fiber type, fabric type and textile dyeing and finishing pro-
cesses, the procedure was as follows:

1. Specification of fiber usage according to fiber type,
fiber form (staple, tow, filament), and fabric type.
2. Identification of major processes used in the dyeing
and finishing of textile materials.
3. Estimation of the poundage of each fiber for each dyeing and
finishing process.

The fiber usage data used in this study is for the year 1973.
Although 1973 was a peak production year, it is considered more typical than
1974 and 1975 for which some end-use data is also available. The fiber
consumption data for 1976 correlates well with that for 1973, whereas 1974
and 1975 were atypical years. The year 1973 was also chosen because data
was available with respect to the textile dyeing and finishing machinery
inplace in 1973 (U.S. Department of Commerce) and not for subsequent years.

The November, 1975 issue of "Textile Organon" includes a survey of the
consumption of textile fibers according to end-use for the year 1973. The

-19-
survey provides a breakdown of man-made fibers between rayon and acetate, and noncellulosic man-made fibers into nylon, polyester, acrylic, and polyolefin fibers. However, domestic shipments of these man-made fibers in 1973 are also given, making possible a breakdown of the end-use fiber consumption data according to each fiber type. Thus, the end-use survey data and domestic shipment data for man-made fibers have been combined to arrive at an end-use survey in which poundages of each fiber, both staple and filament, can be specified according to end-use and fabric type. The results are shown in Table II.

Sources of Information

4. Private Communications - The American Yarn Spinners Association, Inc.
5. Private Communications with Fiber Manufacturers, Carpet Manufacturers and Textile Manufactureres.

Manufactured Weight by Finishing Process

The next step in this work was the identification of those processes which are used in dyeing and finishing. There is no standard set of dyeing and finishing processes which are used for a particular fiber. However,
TABLE II
FIBER CONSUMPTION
YEAR - 1973
(Millions of Pounds)

<table>
<thead>
<tr>
<th>END-USE</th>
<th>NYLON STAPLE-TOW AMT. (%)*</th>
<th>NYLON FILAMENT AMT. (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apparel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>24 3.9</td>
<td>475 30.2</td>
</tr>
<tr>
<td>Broadwoven</td>
<td>19 3.1</td>
<td>47 3.0</td>
</tr>
<tr>
<td>Knit-Circular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hosiery</td>
<td>-</td>
<td>63 4.0</td>
</tr>
<tr>
<td>Half-Hose</td>
<td>-</td>
<td>53 3.4</td>
</tr>
<tr>
<td>Otherweft</td>
<td>-</td>
<td>119 7.6</td>
</tr>
<tr>
<td>Knit-Warp</td>
<td>-</td>
<td>193 12.2</td>
</tr>
<tr>
<td>Other</td>
<td>5 0.8</td>
<td>-</td>
</tr>
<tr>
<td><strong>Home Furnishings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>559 91.0</td>
<td>635 40.3</td>
</tr>
<tr>
<td>Carpets-Rugs</td>
<td>533 86.8</td>
<td>610 38.7</td>
</tr>
<tr>
<td>Upholstery</td>
<td>10 1.6</td>
<td>20 1.3</td>
</tr>
<tr>
<td>Curtains, Draperies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blankets, Bed Spreads</td>
<td>-</td>
<td>5 0.3</td>
</tr>
<tr>
<td>Other</td>
<td>16 2.6</td>
<td>-</td>
</tr>
<tr>
<td><strong>Industrial and Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31 5.1</td>
<td>464 29.5</td>
</tr>
<tr>
<td>Tires</td>
<td>-</td>
<td>274 17.4</td>
</tr>
<tr>
<td>Chafer</td>
<td>-</td>
<td>16 1.0</td>
</tr>
<tr>
<td>Other</td>
<td>31 5.0</td>
<td>174 11.1</td>
</tr>
<tr>
<td><strong>All End-Use</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>614 100.0</td>
<td>1574 100.0</td>
</tr>
</tbody>
</table>

* Based on Total Fiber Consumed
## TABLE II CONTINUED

**FIBER CONSUMPTION**

**YEAR - 1973**

*(Millions of Pounds)*

<table>
<thead>
<tr>
<th>END-USE</th>
<th>ACRYLIC-MODACRYLIC TOW-STAPLE</th>
<th>ACRYLIC-MODACRYLIC FILAMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMT.</td>
<td>(%)</td>
</tr>
<tr>
<td><strong>Apparel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>46.5</td>
<td>65.9</td>
</tr>
<tr>
<td>Broadwoven</td>
<td>20</td>
<td>2.8</td>
</tr>
<tr>
<td>Knit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jersey</td>
<td>98</td>
<td>13.9</td>
</tr>
<tr>
<td>Double</td>
<td>70</td>
<td>9.9</td>
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<tr>
<td>Sweaters</td>
<td>84</td>
<td>11.9</td>
</tr>
<tr>
<td>Pile-Fleece</td>
<td>85</td>
<td>12.1</td>
</tr>
<tr>
<td>Half-Hose</td>
<td>33</td>
<td>4.7</td>
</tr>
<tr>
<td>Hand-Knit Yarns</td>
<td>75</td>
<td>10.6</td>
</tr>
<tr>
<td><strong>Home Furnishings</strong></td>
<td><strong>Total</strong></td>
<td>233</td>
</tr>
<tr>
<td>Carpets-Rugs</td>
<td>169</td>
<td>24.0</td>
</tr>
<tr>
<td>Blankets</td>
<td>42</td>
<td>6.0</td>
</tr>
<tr>
<td>Draperies-Upholstery</td>
<td>Curtains</td>
<td>16</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Industrial and Other</strong></td>
<td><strong>Total</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>All End-Uses</strong></td>
<td><strong>Grand Total</strong></td>
<td>705</td>
</tr>
</tbody>
</table>

* Based on Total Fiber Consumed
TABLE II CONTINUED

FIBER CONSUMPTION

YEAR - 1973

(Millions of Pounds)

<table>
<thead>
<tr>
<th>END-USE</th>
<th></th>
<th>POLYESTER TOW-STAPLE</th>
<th>POLYESTER FILAMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AMT.</td>
<td>(%)*</td>
</tr>
<tr>
<td>Apparel</td>
<td>Total</td>
<td>903</td>
<td>58.7</td>
</tr>
<tr>
<td></td>
<td>Broadwoven</td>
<td>705</td>
<td>45.8</td>
</tr>
<tr>
<td></td>
<td>Circular Knits</td>
<td>171</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>Warp Knits</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sweaters-Hand</td>
<td>8</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Knit Yarns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pile Fleece</td>
<td>16</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Half Hose</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Home Furnishings</td>
<td>Total</td>
<td>561</td>
<td>36.5</td>
</tr>
<tr>
<td></td>
<td>Carpets-Rugs</td>
<td>185</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Blankets</td>
<td>10</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Fiber Fill</td>
<td>135</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>Broadwoven</td>
<td>189</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>(Sheets-Pillowcases)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Draperies - Upholstery Etc.</td>
<td>29</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>13</td>
<td>0.3</td>
</tr>
<tr>
<td>Industrial</td>
<td>Total</td>
<td>74</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Tires</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Miscellaneous Other</td>
<td>74</td>
<td>4.8</td>
</tr>
<tr>
<td>All End-Use</td>
<td>Grand Total</td>
<td>1548</td>
<td>100.0</td>
</tr>
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* Based on Total Fiber Consumed
<table>
<thead>
<tr>
<th>END-USE</th>
<th>RAYON TOW-STAPLE AMT. (%)</th>
<th>RAYON FILAMENT AMT. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparel and Home Furnishings Total</td>
<td>615.3 86.7</td>
<td>65 33.0</td>
</tr>
<tr>
<td>Apparel and Home Furnishings Broadwoven</td>
<td>382.7 53.9</td>
<td>51 25.9</td>
</tr>
<tr>
<td>Apparel and Home Furnishings Knits</td>
<td>16.1 2.3</td>
<td>14 7.1</td>
</tr>
<tr>
<td>Apparel and Home Furnishings Nonwoven</td>
<td>186.7 26.3</td>
<td>- -</td>
</tr>
<tr>
<td>Apparel and Home Furnishings Carpets</td>
<td>21.1 3.0</td>
<td>- -</td>
</tr>
<tr>
<td>Apparel and Home Furnishings Craft Yarns</td>
<td>7.7 1.1</td>
<td>- -</td>
</tr>
<tr>
<td>Apparel and Home Furnishings Blankets</td>
<td>1.0 0.1</td>
<td>- -</td>
</tr>
<tr>
<td>Industrial Total</td>
<td>0 0</td>
<td>120 60.9</td>
</tr>
<tr>
<td>Industrial Narrow Woven</td>
<td>- -</td>
<td>10 5.1</td>
</tr>
<tr>
<td>Industrial Tires (Chafer)</td>
<td>- -</td>
<td>83 42.1</td>
</tr>
<tr>
<td>Industrial Other Rubber Industrial</td>
<td>- -</td>
<td>27 13.7</td>
</tr>
<tr>
<td>Other Total</td>
<td>94.2 13.3</td>
<td>12 6.1</td>
</tr>
<tr>
<td>All End-Uses Grand Total</td>
<td>709.5 100.0</td>
<td>197 100.0</td>
</tr>
</tbody>
</table>

* Based on Total Fiber Consumed
TABLE II CONTINUED

FIBER CONSUMPTION

YEAR - 1973

(Millions of Pounds)

<table>
<thead>
<tr>
<th>END-USE</th>
<th>ACETATE-STAPLE-TOW AMT.</th>
<th>ACETATE FILAMENT AMT.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)*</td>
<td>(%)*</td>
</tr>
<tr>
<td><strong>Apparel and Home Furnishings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>369.5</td>
</tr>
<tr>
<td>Broadwoven</td>
<td>-</td>
<td>166.7</td>
</tr>
<tr>
<td>Knits-Circular and Flat</td>
<td>-</td>
<td>202.8</td>
</tr>
<tr>
<td><strong>Industrial</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>10.5</td>
</tr>
<tr>
<td>Narrow Woven</td>
<td>-</td>
<td>10.5</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>12.3</td>
</tr>
<tr>
<td><strong>All End-Uses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>0</td>
<td>392.3</td>
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</tbody>
</table>

* Based on Total Fiber Consumed
<table>
<thead>
<tr>
<th>END-USE</th>
<th>COTTON AMT. (%)</th>
<th>WOOL AMT. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apparel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1609</td>
<td>122.2</td>
</tr>
<tr>
<td>Suits, Coats, Slacks (M)</td>
<td>317</td>
<td>25</td>
</tr>
<tr>
<td>Suits, Coats, Slacks (W)</td>
<td>186</td>
<td>55</td>
</tr>
<tr>
<td>Dresses, Playsuits (W)</td>
<td>105</td>
<td>8</td>
</tr>
<tr>
<td>Recreational</td>
<td>44</td>
<td>4</td>
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<tr>
<td>Work - Utility</td>
<td>140</td>
<td>-</td>
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<tr>
<td>Shirts (M)</td>
<td>185</td>
<td>-</td>
</tr>
<tr>
<td>Blouses</td>
<td>72</td>
<td>-</td>
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<tr>
<td>Underwear (M)</td>
<td>223</td>
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<tr>
<td>Underwear (W)</td>
<td>81</td>
<td>-</td>
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<tr>
<td>Apparel Lining</td>
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<td>-</td>
</tr>
<tr>
<td>Sweaters</td>
<td></td>
<td>20.0</td>
</tr>
<tr>
<td>Other</td>
<td>162</td>
<td>10.2</td>
</tr>
</tbody>
</table>

| **Home Furnishings**        |                |               |
| Total                       | 1109           | 50.2          |
| Bedspreads, Quilts          | 97             | -             |
| Sheets - Other Bedding      | 302            | -             |
| Towels                      | 315            | -             |
| Blankets                    | -              | 3.3           |
| Draperies - Upholstery      | 281            | 3.8           |
| Carpets - Rugs              | -              | 43.1          |
| Other                       | 114            | -             |

| **Other Consumer Products** |                |               |
| Total                       | 393            | 16.3          |
| Retail Piece Goods          | 137            | 5.0           |
| Narrow Fabrics              | 88             | 2.2           |
| Shoes - Slippers            | 54             | -             |
| Medical - Surgical - Sanitary | 83        | -             |
| Craft and Handwork Yarns    |                | 11.0          |
| Other                       | 31             | 0.3           |

(continued on the next page)

* Based on Total Fiber Consumed
TABLE II CONTINUED

FIBER CONSUMPTION

YEAR - 1973

(Millions of Pounds)

<table>
<thead>
<tr>
<th>END-USE</th>
<th>COTTON AMT. (%)*</th>
<th>WOOL AMT. (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>461</td>
<td>8.0 4.0</td>
</tr>
<tr>
<td>Transportation Fabric</td>
<td>62 1.6</td>
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<tr>
<td>Sewing Thread</td>
<td>83 2.2</td>
<td>-</td>
</tr>
<tr>
<td>Rope - Cordage</td>
<td>39 1.1</td>
<td>-</td>
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<tr>
<td>Coated Fabric</td>
<td>76 2.0</td>
<td>-</td>
</tr>
<tr>
<td>Felts</td>
<td>- 8.7 3.9</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>201 5.3 0.2</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Export</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>221 5.8 24.6 11.1</td>
<td></td>
</tr>
<tr>
<td>Woven and Knits</td>
<td>199 5.2 1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Yarn - Thread</td>
<td>- 23.5 10.6</td>
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<tr>
<td>Other</td>
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<td><strong>All End-Uses</strong></td>
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<tr>
<td>Grand Total</td>
<td>3793 100.0</td>
<td>222.2 100.0</td>
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</table>

* Based on Total Fiber Consumed
if the fabric construction, color design, and end-use properties in the finished product are specified, there are preferred dyeing and finishing processes for that product. The variety of fabric constructions, color designs, and end-use properties which are required is responsible for such a variety of processes in dyeing and finishing. It would be a formidable task to determine quantitatively the poundage of each fiber for each process with the very limited information available. Therefore, an attempt has been made to obtain the best estimates possible for the poundage of fiber by each dyeing and finishing process. These estimates are derived from a variety of sources including discussions with textile manufacturers, fiber producers, the U. S. Census Bureau, the American Textile Manufacturers Institute, the American Yarn Spinners Association, Inc. and the investigators' experience.

Table III details wet processing data for the fiber consumption data shown in Table II, with the omission of those data for fibers which do not require textile dyeing and finishing. In compiling this table, glass fiber, polypropylene fiber, jute and hemp have not been included even though very small amounts of these fibers are subject to textile finishing. Estimates of the poundage of each fiber by fabric type and dyeing and finishing process were made and tabulated.

Explanatory Notes for Table III

1. Yarn dyeing versus fabric dyeing

The color design of some fabrics, i.e., plaids and stripes, requires that the fibers be dyed either as stock or yarn. It is estimated that approximately 10 per cent of all spun yarns
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used in knits are package dyed. This percentage has been used in estimating the poundage of fiber packaged dyed with the remaining fiber being dyed in the piece or printed. This estimate of 10 per cent of package dyed fiber has also been applied to spun yarn used for woven fabric.

2. Breakdown of fiber dyed in atmospheric becks, pressure becks, and jet dyeing machines

Estimates of this breakdown were based on considerations of the numbers of these machines in place in 1973 and knowledge gained in visits to many dyeing and finishing plants.

3. Processes used for carpets

The data presented was compiled by a major fiber producer.

4. Fiber blends

The assumption was made that approximately 90 per cent of all staple polyester in knits is in the form of a blend with cotton. For broadwovens, the staple polyester will primarily be in blends with cotton with some rayon and wool blends included.

Legend

A. S,T - staple and tow respectively
   F - filament
B. Predry

IR - infra-red

M - mechanical (includes vacuum and centrifugal)

C - steamcans

C. Drying

Amount of fiber which must be dried, but not including the drying inherent in a given continuous process. For example, the drying of batch dyed fiber is a separate process and is included in this column.

D. Preparation

Included here are the poundages of fiber for prepared in processes and machinery which are separate and distinct from the processes of dyeing. For example, the continuous preparation processes and equipment for woven cotton and cotton/polyester blends is separate and distinct from the dyeing and/or printing process. On the other hand, polyester knits which are to be beck dyed can be scoured in the same machine in which the dyeing is made.

E. Fabric Finishing - Other

This column includes a unique process associated with carpets, namely, the application of a secondary backing to the carpet.
IV. PROCESS INVESTIGATION RESULTS

The following were identified as the major processes within the wet processing segment of the textile industry. Data relevant to energy consumption was obtained from both published and unpublished sources as well as from measurements conducted during plant visits. The processes are segregated into batch and continuous processes. Where calculations were necessary to determine energy consumption and waste, a sample method was summarized in an appendix.

Atmospheric Dye Becks

Atmospheric dye becks (kettles) are common in the textile industry. The operation is fairly simple. Fabric to be dyed is placed in a large vessel containing water, to which the dye and any supplemental chemicals are added. Generally, the dyes require temperatures near the boiling point of water for fixation. Water is normally heated by direct injection (sparging) of steam into the vessel. An energy schematic for the complete system is illustrated in Figure 2. The type material, color and type dye determines the time held at elevated temperatures.

Figure 3 illustrates an atmospheric dye beck used in batch dyeing. A composite energy system with the flows indicated associated with atmospheric dye becks is shown in Figure 4. Refer to Appendix A for typical energy balance calculations.

Conclusions from field measurements and energy balance calculations shown in Table I are summarized on the following page and illustrated in Figure 5.
Energy Consumption—Atmospheric Dye Becks

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<th>Application</th>
<th>Energy In</th>
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<td>Electric KW-hrs./lbs.</td>
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<td>1. Carpet</td>
<td>.03</td>
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<tr>
<td>2. Fabric</td>
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</table>

Some generalizations apply to the above results. Electrical energy consumption is not only proportionately small but is constant and cannot be significantly reduced. Other than reducing exhaust fan power for thermal reasons, potential savings of electrical energy are not considered sufficient to justify further investigation.

The amount of thermal energy, consumed in the form of hot water and steam, can vary widely in any specific atmospheric dye beck cycle due to a number of variables. In general, energy consumption is proportional to the following:

- Dye liquor/fabric ratio
- Hold time at dye fixation temperatures
- Number of adds and redyes
- Type of material being dyed
- Class of dye used

The total textile production utilizing atmospheric becks is separated into carpet or fabric since longer cycle times are experienced in dyeing fabric. In addition, scouring, bleaching, and extra rinsing are included in the fabric batch runs. Of the 1610 million pounds of product, 605 million pounds are carpet and 1005 million pounds are fabric.
System Heat Balance for Atmospheric Becks
Atmospheric Dye Beck

Figure 2
Figure 3: Atmospheric Beck Flows

- Ambient Water
- Ambient Air
- Steam 100%
- Heated Water 49%
- Heated Air Steam 49%
- Loss Exhausted to Atmosphere 45% to 60% Proportional to Boil Cycle Time
- Loss to Drain 40% to 55% Proportional to Liquor Ratio
- Other Losses 2%
ENERGY BALANCE IN TYPICAL ATMOSPHERIC BECK

IN | OUT
---|---

Thermal 1

Electric (Nil)

Friction (Nil)

Radiation Convection

Exhaust

Fabric (Nil)

Water

Figure 4
Thermal Energy Consumption:

Carpet:

\[
\frac{(605 \times 10^6 \text{ pounds carpet}) \times (10,400 \text{ BTU/lb})}{0.78} = 8.07 \times 10^{12} \text{ BTU}
\]

\[
\frac{8.07 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1.37 \times 10^6 \text{ BOE}
\]

Fabric:

\[
\frac{(1005 \times 10^6 \text{ pounds fabric}) \times (18,350 \text{ BTU/lb})}{0.78} = 2.36 \times 10^{13} \text{ BTU}
\]

\[
\frac{2.36 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 4.02 \times 10^6 \text{ BOE}
\]

Total: 1.37 \times 10^6 \text{ BOE} + 4.02 \times 10^6 \text{ BOE} = 5,390,000 \text{ BOE}

Electrical Energy Consumption:

Carpet:

\[
(0.03 \text{ KW-Hrs}) \times (11000 \text{ BTU/lb. \ KW-HR}) = 330 \text{ BTU/lb.}
\]

\[
(330 \text{ BTU/lb.}) \times (605 \times 10^6) = 1.99 \times 10^{11} \text{ BTU}
\]

\[
\frac{1.99 \times 10^{11}}{5.88 \times 10^6 \text{ BTU/Barrel}} = 3.39 \times 10^4 \text{ barrels}
\]

Fabric:

Fabric electrical requirement assumed equal to 600 BTU/lb. due to longer cycle times.
(600 BTU/lb.) (1005 x 10^6 lb.) = 6.03 x 10^{11} BTU

\[
\frac{6.03 \times 10^{11} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1.02 \times 10^5 \text{ BOE}
\]

Total: \(1.02 \times 10^5 \text{ BOE} + 3.39 \times 10^4 \text{ BOE} = 1.36 \times 10^5 \text{ BOE}\)

Total Energy Consumption:

\[
1.36 \times 10^5 \text{ BOE} + 5.39 \times 10^5 \text{ BOE} = 5.52 \times 10^6 \text{ BOE}
\]

Conservation Estimate:

An estimate of efficiency for this process is based upon the following considerations:

- All energy exhausted to atmosphere is wasted energy not necessary for the process.
- All recovered energy cannot be utilized in the beck process with existing dye procedures.

Energy consumption can be reduced by:

- Lowering liquor ratio
- Eliminating (reducing) exhaust
  - Better heat transfer from steam to water (temperature gradients)
  - Blocking raw steam escape path (cover)
  - Fan (remove or reduce)
  - Doors (avoid heating air and reduce convection losses)
  - Desuperheating steam prior to sparging
  - Better controls
- Recovery of heat in waste water

- New Procedures
  . Modify dye procedures to reuse hot water
  . Foam dyeing
  . Solvent dyeing
  . Low temperature dyeing
  . Standing dye bath
  . Reducing the number of adds and redyes

Due to present dyeing procedures and practical limitations upon obtaining all benefits, it is estimated that 50% near term reduction in thermal energy consumption is practical with minimal research and development into equipment modification. Near term conservation estimate is, therefore, 2.74 x 10^6 barrels of oil equivalent. Additionally, if a procedural change such as the standing dye bath (refer to section VII) technique is applied to atmospheric beck processing, 70% of the water now requiring heat-up and maintenance of temperature could be eliminated, thereby allowing an additional 70% thermal energy reduction. A longer range implementation of both equipment and process could then effect the following energy savings:

Equipment Modification:

\[(0.50) (1.37 \times 10^6 \text{ BOE}) = 6.86 \times 10^5 \text{ BOE}\]

Process Modification:

\[(0.70) (6.86 \times 10^5) = 4.80 \times 10^5 \text{ BOE}\]
Total Energy Savings:

\[ 6.86 \times 10^5 \text{ BOE} + 4.80 \times 10^5 \text{ BOE} = 1.17 \times 10^6 \text{ BOE} \]

Due to technical and economical limitations it is estimated that only approximately 80% of the textile industry utilizing this process would implement both types of modifications. Therefore, an industry-wide savings would result in:

\[ (0.80)(1.17 \times 10^6 \text{ BOE}) = 9.33 \times 10^5 \text{ BOE} \]

Likewise, in the fabric processing, a standing dye bath could be applied to achieve an additional 70% thermal reduction. Long range implementation of both equipment and process modification would then approximate the following energy savings:

**Equipment Modification:**

\[ (0.50)(4.12 \times 10^6 \text{ BOE}) = 2.06 \times 10^6 \text{ BOE} \]

**Process Modification:**

\[ (0.70)(2.06 \times 10^6 \text{ BOE}) = 1.44 \times 10^6 \text{ BOE} \]

**Total Energy Savings:**

\[ (2.06 \times 10^6 \text{ BOE}) + (1.44 \times 10^6 \text{ BOE}) = 3.50 \times 10^6 \text{ BOE} \]

However, as in the carpet process, certain technical and economical limitations are imposed on firms and, therefore, it is estimated that 60% of textile firms utilizing this process could feasibly implement these two processes. Applying this on an industry-wide basis:
(.60) (3.50 x 10^6 BOE) = 2.01 x 10^6 BOE

Combining the carpet and fabric process a total energy savings is estimated at:

(2.01 x 10^6 BOE) + (9.33 x 10^5 BOE) = 3.03 x 10^6 BOE
Hosiery Dyeing Machines

The most common hosiery dyeing machine employed in the U. S. is the overhead paddle. The operation of the machine and the concept is similar to a beck. The machine relies on a paddle that contacts the water surface for circulation of the hosiery. Curved walls of the tank deflect the flow imparted by the steam injection. The paddle machines generally are not covered, and thus heat losses are similar to the beck.

Ladies' nylon hosiery are sometimes dyed in a rotating drum machine to minimize plucking of the fine-denier yarns. The goods are packed into a smooth perforated drum which rotates freely in a shell casing. The drum rotation direction alternates automatically. The machine has steam escape ports so that atmospheric conditions are maintained. Ladies' hosiery can also be dyed in paddle machines by placing them in mesh bags for protection.

Present developments have introduced pressure hosiery dyeing machines that can reach 140°C and also continuous dyeing and finishing systems. These methods have not been heavily utilized by U. S. industry, however.

Because of the similarities for hosiery dyeing and atmospheric beck fabric dyeing, the same energy consumption found for atmospheric beck dyeing of fabrics will be applied.

Thermal Energy Consumption:

\[
\frac{18,350 \text{ BTU/lb.}}{0.78} \left(465 \times 10^6 \text{ lbs.} \right) = 1.09 \times 10^{13} \text{ BTU}
\]

\[
\frac{1.09 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1.86 \times 10^6 \text{ BOE}
\]
Electrical Energy Consumption:

\[(600 \text{ BTU/lb.}) (465 \times 10^6 \text{ lb.}) = 2.79 \times 10^{11} \text{ BTU}\]

\[\frac{2.79 \times 10^{11} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 47,000 \text{ BOE}\]

Total: \[1,860,000 \text{ BOE} + 47,000 \text{ BOE} = 1,907,000 \text{ BOE}\]

Conservation Estimate:

Assuming a 50% savings due to the same equipment modifications as for atmospheric becks used in fabric dyeing, results as follows:

\[\frac{(18,350 \text{ BTU/lb.}) (.5)}{.78} = 11,700 \text{ BTU/lb.}\]

Applying an application factor of 60%:

\[(11,700 \text{ BTU/lb.}) (465 \times 10^6 \text{ lbs.}) (.60) = 3.26 \times 10^{12} \text{ BTU}\]

\[\frac{3.26 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 555,000 \text{ BOE}\]
Jig Dyeing

The basic machine is illustrated in Figure 5. The open-width material is wound above a shallow trough filled with dye liquor. The rollers pull the cloth through the dye liquor in automatically altering directions, with guide rollers at the tank bottom insuring immersion. An exceedingly low liquor ratio is required, as only a few yards of a material are immersed at a time. Consequently, since the water volume per unit of goods is much lower than in becks, the energy consumption is correspondingly lower. The basic concepts of the atmospheric jig, however, are the same as the beck (steam injection, temperatures, evaporative losses, etc.). The jig has traditionally been used for cotton and acetate fabrics because the dyes utilized in these cases do not exhaust well. The trend to polyester/cotton blends dyed on continuous ranges has sharply reduced jig dyeing of cotton, and acetate has remained a low-volume fiber (see Table III). High-pressure jigs have been introduced for dyeing mainly polyester above 100°C, but these have not made sharp inroads into the American textile market.

Since jig dyeing data was unavailable during Phase I of this project, sample calculations were obtained from the Shirly Institute Publication 513.

Thermal Energy Consumption:

\[
\frac{(2100 \text{ BTU/lb.}) \times (448 \times 10^6 \text{ lbs.})}{.78} = 1.21 \times 10^{12} \text{ BTU}
\]

Electric Energy Consumption:

\[
\frac{(200 \text{ BTU/lb.}) \times (448 \times 10^6 \text{ lbs.})}{.3} = 2.99 \times 10^{11} \text{ BTU}
\]
Total: \( 1.21 \times 10^{12} \text{ BTU} + 2.99 \times 10^{11} \text{ BTU} = 1.51 \times 10^{12} \text{ BTU} \)

\[
\frac{1.51 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 257,000 \text{ BOE}
\]

Conservation Estimate:

It is estimated that approximately 1000 BTU/lb. can be saved in the jig dyeing process with the same considerations delineated in atmospheric becks.

\[
(1000 \text{ BTU/lb.}) (448 \times 10^6 \text{ lbs.}) = 4.48 \times 10^{11} \text{ BTU}
\]

\[
\frac{4.48 \times 10^{11} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 76,000 \text{ BOE}
\]

However, economic and technical factors will allow only an estimated 60% of those firms utilizing this process to feasibly implement these measures. Therefore, industry wide savings would result as follows:

\[
(.60) (76,000 \text{ BOE}) = 46,000 \text{ BOE}
\]
Pressure Dye Becks

Pressure dye becks are another type of batch dyeing process. A schematic of the basic pressure beck is shown in Figure 6. They can be simply characterized as enclosed atmospheric becks which can withstand pressure up to approximately 50 psig. However, pressure becks differ from atmospheric becks in several aspects. First, the high pressure capability dictates a closed vessel with no vapor exhaust vent. Secondly, heat transfer to the bath is accomplished indirectly through a heat exchanger rather than from direct steam sparging into the dye liquor. Therefore, increased use of electrical energy is required for water circulation.

The following summarizes the energy consumption data from a sample pressure beck and includes the effect of different shades and complete procedures. Refer to Appendix B for sample calculations.

<table>
<thead>
<tr>
<th>Shade</th>
<th>Electrical, KW-Hrs./lb</th>
<th>Thermal, BTU/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>.05</td>
<td>5,300 (Includes prescour)</td>
</tr>
<tr>
<td>Medium</td>
<td>.06</td>
<td>4,600 (No Scour)</td>
</tr>
<tr>
<td>Dark</td>
<td>.07</td>
<td>5,700 (Includes afterscour)</td>
</tr>
<tr>
<td>Average</td>
<td>.06</td>
<td>5,000 (Refer to Appendix B)</td>
</tr>
</tbody>
</table>
Figure 6
Pressure Beck

OVERHEAD SPRAY LINE

OVERFLOW DRAIN

HEAT EXCHANGER

CENTRIFUGAL PUMP

WATER FILL LINE

DRAIN
Thermal Energy Consumption:

\[
\frac{(534 \times 10^6 \text{ lbs.}) \times (5,000 \text{ BTU/lb})}{.78} = 3.42 \times 10^{12} \text{ BTU}
\]

Electrical Energy Consumption:

Per pound: \((.06)(11,000) = 660 \text{ BTU/lb}\)

\[
(.06 \text{ KW-HRS/lb}) (534 \times 10^6 \text{ lb.}) \times (11,000 \text{ BTU/KW-HR}) = 3.52 \times 10^{11} \text{ BTU}
\]

Total:

\[
3.42 \times 10^{12} + 3.52 \times 10^{11} = 3.77 \times 10^{12} \text{ BTU}
\]

\[
\frac{3.77 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 641,000 \text{ BOE}
\]

Conservation estimates:

Energy conservation potential due to equipment modification is considered minimal with this process. By reducing liquor ratios and insulating to reduce radiation and convection losses, it is estimated that 10% of present thermal requirements can be saved.

\[
\frac{(5000 \text{ BTU/lb.}) \times (.10) (534 \times 10^6 \text{ lbs.})}{(.78) (5.88 \times 10^6 \text{ BTU/barrel})} = 58,000 \text{ BOE}
\]

As for the atmospheric beck process, an additional 70% can be saved if research into procedural changes are successful. However, due to economic and technical limitations it is estimated that approximately 60% of those firms utilizing this process can feasibly implement these changes. Therefore, the following industry-wide savings would result:
(641,000 BOE - 58,000 BOE) (.70) (.60) = 245,000 BOE

Total: 58,000 BOE + 245,000 BOE = 303,000 BOE
Jet Dyeing

Batch jet dyeing machines were developed to meet the rising demand for dyeing double-knit fabrics made from 100% texturized polyester yarns. Carrier spotting and creasing of this fabric in atmospheric or pressure becks were the major problems responsible for the development of jet systems.

In the jet dyeing machine, a portion of the dye liquor which is under pressure is withdrawn from the bath and recycled by passing through a Venturi tube. The liquor is discharged from the tube as a confined stream moving in a closed, curved path. The fabric, entered in rope form as an endless loop, is introduced into the center of the moving liquid stream so that the momentum of the stream alone propels the fabric, discharges it into the dyebath, and circulates it through. The movement of the fabric by jet streams rather than mechanical means reduces substantially the lengthwise tension of the fabric associated with beck dyeing.

Jet dyeing machines are of the partially-flooded and fully flooded types. The partially-flooded machines require lower liquor ratios, and hence require less hot water but suffer from dyebath foaming and tangling problems. The fully-flooded machines overcome the foaming problems and further reduce lengthwise tension, but require high liquor ratios and create fabric feed problems. Efforts are underway to overcome most of these problems on both types of machines.

Jet dyeing machines are closed, pressurized systems with heat transfer accomplished through a heat exchanger like a pressure beck. Energy losses are, therefore, mainly due to radiation and drain losses. With the high velocity jet streams, the pumps of a jet dyeing machine consume considerable quantities of electricity in comparison to other fabric dyeing processes.
The following summary presents the energy consumption of a jet dyeing machine based on averaged data from different color production runs, one measured run, and machine specifications. Sample calculations are detailed in Appendix C.

Energy Consumption--Jet Dyeing

<table>
<thead>
<tr>
<th>Electrical</th>
<th>Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>.08 KW-HR/\text{lb}_F</td>
<td>7200 BTU/\text{lb}_F</td>
</tr>
</tbody>
</table>

Thermal Energy Consumption:

\[
\frac{(7200 \text{ BTU/\text{lb}})(431 \times 10^6 \text{ lbs.)}}{.78} = 3.99 \times 10^{12} \text{ BTU}
\]

Electrical Energy Consumption:

\[
\left(0.08 \frac{\text{KW-HR}}{\text{lb}}\right) \left(11,000 \frac{\text{BTU}}{\text{KW-HR}}\right) = 880 \text{ BTU/\text{lb}}
\]

\[
\left(880 \frac{\text{BTU}}{\text{lb}}\right) \left(396 \times 10^6 \text{ lbs.}\right) = 3.48 \times 10^{11} \text{ BTU}
\]

Total:

\[
3.99 \times 10^{12} + 3.48 \times 10^{11} = 4.34 \times 10^{12} \text{ BTU}
\]

\[
\frac{4.34 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 738,000 \text{ BOE}
\]

Conservation Estimate:

Since heat recovery from drain water is presently being accomplished,
insulation is considered the only modification practical to effect energy conservation. Potential savings are approximately 13% of thermal consumption.

\[
\frac{(13) \times (3.99 \times 10^{12} \text{ BTU})}{5.88 \times 10^6 \text{ BTU/BOE}} = 88,000 \text{ BOE}
\]

Assuming that the proposed dyebath reuse research is successful, an additional 70% can be conserved. Applying this to 60 of the industry, the following industry-wide savings can be achieved:

\[
(738,000 \text{ BOE} - 88,000 \text{ BOE}) \times 0.70 \times 0.60 = 273,000 \text{ BOE}
\]

\[
88,000 \text{ BOE} + 273,000 \text{ BOE} = 361,000 \text{ BOE}
\]
Package and Beam Dyeing

Textile styles often require that fabrics be woven or knitted from colored yarns. This procedure allows patterns and effects not obtainable by traditional textile printing operations on broad-woven fabrics. Both staple fiber yarns and continuous-filament yarns may be dyed before fabric formation. A recent upsurge in package yarn dyeing has resulted from the rapid growth of colored, 100% textured polyester yarns used in patterned knit fabrics. Beam machines can be used to dye both fabric and yarn.

Conceptually, yarn packaged and beam dyeing are themselves similar and both are somewhat related to pressure beck and pressure jet dyeing. In package dyeing, the yarns are wound onto a stainless steel perforated cylinder or spring to form the package. The packages are placed in a machine, which is fitted with an open circulation system to insure constant flow of liquor from the main kier (vessel containing the packages) into a small open expansion vessel. The liquor can then be returned to the kier at the same rate. The expansion vessel allows for the increase in volume when the dyebath is placed under pressure at temperatures above $212^\circ F$ and also provides a convenient point at which chemical additions to the dye liquor may be made at any time or temperature. Practically all yarn packages are dyed today under high temperature and pressure. The liquor is alternately pumped through the perforated tube or spring form of the package and from the outside of the package by way of a reversing valve.

Beam dyeing of yarn is identical to package dyeing except that the yarn is wound on a large cylinder (beam) instead of on separate small packages. The operating conditions of high temperature and pressure are the same as in package dyeing.
Energy considerations for pressure package and pressure beam dyeing of yarn are similar to those for pressure becks and jets. If the machine is sealed well, the vast majority of energy is lost primarily to the drains and secondarily to radiation from the beck walls.

Fabrics (mainly knits) are sometimes dyed on beams. Such fabric dyeing systems are often atmospheric in nature, and thus energy use is similar to that for atmospheric dye becks. The beam machine may be pressurized with the cloth rolled on a perforated, hollow cylinder and held stationary in any enclosed chamber at above $212^\circ F$. The liquor is pumped radially through the beam, normally from inside to outside, but the flow may be reversed as in the typical yarn package dyeing machine.

The calculations in Appendix D indicate a high energy consumption per pound of yarn processed even though the equipment utilized is similar to pressure becks. Examination of the dye cycle explains the discrepancy. Process steps other than dyeing are included in the dye cycle. Specifically, additional rinses, scouring, and running washes are performed with the running washes being especially energy intensive. The following summarizes the energy consumption from various package dyeing procedures.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td>8,900</td>
<td>.10</td>
</tr>
<tr>
<td>Fiber Reactive</td>
<td>23,200</td>
<td></td>
</tr>
<tr>
<td>Blend 41 Bleach</td>
<td>26,000</td>
<td></td>
</tr>
<tr>
<td>Napthol</td>
<td>34,100</td>
<td></td>
</tr>
<tr>
<td>Disperse</td>
<td>19,000</td>
<td></td>
</tr>
<tr>
<td>38 Bleach</td>
<td>33,000</td>
<td></td>
</tr>
<tr>
<td>41 Bleach</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>Vat</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td>Weighted average:</td>
<td>22,420</td>
<td>.10</td>
</tr>
</tbody>
</table>
### Dye Procedure

<table>
<thead>
<tr>
<th></th>
<th>Thermal, BTU/lb.</th>
<th>Electrical, KW-HRS/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Sample 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bleach</strong></td>
<td>6,320</td>
<td>.12</td>
</tr>
<tr>
<td><strong>Direct</strong></td>
<td>2,205</td>
<td>.06</td>
</tr>
<tr>
<td><strong>Vat</strong></td>
<td>3,985</td>
<td>.11</td>
</tr>
<tr>
<td><strong>Naphthol</strong></td>
<td>4,753</td>
<td>.16</td>
</tr>
<tr>
<td><strong>Sulphur</strong></td>
<td>7,301</td>
<td>.12</td>
</tr>
<tr>
<td><strong>Fiber Reactive</strong></td>
<td>6,185</td>
<td>.11</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>5,125</td>
<td>.113</td>
</tr>
</tbody>
</table>

**Sample 3:**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cecoilan</strong></td>
<td>14,000</td>
<td>.27</td>
</tr>
<tr>
<td><strong>Nylon Stable</strong></td>
<td>12,600</td>
<td>.13</td>
</tr>
<tr>
<td><strong>Nylon Filament</strong></td>
<td>12,600</td>
<td>.13</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>13,100</td>
<td>.18</td>
</tr>
</tbody>
</table>

Sample 1 does not decrease energy requirements from heat recovery since at the time the data was received heat recovery equipment was not installed. Appendix D calculations indicate a theoretical requirement of 5,713 BTU/lb. if maximum recovery were utilized. Since this number is close to the Sample 2 average of 5,125 BTU/lb., it is assumed that Sample 2 included heat recovery. However, the amount of heat recovery on an industry-wide basis is unknown, so a straight average will be used as the process requirement. This assumes one-half are utilizing heat recovery equipment.

\[
\frac{22,420 + 5,125 + 13,100}{3} = \frac{40,644}{3} = 13,500 \text{ BTU/lb.}
\]

\[
\frac{.10 + .113 + .18}{3} = \frac{.383}{3} = .131 \text{ KW-HRS/lb.}
\]
Thermal Energy Consumption:

\[
\frac{(1,018 \times 10^6 \text{ lbs.}) (13,500 \frac{\text{BTU}}{\text{lb.}})}{.78} = 1.76 \times 10^{13} \text{ BTU}
\]

Electrical Energy Consumption:

Per Pound: \( (.18 \frac{\text{KW-HRS}}{\text{lb.}}) (11,000 \frac{\text{BTU}}{\text{KW-HR}}) = 1,980 \frac{\text{BTU}}{\text{lb.}} \)

\[
(1,018 \times 10^6 \text{ lbs.}) (1,980 \frac{\text{BTU}}{\text{lb.}}) = 2.02 \times 10^{12} \text{ BTU}
\]

Total:

\[
1.76 \times 10^{13} + 2.02 \times 10^{12} = 1.96 \times 10^{13} \text{ BTU}
\]

\[
\frac{1.96 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 3.34 \times 10^6 \text{ BOE}
\]

Conservation estimate:

From Appendix D, 75% reduction can be accomplished with heat recovery. However, it is estimated that 75% are presently utilizing recovered heat. Therefore, potential savings = \[
\frac{(.75) (.25) (13,500 \frac{\text{BTU}}{\text{lb.}}) (1018 \times 10^6 \text{ lb.})}{(5.88 \times 10^6) (.78)}
\]

\[
= 562,000 \text{ BOE}
\]

An additional 70% can be saved through implementation of the proposed dyebath reuse research if successful. Applying this to 60% of the industry the following energy savings will result:

\[
(3.34 \times 10^6 \text{ BOE} - 562,000 \text{ BOE}) (.70) (.60) = 1.17 \times 10^6 \text{ BOE}
\]

Total: \[
1.17 \times 10^6 \text{ BOE} + 562,000 \text{ BOE} = 1.73 \times 10^6 \text{ BOE}
\]
Stock Dyeing

Stock dyeing is the coloration of fibers that are still in the randomized (unoriented) state. The process is used mainly in this country for dyeing acrylic fibers though wool is also often dyed in this manner. The loose stock machine is similar to the package dyeing machine in concept, being presurized with forced circulation of the dye liquor in alternating direction. The overall utilization of stock machines in the U. S. today is relatively low. The following summary was derived from James Farrow's report "Energy Consumed in Various Textile Processes." Energy requirements for the drying of fibers dyed by this method are excluded here and included under the dryer section.

Energy Consumption--Stock Dyeing, BTU/lb.

<table>
<thead>
<tr>
<th>Type Dye</th>
<th>Thermal</th>
<th>Electrical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>3,271</td>
<td>586</td>
<td>3,857</td>
</tr>
<tr>
<td>Vat</td>
<td>5,660</td>
<td>672</td>
<td>6,332</td>
</tr>
<tr>
<td>Naphthol</td>
<td>7,154</td>
<td>798</td>
<td>7,952</td>
</tr>
<tr>
<td>Premetallized</td>
<td>4,018</td>
<td>428</td>
<td>4,446</td>
</tr>
<tr>
<td>Basic</td>
<td>7,035</td>
<td>700</td>
<td>7,735</td>
</tr>
<tr>
<td>Average</td>
<td>5,428</td>
<td>637</td>
<td>6,064</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylan</td>
<td>11,200</td>
<td>.13</td>
</tr>
<tr>
<td>Nylon</td>
<td>15,500</td>
<td>.27</td>
</tr>
<tr>
<td>Average</td>
<td>13,300</td>
<td>.20</td>
</tr>
</tbody>
</table>

Thermal Energy Average:

\[
\frac{13,300 + 5,428}{2} = 9,364 \text{ BTU/lb.}
\]
Electrical Energy Average:

\[
(.20 \text{ KW-HRS/lb.}) (11,000 \frac{\text{BTU}}{\text{KW-HR}}) = 220 \text{ BTU/lb.}
\]

\[
\frac{(637 + 220)}{2} = 428 \text{ BTU/lb.}
\]

Thermal Energy Consumption:

\[
(9,364 \text{ BTU/lb.}) (375 \times 10^6 \text{ lb.}) = 4.50 \times 10^{12} \text{ BTU}
\]

Electric Energy Consumption:

\[
\frac{(428 \text{ BTU/lb.}) (375 \times 10^6 \text{ lb.})}{.3 (\% \text{ conversion efficiency})} = .54 \times 10^{12} \text{ BTU}
\]

Total Energy Consumption:

\[
(4.50 \times 10^{12}) + (.54 \times 10^{12}) = 5.04 \times 10^{12} \text{ BTU}
\]

\[
\frac{5.04 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/barrel}} = 857,000 \text{ BOE}
\]

Conservation Potential:

Assuming heat recovery from this process is common to the industry (as in this sample), conservation is considered limited to reducing radiation losses and reducing the liquor ratio. Therefore, conservation potential is estimated at 10% of the thermal energy requirement.

\[
(.10) (857,000 \text{ BOE}) = 86,000 \text{ BOE}
\]
Assuming success of the proposed dyebath reuse research an additional 70% can be saved in 60% of the industry. This would, result in the following energy savings:

\[(857,000 \text{ BOE} - 86,000 \text{ BOE}) \times 0.70 \times 0.60 = 324,000 \text{ BOE}\]

Total: \[324,000 \text{ BOE} + 86,000 \text{ BOE} = 410,000 \text{ BOE}\]
Slashing (Sizing)

In the weaving operation, the warp yarns are subjected to considerable abrasion and, therefore, must be protected in some way to minimize yarn damage and ultimately yarn breakage. The amount of protection required depends on the fiber used, the yarn construction and the mechanical action to which the yarn is subjected during the weaving operation. To protect the warp yarns, they are given a protective coating. The process of coating the yarns is known as sizing. In the sizing process the warp yarns are impregnated by passing through a hot aqueous bath containing the sizing materials followed by drying. The yarns are dried by passing the impregnated yarns over steam-heated drying cans.

The composition of the size mix is determined by the fiber content of the yarns, their construction, and the mechanical action to which they are subjected in weaving. All sizes are based on polymeric materials (usually starch or polyvinyl alcohol (PVA)). Other additives to the size mix include materials which modify the mechanical properties of the protective film, materials which modify the viscosity of the size mix, surface active materials, defoaming agents, deliquescent, lubricants and preservatives. After application of the size, the excess water must be removed and the yarns separated.

The energy required in sizing is primarily that required to prepare the aqueous size mix and maintain its temperature at some constant value under atmospheric conditions. However, the largest requirement is from the subsequent drying which will be included here as part of the slashing process. These calculations are detailed in Appendix E.
Thermal Energy Consumption:

\[
(3,905 \times 10^6 \text{lbs.}) \cdot (2,230 \text{ BTU/lb.}) \cdot \frac{.78}{1.12} = 1.12 \times 10^{13} \text{ BTU}
\]

Electrical Energy Consumption:

considered nil

Total:

\[
\frac{1.12 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1,900,000 \text{ BOE}
\]

Conservation Estimate:

Since the largest energy requirement in sizing is the drying operation and since can dryers are usually employed (which is an efficient drying method), it is estimated that only an insignificant reduction in energy requirements can be achieved.
Singeing

Fabrics made from spun yarns (staple fiber) have short hairs projecting from their surface which must be removed if a smooth surface appearance of the fabric is desired. This is accomplished by a process known as singeing. The hairs are removed by passing the fabric through a low-heat gas flame at high rates of speed. Considerable care must be exercised in order to prevent damage to the fabric. The fabric must be uniformly dry prior to singeing in order to obtain uniform results. Some fabrics are singed on one side only and some are singed on both sides. Immediately following the singeing operation, the fabric must be quenched in water to prevent possible flaming. The quench bath may also contain the chemicals necessary for the next operation, namely the desizing process.

The near-total energy requirement in the singeing process is natural gas firing of the burners. Measurement data is unavailable at this time but will be included in a later revision to this report if it becomes available. However, it is estimated that singeing requires only about 200 BTU/lb. and that approximately 20% can be saved by matching gas flame width to the fabric width.

Total Energy Consumption:

\[
(200 \text{ BTU/lb.}) \times (3717 \times 10^6) = 7.43 \times 10^{11} \text{ BTU}
\]

\[
\frac{7.43 \times 10^{11} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 126,000 \text{ BOE}
\]

Conservation Estimate:

\[
(.2) (126,000) = 25,000 \text{ BOE}
\]
Continuous Preparation Range

Different preparation processes may be accomplished separately or combined in a continuous range. In this report, desizing, scouring and bleaching constitute the continuous preparation process.

Desizing:

Before the fibers composing the fabric can be purified by scouring and bleaching, it is necessary to remove the size material applied to the warp yarns to protect them during the weaving operation. The chemicals used in desizing as well as the conditions used depend on the chemical composition of the size and its disposition in the fabric, e.g., if PVA is the size, it can be removed by treatment with hot water. Fabrics having a dense construction require more severe conditions than those having a loose construction. The application of the desize solution is accomplished continuously by padding. Padding is followed by batching of the fabric or steaming depending on the composition of the size and the process rate. The fabric is then thoroughly rinsed before moving to the next operation.

With some fabrics the desizing step is not carried out as a separate step, but is accomplished during the later step of scouring. Cotton and cotton/polyester woven fabrics, however, are invariably desized prior to scouring.

Sources of energy loss in a desizing apparatus are similar to atmospheric becks, i.e., evaporation to the exhaust, convection and radiation, and hot water to the drains. However, the evaporation losses contained in the exhaust to the atmosphere are of a much lower magnitude than for atmospheric becks.
Bleaching:

Fabrics produced from man-made fibers do not usually require bleaching. When bleaching of synthetics is required it is usually carried out batch-wise. Practically all cotton and cotton/polyester woven fabrics are bleached. Both batch and continuous processes are used; however, overwhelmingly the most common process used is continuous. The common bleaching agents for cotton are hydrogen peroxide and sodium hypochlorite. The bleaching process with hydrogen peroxide is essentially the same as that described previously for continuous scouring. The desized, scoured fabric is first impregnated with the hot bleaching solution containing hydrogen peroxide, sodium silicate, caustic soda, surfactant, and chelating agents. The impregnated fabric then passes to a steamer (usually a J-box). The fabric is steamed in the J-box for 30 to 60 minutes after which it is thoroughly washed and dried. The fabric speed through the bleaching process is 100 to 200 yards per minute, the speed being determined primarily by the fabric weight.

Sources of energy loss in continuous bleaching is the same as in continuous scouring. The bleaching process using hypochlorite requires much less energy than the hydrogen peroxide process since the bleaching temperature should not be allowed to exceed 140°F. This process can also be carried out batch-wise or continuously. Following the bleaching step, the fabric must be "soured" (treatment with acid) and "antichlored" (treatment with reducing agent such as sodium bisulfite) to destroy the remaining bleaching agent. The bleached fabric is then neutralized, washed thoroughly, and dried.
Thermal Energy Consumption:

\[(2111 \text{ BTU/lb.})(3863 \times 10^6 \text{ lbs.}) = 8.10 \times 10^{12} \text{ BTU}\]

\[
\frac{8.10 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1,380,000 \text{ BOE}
\]

Electrical Energy Consumption:

\[(145 \text{ BTU/lb.})(3207 \times 10^6 \text{ lb.}) = 4.65 \times 10^{11} \text{ BTU}\]

Total:

\[(8.10 \times 10^{12}) + (4.65 \times 10^{11}) = 8.57 \times 10^{12} \text{ BTU}\]

\[
\frac{8.57 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1,457,000 \text{ BOE}
\]

Conservation Estimate:

Most plants visited were recovering energy from the hot wash water. Therefore, only small savings from more efficient equipment substitution appear possible. However, a savings of 1,000 BTU/lb. appears possible if research into a chemical combination of the desizing, scouring, and bleaching operations is successful. Even if viable, the procedural change would only apply to cotton and cotton blends or approximately 45% of the weight of fiber processed.

\[(1000 \text{ BTU/lb.})(3863 \times 10^6 \text{ lbs.})(.45) = 1.74 \times 10^{12} \text{ BTU}\]

\[
\frac{1.74 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 296,000 \text{ BOE}
\]
Mercerization

The process known as mercerization is unique to natural cellulosic fibers, primarily cotton. It is inserted at either of two points in the cleaning operations: between desizing and scouring or between scouring and bleaching. The word mercerization usually refers to a continuous treatment of cotton yarns or fabrics with aqueous solutions of sodium hydroxide (14% - 20% by weight) at room or higher temperature followed by the application of tension and finally the removal by rinsing of the sodium hydroxide with the fabric under tension. The treatment causes the conversion of crystalline forms referred to as Cellulose I to Cellulose II. The cross section of the fiber changes from a rather irregular shape to a near circular shape and the fiber becomes more lustrous. The strength of the yarns is increased and their dyeing behavior is altered. In order to obtain yarns or fabrics with special elastic properties for specific applications such as bandages the mercerization is carried out under slack conditions, i.e., with essentially no tension.

Energy considerations for mercerization involve mainly the hot water used in application of the sodium hydroxide and in the strenuous washings required to completely remove the chemical. The system is atmospheric and thus energy losses are similar to those for other continuous atmospheric equipment.

The following summary was derived from James Farrow's report "Energy Consumed in Various Textile Processes." The data are for open-rope polyester/cotton blend fabric on mercerizer ranges which include mangle, mercerize, and drying segments.
Energy Consumption--Mercerization, BTU/lb.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thermal</th>
<th>Electrical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3300</td>
<td>245</td>
<td>3545</td>
</tr>
<tr>
<td>2</td>
<td>5765</td>
<td>294</td>
<td>6059</td>
</tr>
<tr>
<td>3</td>
<td>6342</td>
<td>204</td>
<td>6546</td>
</tr>
<tr>
<td>Average</td>
<td>5136</td>
<td>248</td>
<td>5384</td>
</tr>
</tbody>
</table>

Thermal Energy Consumption:

\[
(5136 \text{ BTU/lb.}) \cdot (1728 \times 10^6 \text{ lb.}) = 8.88 \times 10^{12} \text{ BTU}
\]

Electric Energy Consumption:

\[
(248 \text{ BTU/lb.}) \cdot (1728 \times 10^6 \text{ lb.}) = 4.29 \times 10^{11} \text{ BTU}
\]

Total Energy Consumption:

\[
(8.88 \times 10^{12}) + (4.29 \times 10^{11}) = 9.31 \times 10^{12} \text{ BTU}
\]

\[
\frac{9.31 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1.572 \times 10^6 \text{ BOE}
\]

Conservation Potential:

Most of the energy requirements are consumed in the drying operation which in this process are usually steam cans. Since steam cans are an inherently efficient thermal drying method, conservation potential in mercerization is considered limited.
Fabric Dye Range

Continuous and semi-continuous processes are inherently more complicated than batch processes. There is no standard operation in the textile industry that can be isolated as an all-encompassing example of a continuous dyeing range. Rather, each plant generally has its own arrangement of the components comprising the continuous dyeing range, depending on the fiber, dye class, and styles being run. All of the processes revolve around the "pad-fix" concept. The dye is padded from a narrow trough that contains a hot, fairly concentrated solution of the necessary chemicals. The cloth is then squeezed to remove excess solution before fixation, and the fabric is also "predried" (moisture reduced to less than 30% by weight).

The "fixation" of the dye is where the majority of the energy is spent in continuous and semi-continuous operations. The fixation may occur in several steps, and heat may be supplied directly by either steam, electricity, or natural gas, with the latter being utilized most often today in the industry due to its price and clean burning characteristics. The sequence of events in fixation can take several paths, depending on the fibers and dye classes involved. Some common sequences are:

- Pad-Batch (semi-continuous)
- Pad-Dry
- Pad-Dry-Bake
- Pad-Dry-Chemical Pad-Steam
- Pad-Dry-Thermofix-Chemical Pad-Steam
The predrying step before high temperature fixation is to prevent dye migration. If the moisture content of the fabric is greater than approximately 30% by weight, the dye will have enough liquid medium to migrate when the fabric abruptly enters the high temperature zone (termed "shocking" the fabric). The migration results mainly in unlevel (spotty and streaky) dyeings. Predrying of fabric is discussed in detail under a separate section.

The common sequences given are the main components of semi-continuous and continuous dyeing systems. Individual plants may have additional components. For example, a large finishing plant in the southeast employs the following total sequence for cotton/polyester blend woven fabrics on one of its dyeing ranges:

feed - dye pad - dry cans - scray - infrared predryer - dry cans -
thermosol (bake) - chemical pad - steam - wash

In a "typical" range illustrated in Figure 7, energy losses occur via radiation from the dry cans, infrared predryers, thermosol and steamer. Hot water in the atmospheric washers and, to a lesser extent, in the impregnation troughs also contributes to energy losses.

The following summarizes the energy consumption from the samples in Appendix G.

| Energy Consumption - Continuous Dye Range, BTU/lb. |
|---------------------------------|---------------------------------|
| Thermal                        | Electrical                     |
| 4400                           | 149                            |

-71-
TYPICAL CONTINUOUS RANGE

Figure 7
Thermal Energy Consumption:

\[(4400 \text{ BTU/lb.})(2493 \times 10^6 \text{ lb.}) = 1.10 \times 10^{13} \text{ BTU}\]

Electrical Energy Consumption:

\[(149 \text{ BTU/lb.})(2493 \times 10^6) = 3.71 \times 10^{11} \text{ BTU}\]

Total:

\[(1.10 \times 10^{13}) + (3.71 \times 10^{11}) = 1.13 \times 10^{13} \text{ BTU}\]

\[
\frac{1.13 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1,929,000 \text{ BOE}
\]

Conservation Estimate:

The following considerations are by William Weygand, Jr. of E. I. DuPont de Nemours and Co., Inc. 55

- 95% of energy consumed in continuous dyeing required to dry the fabric.
- Infrared predryers are inefficient means of removing moisture. 40 lb. air circulation/lb. water evaporated required.
- Infrared units normally remove 25% moisture. Sample data used 55%, thus predryer could use as much as 7.0 \times 10^6 \text{ BTU/HR.}
- Insulation of equipment will result in an energy savings.
- Major savings in energy (49%) is possible by:
  - Counterflow thermosol exhaust.
  - Use predryer exhaust (1% humidity) to make-up in dryers and thermosol units.
- Install 50% heat recovery devices on dryer and thermosol exhausts.
- Use of counterflow heat exchanger on wash boxes.
- Longer range pressure steam development of dye could result in 50% savings by eliminating dryer operation.

Therefore, the following savings are concluded:

\[(.49) (1.10 \times 10^{13} \text{ BTU}) = 5.39 \times 10^{12} \text{ BTU}\]

\[
\frac{5.39 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 917,000 \text{ BOE}
\]

Assuming that 80% of those firms utilizing this process could implement these modifications, the following savings would be achieved:

\[(.80) (917,000 \text{ BOE}) = 734,000 \text{ BOE}\]
Finishing Range

A continuous finishing range is similar to a continuous dye range where most of the energy required is for chemical fixation. The basic difference from a dye range is that a finish chemical (i.e., to effect permanent press characteristics) is applied rather than a dye. A typical equipment arrangement will include, 1) a mangle to squeeze out excess water, 2) a stack of can dryers, 3) a trough to pad on the specified finishing chemicals, 4) a tenter frame dryer, and 5) a curing oven. Energy consumption is calculated in Appendix H and summarized below.

Thermal Energy Consumption:

\[(7,810 \text{ BTU/lb.}) (3,207 \times 10^6 \text{ lb.}) = 2.50 \times 10^{13} \text{ BTU} \]

Electrical Energy Consumption:

\[(660 \text{ BTU/lb.}) (3207 \times 10^6 \text{ lb.}) = 2.12 \times 10^{12} \text{ BTU} \]

Total:

\[(2.50 \times 10^{13}) + (212 \times 10^{12}) = 2.71 \times 10^{13} \text{ BTU} \]

\[\frac{2.71 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 4,620,000 \text{ BOE} \]

Conservation Estimate:

Aside from the energy conserved by "tuning" each dryer, a systems approach to the individual dryer types in the range can be applied. The prepard dryer usually consists of stacks of steam cans. It does not appear that their waste heat can be utilized. However, the predryer is usually
an infrared with hot air exhausted to the atmosphere. The following waste
exhausted from the predryer was measured in the first three samples from
Source 1.

1. \(2.03 \times 10^6 \text{ BTU/lb.} + 359 \text{ BTU/lb.}\)
2. \(3.03 \times 10^6 \text{ BTU/lb.} + 581 \text{ BTU/lb.}\)
3. \(.97 \times 10^6 \text{ BTU/lb.} + 272 \text{ BTU/lb.}\)

Avg. 400 BTU/lb.

If all exhaust from the predryers were ducted to the tenter frame, an average of 400 BTU/lb. or 12% would be saved. In a finishing range where the infrared predryer was ducted to the tenter frame, only 73% and 53% of the energy was required compared to two similar unducted ranges (excluding prepad dryer and curing oven). Considering the entire range, 13% to 30% of the total would be saved from this predryer exhaust rerouting. With all modifications included, it is estimated that thermal energy consumption in a finishing range can be reduced 50% (refer to the section on continuous dye ranges).

\[
\frac{(0.50) (7810 \text{ BTU/lb.}) (3207 \times 10^6 \text{ lbs.})}{(5.88 \times 10^6 \text{ BTU/BOE})} = 2,130,000 \text{ BOE}
\]

Assuming that 80% of those firms utilizing this process can economically implement all modifications, resulting energy savings would be:

\[
(0.80) (2,130,000 \text{ BOE}) = 1,704,000 \text{ BOE}
\]
Carpet Dyeing

In the carpet segment of the textile industry, a common continuous dyeing machine is the Kuster Dye Range. Here, the carpet is processed open-width in long production runs. It first enters a box containing wetting agent and water and continues through a hydraulic squeeze roll which effects uniform wetness. Dye liquor is then cascaded onto the wet-out carpet. The carpet subsequently enters a large steamer at the top and is carried through 20 foot vertical loops by powered rollers. Since the carpet enters cold with 2-3 times dye liquor by weight, gravity induces the dye liquor to run downward in the first pass which levels the color. The additional retention time in the steamer "fixes" the dye to the carpet fiber. It is desirable to maintain a saturated steam environment within the steamer which is obtained by introducing line steam through a water pump in the bottom. As the carpet exits the steamer, it enters a series of wash boxes, continues over a vacuum extractor and enters a dryer.

In the steamer, thermal energy consumption per pound of carpet is proportional to the following:

- weight of carpet
- retention time (line speed)
- presence of superheated steam
- exhaust rate to atmosphere

The following estimates are derived from calculations in Appendix J.
Thermal Energy Consumption:

\[
(9,600 \frac{\text{BTU}}{\text{lb.}}) (357 \times 10^6 \text{ lbs.}) = 3.43 \times 10^{12} \text{ BTU}
\]

Electrical Energy Consumption:

\[
(.12 \frac{\text{KW-HRS}}{\text{lb.}}) (11,000 \frac{\text{BTU}}{\text{KW-HR}}) = 1,300 \frac{\text{BTU}}{\text{lb.}}
\]

\[
(1,300 \frac{\text{BTU}}{\text{lb.}}) (357 \times 10^6 \text{ lbs.}) = 4.64 \times 10^{11} \text{ BTU}
\]

Total:

\[
(4.39 \times 10^{12}) + (4.64 \times 10^{11}) = 3.90 \times 10^{12} \text{ BTU}
\]

\[
\frac{4.86 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 663,000 \text{ BOE}
\]

Conservation Estimate:

An example of potential reduction in steam use was illustrated by one company's experiments. The steamer was being supplied by approximately 51,000 lbs./hr. of steam. Temperature checks indicated that the steamer environment was superheated steam. By making adjustments to insure a saturated steam environment, steam consumption was reduced to approximately 8,000 lbs./hr. A further reduction to about 6,000 lbs./hr. steam use was accomplished by reducing exhaust.

Appendix J delineates measurements in another plant and indicates an average of 9,600 BTU/lb. is required. If all Kuster production could be accomplished with a consumption of 8,000 BTU/lb., the following conservation potential would be realized industry-wide:
\[(357 \times 10^6 \text{ lbs.}) \times (9,600 - 8,000) \text{ \frac{BTU}{lb.}} = 5.712 \times 10^{11} \text{ BTU}\]

\[
\frac{5.712 \times 10^{11} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 97,000 \text{ BOE}
\]

Again, it is anticipated that only 80% of the conservation is applicable industry-wide:

\[(.80) (125,000 \text{ barrels}) = 78,000 \text{ BOE}\]
Printing Range

Printing is a form of continuous, pad-fix dyeing of open-width fabric or carpet. The major difference between printing and pad-fix dyeing is that since a pattern is being developed instead of a solid shade, individual pieces of the pattern with its own particular color must be applied at separate points in the production line. After the complete pattern is applied, the fabric is generally run through a predrying operation followed by a fixation step at high temperatures in either a natural gas or steam-fired oven. Prints currently account for about 25% of the woven goods sold in the apparel market.

In conventional printing, the pattern is generally applied by three means; flat-bed screens, rotary-screens, and engraved copper rollers. The flat-bed screen printing machines are actually semi-continuous with the fabric carried open width on a continuous belt and stopping at each "station" under the flat screen containing the desired segment of the pattern. The screen is then lowered to the fabric, and a rubber squeegee moves the dye paste weftwise across the cloth. The screen is then raised, the fabric moves a set distance to the next station, and the sequence is repeated.

Rotary screen printing machines have the screens formed in a cylindrical shape with the pattern contained on the outside surface. The printing paste is fed to the inside of the rotary screen by pump from an external supply and through the mesh to the fabric. Unlike flat-bed screen printing, the fabric moves continuously without the stop-start sequence, and the rotating screens themselves are sequenced to apply the pattern.
Roller printing with engraved, cylindrical copper rollers is one of the oldest forms of printing. The relevant pattern section is etched into the surface of the rollers. Operation follows the same principles as roller-screen printing with the process being fully continuous.

Recent innovations in conventional printing have been in the area of dye injection of the pattern by needles or thin, high-pressure jet streams. These computer-controlled processes have mainly been adapted to intricate printing operations on carpet and upholstery fabric. After the pattern is injected into the material, fixation is accomplished by the usual high-temperature techniques.

Energy use in conventional printing, as in other continuous dyeing processes, is confined mainly to the fixation step and, to a lesser extent, afterscour operations. Energy in application of the pattern is totally electrical (in moving the fabric, rotating rollers, etc.), and is much lower in total BTU's than the gas or steam heat required for predrying, fixation, and afterscour. A variety of methods have been used to fix the dye, including:

- Baking (dry heat, 320°F - 390°F)
- Pressure steaming (1 - 25 atm)
- High temperature steaming (350°F - 390°F)
- Normal steaming (212°F - 230°F)
- Wet development
- Pad-batch development
- Flash ageing

The last three methods which require little fixation energy were developed for reactive dyes. This dye class, however, requires an especially strenuous afterscour-wash to remove unfixed dye and overall energy consumption is high.
A new form of printing, heat transfer printing, has grown with the increase in 100% polyester knit fabrics in the past few years (reported at about 5-7% of the total print market in 1976 and projected to grow to 20% by 1980). Heat-transfer is a two-step process. The desired pattern is first printed on paper by conventional paper-printing techniques. Dyes used must be disperse dyes that "sublime" (go directly from a solid to a vapor state on heating). The printed paper is then placed in contact with the fabric under heat and pressure. The pattern is transferred by subliming from the paper, condensing on the fiber surface, and subsequently diffusing into the fiber interior. A relatively mild afterwashing is necessary to remove unfixed dye.

From claims made thus far, it appears that heat-transfer printing may have some energy advantages over conventional pad-fix printing operations. Dwell time is especially short, although fairly high temperature and pressures are required for sublimation to occur (normally around 5 psi and greater than 200°C). Disadvantages have been:

1. Limited number of suitable disperse dyes.
2. Only suitable for 100% polyester.
3. Limited use of printed paper, with inherent disposal problems.

More recently, systems employing wet heat transfer techniques have entered the market. These systems allow use of dye classes other than disperse and fibers other than 100% polyester, while maintaining the pressure-temperature transfer capabilities. No definite conclusions as to their widespread acceptance or total energy requirements are available.
The following summarizes energy consumption results from three rotary screen print ranges. The process includes the application of the dye paste, drying and curing.

### Energy Consumption - Rotary Screen Print Range

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thermal</th>
<th>Electrical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,812</td>
<td>236</td>
<td>5,048</td>
</tr>
<tr>
<td>2</td>
<td>15,000</td>
<td>144</td>
<td>15,144</td>
</tr>
<tr>
<td>3</td>
<td>8,225</td>
<td>295</td>
<td>8,520</td>
</tr>
<tr>
<td>Average</td>
<td>9,346</td>
<td>225</td>
<td>9,571</td>
</tr>
</tbody>
</table>

**Thermal Energy Consumption:**

$$(9,346 \text{ BTU/lb.}) (1,018 \times 10^6 \text{ lb.}) = 9.51 \times 10^{12} \text{ BTU}$$

**Electrical Energy Consumption**

$$(225 \text{ BTU/lb.}) (1,018 \times 10^6 \text{ lb.}) = 2.29 \times 10^{11} \text{ BTU}$$

**Total:**

$$(9.51 \times 10^{12}) + (2.29 \times 10^{11}) = 9.74 \times 10^{12} \text{ BTU}$$

$$\frac{9.74 \times 10^{12} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 1,656,000 \text{ BOE}$$

**Conservation Estimate:**

Since the thermal energy requirements are utilized for drying and heat setting, the conservation potential should be the same as for a dryer or...
50%. However, the higher energy consumption when compared to a dryer reflects a sequence of drying steps utilizing different forms of drying. Therefore, it is estimated that the added complexity of a range reduces the conservation potential to 28%.

\[
.28 \times (9,346 \text{ BTU/lb.}) \times (1,018 \times 10^6 \text{ lb.}) = 2.66 \times 10^{12} \text{ BTU}
\]

\[
\frac{2.66 \times 10^{12} \text{ BTU}}{5.88 \times 10^5 \text{ BTU/BOE}} = 453,000 \text{ BOE}
\]
The final process which all textile products generally go through is drying. Drying involves the removal of water from the finished product. The removal of water to an acceptable level requires the use of heat to vaporize the water; however, thermal drying requires over 1,000 BTU per pound of water removed and sizeable quantities of air to transport the water. Drying speed and, therefore, production rate can be increased by mechanical water removal or by preheating the fabric. That portion of the drying process before the fabric is admitted to the tenter frame is classified as predrying.

Predrying can be divided into three main categories:

1. **Infrared**: In this process the fabric is passed in front of a flame to allow the infrared rays to preheat and evaporate some of the water from the fabric.

2. **Mechanical**: Mechanical processes include squeezing and/or vacuum extraction, both of which remove water utilizing mechanical energy.

3. **Steam Cans**: In this process the fabric to be dried is rolled over a series of hot cans. These cans are pressurized with steam and the cold wet fabric is heated on the outside of the can by condensing steam on the inside.

Neither infrared nor mechanical predrying are used to completely dry the fabric. However, steam cans are used both to partially or fully effect drying. Therefore, calculations indicate higher energy consumption for steam cans than for infrared predrying.
The use of either mechanical or thermal energy in removing water from fabrics depends on cost and the desired water content of the material. In many instances, mechanical methods precede steam cans with both preceding the tenter frame. It has been estimated that mechanical water removal requires only approximately 3% of the energy required to force removal by a change of phase. However, water removal by mechanical means is limited to that water not bound chemically to the fibers and is hindered by excessive surface tension forces. The following are examples of energy consumption in various predrying systems.

**Infrared Predryer**

Given: 3,562 pounds processed in one hour
32 x 10 BTU consumed per hour
42.9% initial moisture
24.9% final moisture

lbs. of water evaporated:

\[
3,562 \text{ lb./hr.} \times (42.9\% - 24.9\%) = 641.3 \text{ lb}_w/\text{hr.}
\]

BTU per pound processed:

\[
\frac{3.2 \times 10 \text{ BTU/hr.}}{3,562 \text{ lb./hr.}} = 900 \text{ BTU/lb}_F
\]

**Mechanical Extraction**

**Squeezing/Mangle**

Given: 1,950 lbs. processed in one hour. Initial moisture content of 100%, 4,800 yd² processed in one hour. Final moisture content of 80%. 5 H.P. motor.

5 H.P. - HRS (.7457 KW/HP) = 3.73 KW-HRS

\[
\frac{3.73 \text{ KW-HRS}}{1950 \text{ lbs.}} = 0.0019 \frac{\text{KW-HRS}}{\text{lb.}}
\]
Given: 1,650 pounds processed in one hour. Initial moisture content of 100% 4,800 yd² processed in one hour. Final moisture content of 75%. 5 H.P. motor.

From like calculations:

25 BTU/lb F processed

413 lbs. water removed

Vacuum Extraction

Given: 1,950 lbs./hours. Initial moisture content of 100% 4,800 yd² processed in one hour. Final moisture content of 50%. 40 H.P. motor.

(40 H.P. - HRO (.7457 KW/HP) = 29.83 KW-HRS

\[
\frac{29.83 \text{ KW-HRS}}{1,950 \text{ lbs.}} = 0.0153 \frac{\text{KW-HRS}}{\text{lbs.}}
\]

\[
\frac{0.02 \text{ KW-HRS}}{\text{lb.}} \times (11,000 \frac{\text{BTU}}{\text{KW-HR}}) = 168 \text{ BTU/lb}_F \text{ processed}
\]

1,950 (.5) = 975 lbs. of water removed

Given: 1,650 lbs_F processed in one hour. Initial moisture content of 100% 4,800 yd² processed in one hour. Final moisture content 29%. 40 H.P. motor.

From like calculations:

199 BTU/lb_F processed

1,172 lbs. water removed

Steam Can Dryer

Given for a 33-can dryer:

<table>
<thead>
<tr>
<th>Cans:</th>
<th>23&quot; dia. x 44&quot; face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam:</td>
<td>12 PSIG</td>
</tr>
<tr>
<td>Cloth:</td>
<td>36&quot; 80/80 4.00 yds./lb. grey weight</td>
</tr>
<tr>
<td>Entering:</td>
<td>85% H₂O</td>
</tr>
</tbody>
</table>
Speed: 86 ypm
Total Steam: 1,532 lbs./hr.
Radiation: 11 lbs./can/hr. = 363 lbs./hr.

(1,290 lbs. cloth/hr.) (.85) = 1,097 lbs. H₂O/hr.

\[
\frac{1,532}{1,097} = 1.4 \text{ lbs. steam/} \text{lb} \text{ H}_2\text{O} = 1,400 \text{ BTU/} \text{lb} \text{ H}_2\text{O}
\]

\[
\frac{1,532 \text{ lbs./hr.}}{1,290 \text{ lbs./hr.}} (1,000 \text{ BTU/} \text{lb.}) = 1,188 \text{ BTU/} \text{lb F}
\]

Average of three samples from Farrow are as follows:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2,032</td>
<td>38</td>
<td>2,070</td>
</tr>
</tbody>
</table>

The consumption value will be taken as a straight average from the two sources:

\[
\frac{1,188 + 2,032}{2} = 1,610 \text{ BTU/} \text{lb.}
\]
Dryers

Ovens and tenter frames are utilized to remove moisture from the fabric and for heat setting. The wet fabric enters from the left and is dried and heat set before exiting at the right. Most dryers have temperature controllers and exhaust ducts in each of several zones coupled to individual burners. The dryers fall into two main classes according to the internal air circulation configuration. A flow-through dryer forces the hot air through the fabric with its internal fans while an impingement dryer directs high velocity air onto both surfaces of the fabric.

The removal of water from a solid material by raising its temperature is defined as thermal drying. During the drying of any given wet solid material, two fundamental and simultaneous processes occur: heat is transferred to evaporate the liquid and mass is transferred as a liquid or vapor within the solid and as a vapor from the surface. For a fabric, the passage of moisture from the liquid surface to the outside atmosphere can be divided into three stages: (1) between liquid surface and the underside of the fabric, (2) through the fabric, and (3) between the upper surface of the fabric and the free atmosphere. The first stage is diffusion controlled, while the transfer of vapor between the upper surface of the fabric and the external atmosphere is by diffusion assisted by convection to an amount depending on the degree of motion or turbulence of the air. The factors governing the rates of these processes determine the drying rate. The supply of heat to evaporate the liquid in the fabric can be done by conduction (contact), convection (air flow), radiation (infrared), or a combination of
these. Industrial driers differ fundamentally by the methods of heat transfer employed. Regardless of the mode of heat transfer, heat must flow from the outer surface into the interior of the fabric with the single exception of dielectric drying in which high frequency electrical current generates heat internally and produces a higher temperature inside the material than outside.

Since most tenter frames were installed prior to the swift jump in fuel prices, the design criteria was production rate and not energy efficiency. Hence, most existing oven-type dryers achieve production rates by over supplying heating capacity rather than matching production goals and equipment design. Therefore, an inexpensive method to reduce fuel consumption in existing dryers is to tune the dryer for the specific job. One way is to reduce exhaust air flow and force an increase in the tenter frame's humidity ratio. Doing so eliminates the energy required to heat up excess ambient air to dryer exhaust temperature. Unfortunately, the amount of exhaust reduction possible cannot be calculated on a general basis. Oils and resins are evaporated along with water causing varying amounts of smoke. Reducing exhaust increases the tendency of this smoke to blow out the entrance and exit slots which imposes a practical limit on exhaust reduction. Also, a limit is imposed based upon insurance regulations if combustibles are being evaporated. Figure 8 illustrates the savings which can be obtained as the humidity ratio is increased (hot exhaust air flow decreased) and/or increased predrying. Refer to Appendix K for the calculations which generated Figure 8.

Figure 8 also illustrates the amount of energy which can be saved in the dryer by reducing the moisture level of the fabric prior to entering the dryer.
HUMIDITY RATIO IN EXHAUST, lb. H₂O/lb. Dry Air

Effect of Predrying and Exhaust Controls on Dryers

Figure 8
An examination of energy required for this moisture reduction was considered in the section on predryers, after which a systems approach to drying will yield a savings potential.

Examples from sample dryers now installed are included in Table IV. A direct comparison of samples can be misleading without additional process details. For example, rate of drying and heat setting requirements are not addressed in Figure 8.

Some of the criteria which affect energy consumption in drying equipment are as follows:

- Type of circulation—impingement or flow-through
- Density and configuration of product to be dried
- Material composition—hygroscopic or hydroscopic
- Internal air recirculation versus heat transfer rates
- Amount of excess exhaust and flow path (counterflow)
- Required temperature versus rate and heat setting
- Direct or indirect combustion
- Volatiles and insurance regulations
- Condition of insulation and leaks
- Possibility to use or recover exhaust heat
- Amount of idle time

Thermal Energy Consumption:

Table IV summarizes measured values for different continuous dryers, generally of the tenter frame configuration. The average of the samples
<table>
<thead>
<tr>
<th>Sample</th>
<th>Fuel</th>
<th>Fabric Weight lbs./yd.</th>
<th>% Moisture Entering</th>
<th>Highest Exhaust Temp °F</th>
<th>Exhaust Humidity Ratio</th>
<th>Energy Required BTU/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Propane</td>
<td>2.96</td>
<td>129</td>
<td>247</td>
<td>.04</td>
<td>2,690</td>
</tr>
<tr>
<td>1B</td>
<td>Propane</td>
<td>2.76</td>
<td>122</td>
<td>210</td>
<td>.04</td>
<td>2,250</td>
</tr>
<tr>
<td>2A</td>
<td>Steam</td>
<td>2.12</td>
<td>26</td>
<td>254</td>
<td>.015</td>
<td>1,800</td>
</tr>
<tr>
<td>2B</td>
<td>Steam</td>
<td>.534</td>
<td>16 1/2</td>
<td>193</td>
<td>.012</td>
<td>2,880</td>
</tr>
<tr>
<td>3A</td>
<td>Steam</td>
<td>2.19</td>
<td>55</td>
<td>220</td>
<td>.03</td>
<td>1,610</td>
</tr>
<tr>
<td>3B</td>
<td>Steam</td>
<td>.77</td>
<td>30</td>
<td>300</td>
<td>.04</td>
<td>1,075</td>
</tr>
<tr>
<td>4</td>
<td>Propane</td>
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<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Nat. Gas</td>
<td></td>
<td>35</td>
<td>320</td>
<td>.04</td>
<td>1,160</td>
</tr>
<tr>
<td>7</td>
<td>Nat. Gas</td>
<td>.85</td>
<td>77</td>
<td>380</td>
<td>.03</td>
<td>3,150</td>
</tr>
<tr>
<td>8</td>
<td>Nat. Gas</td>
<td>.85</td>
<td>29</td>
<td>350</td>
<td>.03</td>
<td>2,460</td>
</tr>
<tr>
<td>9</td>
<td>Nat. Gas</td>
<td>.64</td>
<td>50</td>
<td>408</td>
<td>NA</td>
<td>1,220</td>
</tr>
<tr>
<td>10</td>
<td>Nat. Gas</td>
<td>.53</td>
<td>50</td>
<td>400</td>
<td>NA</td>
<td>2,750</td>
</tr>
</tbody>
</table>

Average 2,040
investigated equals approximately 2100 BTU/lb. Figure 9 illustrates a typical heat balance for a common tenter frame dryer.

**Electrical Energy Consumption:**

Electric power is required for the drive motors, recirculation fan motors, combustion (inlet) fan motors and exhaust fan motors. For a 60 foot tenter frame, 120 KW will be used as an average value for electrical energy consumption. Assuming an average of 6,000 lbs./hr. production rate yields .02 KW-HRS/lb.

\[
(.02 \text{ KW-HRS/lb.})(11,000 \text{ BTU/KW-HR}) = 220 \text{ BTU/lb.}
\]

**Total Energy Consumption:**

\[
2,040 + 220 = 2,260 \text{ BTU/lb.}
\]

\[
(2,260 \text{ BTU/lb.})(16,471 \times 10^6 \text{ lbs.}) = 3.72 \times 10^{13} \text{ BTU}
\]

\[
\frac{3.72 \times 10^{13} \text{ BTU}}{5.88 \times 10^6 \text{ BTU/BOE}} = 6,331,000 \text{ BOE}
\]

**Conservation Estimate:**

As previously mentioned, energy required for drying can be reduced by better process control and by equipment modifications. Reduction through process control includes the following:

- Scheduling to reduce idle time
- Reduce curing times to minimum
- Avoid overdrying
- Utilize mechanical predrying to the maximum
ENERGY BALANCE IN DRYING
AND
HEAT SETTING

IN | OUT
---|---

- Radiation
- Convection
- Water Vapor
- Air
- Fabric
- Electric
- Velocity Friction
- Thermal
- Electric

Figure 9
Reduction through equipment changes include:

- Controls to reduce exhaust
- Heat recovery

It is estimated that at least 50% of the present thermal energy requirements can be conserved by combinations of better process control and equipment modifications.

\[
\begin{align*}
(0.5) (2,040 \text{ BTU/lb.}) (16,471 x 10^6 \text{ lb.}) &= 1.68 x 10^{13} \text{ BTU} \\
\frac{1.68 x 10^{13} \text{ BTU}}{5.88 x 10^6 \text{ BTU/BOE}} &= 2,856,000 \text{ BOE}
\end{align*}
\]

Applying an 80% application factor yields:

80% of 2,857,000 = 2,286,000 BOE
V. ENERGY CONSUMPTION PROFILE

The energy consumption profile presented in Table V was generated from individual process energy data and the production matrix from Table III. Both thermal and electrical requirements for each process investigated in Section IV are adjusted for conversion efficiencies associated with change in form from raw fuel to end-use requirements.

A conversion efficiency of 78% is applied to the thermal requirements, except when direct combustion is involved. For electrical conversion, a factor of 11,000 BTU/KW-HR was employed to account for power plant and distribution efficiencies.

In addition, an idle factor increases the industry-wide total. According to previous studies, the amount of idle time on a continuous process reduces efficiency. Whereas, this efficiency reduction can be as high as 50%, a 20% increase is considered reasonable when applied to all continuous processes. Ancillary processes necessary to support the processes investigated were not addressed.
### TABLE V

**Energy Consumption Profile**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batch</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Beck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpet</td>
<td>13,300</td>
<td>330</td>
<td>605</td>
<td>1,370,000</td>
<td>3</td>
</tr>
<tr>
<td>Fabric</td>
<td>23,500</td>
<td>600</td>
<td>1,005</td>
<td>4,020,000</td>
<td>10</td>
</tr>
<tr>
<td>Hosiery</td>
<td>23,500</td>
<td>600</td>
<td>465</td>
<td>1,907,000</td>
<td>5</td>
</tr>
<tr>
<td>Jig</td>
<td>2,700</td>
<td>670</td>
<td>448</td>
<td>257,000</td>
<td>1</td>
</tr>
<tr>
<td>Pressure Beck</td>
<td>6,400</td>
<td>660</td>
<td>534</td>
<td>641,000</td>
<td>2</td>
</tr>
<tr>
<td>Jet</td>
<td>9,200</td>
<td>880</td>
<td>431</td>
<td>738,000</td>
<td>2</td>
</tr>
<tr>
<td>Package/beam</td>
<td>17,300</td>
<td>1,980</td>
<td>1,018</td>
<td>3,340,000</td>
<td>8</td>
</tr>
<tr>
<td>Stock</td>
<td>12,000</td>
<td>1,426</td>
<td>375</td>
<td>857,000</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Continuous</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slashing</td>
<td>2,900</td>
<td>–</td>
<td>3,905</td>
<td>1,900,000</td>
<td>6</td>
</tr>
<tr>
<td>Singeing</td>
<td>200</td>
<td>–</td>
<td>3,717</td>
<td>126,000</td>
<td>1</td>
</tr>
<tr>
<td>Preparation Range*</td>
<td>2,100</td>
<td>150</td>
<td>3,863</td>
<td>1,457,000</td>
<td>5</td>
</tr>
<tr>
<td>Mercerization</td>
<td>5,100</td>
<td>250</td>
<td>1,728</td>
<td>1,583,000</td>
<td>5</td>
</tr>
<tr>
<td>Fabric Dye Range</td>
<td>4,400</td>
<td>150</td>
<td>2,493</td>
<td>1,929,000</td>
<td>6</td>
</tr>
<tr>
<td>Finishing Range</td>
<td>7,800</td>
<td>660</td>
<td>3,207</td>
<td>4,620,000</td>
<td>13</td>
</tr>
<tr>
<td>Carpet Dye Range</td>
<td>12,300</td>
<td>1,300</td>
<td>351</td>
<td>663,000</td>
<td>2</td>
</tr>
<tr>
<td>Printing Range</td>
<td>9,300</td>
<td>230</td>
<td>1,018</td>
<td>1,656,000</td>
<td>5</td>
</tr>
<tr>
<td>Predrying</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrared</td>
<td>900</td>
<td>–</td>
<td>7,528</td>
<td>1,152,000</td>
<td>3</td>
</tr>
<tr>
<td>Mechanical</td>
<td>–</td>
<td>200</td>
<td>4,895</td>
<td>166,000</td>
<td>3</td>
</tr>
<tr>
<td>Steam Cans</td>
<td>1,600</td>
<td>–</td>
<td>4,124</td>
<td>1,122,000</td>
<td>3</td>
</tr>
<tr>
<td>Drying</td>
<td>2,100</td>
<td>200</td>
<td>16,471</td>
<td>6,331,000</td>
<td>19</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Idle time (.2 x 22,705,000) =</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4,541,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40,376,000</td>
</tr>
</tbody>
</table>

* Includes desizing, scouring, and bleaching in a single continuous range.
VI. ENERGY CONSERVATION POTENTIAL

The estimates of energy conservation potential for each process extrapolated to an industry-wide basis are presented in Table VI. Economic considerations and lack of data specifying present standard industry practices led to the inclusion of an application factor in deriving a total savings estimate.

<table>
<thead>
<tr>
<th>Process</th>
<th>Savings, BTU/lb.</th>
<th>Fiber Processed Millions of Pounds</th>
<th>Application, %</th>
<th>Energy Saved, BOE of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batch</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Beck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpet</td>
<td>11,300</td>
<td>605</td>
<td>80</td>
<td>930,000</td>
</tr>
<tr>
<td>Fabric</td>
<td>20,000</td>
<td>1,005</td>
<td>60</td>
<td>2,100,000</td>
</tr>
<tr>
<td>Hosiery</td>
<td>11,700</td>
<td>465</td>
<td>60</td>
<td>555,000</td>
</tr>
<tr>
<td>Jig</td>
<td>1,000</td>
<td>448</td>
<td>60</td>
<td>46,000</td>
</tr>
<tr>
<td>Pressure Beck</td>
<td>4,600</td>
<td>534</td>
<td>60</td>
<td>303,000</td>
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<tr>
<td>Jet</td>
<td>6,800</td>
<td>431</td>
<td>60</td>
<td>361,000</td>
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<tr>
<td>Package/beam</td>
<td>12,600</td>
<td>1,018</td>
<td>80</td>
<td>1,730,000</td>
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<td>Stock</td>
<td>8,000</td>
<td>375</td>
<td>80</td>
<td>410,000</td>
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<tr>
<td><strong>Continuous</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Slashing</td>
<td></td>
<td>3,905</td>
<td>NA</td>
<td>-</td>
</tr>
<tr>
<td>Singe</td>
<td>40</td>
<td>3,717</td>
<td>100</td>
<td>25,000</td>
</tr>
<tr>
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<td>NA</td>
<td>296,000</td>
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<tr>
<td>Mercerize</td>
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<td>1,728</td>
<td>NA</td>
<td>-</td>
</tr>
<tr>
<td>Fabric Dye Range</td>
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<td>2,493</td>
<td>80</td>
<td>734,000</td>
</tr>
<tr>
<td>Finishing Range</td>
<td>3,900</td>
<td>3,207</td>
<td>80</td>
<td>1,704,000</td>
</tr>
<tr>
<td>Carpet Dye Range</td>
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<td>357</td>
<td>80</td>
<td>78,000</td>
</tr>
<tr>
<td>Printer</td>
<td>3,300</td>
<td>1,018</td>
<td>28</td>
<td>453,000</td>
</tr>
<tr>
<td>Predryer</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Infrared</td>
<td>500</td>
<td>7,528</td>
<td>80</td>
<td>512,000</td>
</tr>
<tr>
<td>Mechanical</td>
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<td>4,895</td>
<td>NA</td>
<td>-</td>
</tr>
<tr>
<td>Steam Cans</td>
<td></td>
<td>4,124</td>
<td>NA</td>
<td>-</td>
</tr>
<tr>
<td>Dryers</td>
<td>1,100</td>
<td>16,471</td>
<td>80</td>
<td>2,286,000</td>
</tr>
</tbody>
</table>

Total 12,545,000
VII. PROPOSED RESEARCH PROGRAMS

The Phase I results defining wet process energy consumption and potential reduction indicate where research and development should be of most benefit in conserving energy. Batch dyeing and the broader area concerned with drying will, therefore, be the focus of attention in the remaining Phase II effort.

Reuse of the dyebath in atmospheric beck dyeing will be investigated for carpet, hosing, and fabric. Additionally, the feasibility of dyebath reuse in pressure batch dyeing will be investigated for yarn package dyeing. Another process area that will be examined is the improvement and combination of washing, desizing, scouring and bleaching conducted in preparation ranges. Equipment modification efforts will be concentrated on improved predrying, exhaust heat reclamation, and documentation of cost/benefit from several changes to atmospheric becks.

In general, the Georgia Tech School of Textile Engineering will concentrate on procedural changes and new methods while the Georgia Tech Engineering Experiment Station will apply its efforts in the area of equipment modifications and systems approach. Processes are typically treated as separate operating entities. The E.E.S. plans to investigate integration of these processes in order to achieve maximum utilization of heretofore wasted energy from individual systems.

Dyebath Reuse

Phase I has confirmed that batch processes account for a large portion of the materials dyed in this country (see Table III). In the 1973 base year, 5139 million pounds (59% of total textile goods) were dyed on the following batch machines: atmospheric beck, atmospheric jig, pressure package, pressure beck, pressure jet, pressure beam, atmospheric paddle, stock, skein, and space dye machines. Large volume users were the atmospheric beck (1610 M lbs.), atmospheric paddle (465 M lbs.), pressure package (888 M lbs.), pressure beck (534 M lbs.) and pressure jet (431 M). In the atmospheric becks, the main items dyed were carpets (431 M lbs. nylon, 153 M lbs. polyester) and cotton and cotton/polyester.
knit fabric (401 M lbs. total). The atmospheric paddle machine is used almost exclusively for men's and women's hosiery (220 M lbs. of nylon, 117 M lbs. of acrylic-modacrylic, 83 M lbs. of cotton and 45 M lbs. other). In the pressure machinery, the large-volume products dyed on package machines were polyester (174 M lbs. filament, 106 M lbs. staple) and cotton (354 M lbs.). On the pressure becks and pressure jets, the large volume fiber was polyester filament (473 M lbs. on the becks, 238 M lbs. on the jets).

Two basic types of procedures are used for textile coloration -- pad fix (continuous) processes and exhaust (batch) processes. Continuous dyeing is used primarily for long runs of a given fabric style. Due to their continuous nature and the use of relatively small volumes of dye liquor, these processes tend to be more efficient than batch processes. Exhaust processes are generally very inefficient in utilization of chemicals, water and energy and generate large volumes of waste which must be treated. Despite these disadvantages the versatility, ease of control, and short run capability of exhaust processes make them very attractive for coloration of many textile products.

As the Table III data indicates, batch processes are still utilized in large numbers. The future projections by the DuPont Textile Fibers Department for 1979, based on the way atmospheric becks are now operated, give the following breakdown for coloration methods of nylon carpets:

<table>
<thead>
<tr>
<th>Coloration Methods</th>
<th>% of Domestic Broadloom, Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Present and Future Forecast</strong></td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td>1979</td>
</tr>
<tr>
<td>Beck</td>
<td>30 ± 5</td>
</tr>
<tr>
<td>Continuous yarn</td>
<td>14</td>
</tr>
<tr>
<td>Continuous fabric/&quot;TAK,&quot; etc.</td>
<td>28 ± 5</td>
</tr>
<tr>
<td>Printing</td>
<td>19</td>
</tr>
<tr>
<td>Other (stock, solution, skein, package)</td>
<td>9</td>
</tr>
</tbody>
</table>
This forecast is based on the inefficient way becks are presently operated (see Section IV), and is thus conservative if the modifications detailed in this report are adopted. The overall conclusion is that batch processes are and will continue to be a major factor in the textile industry.

In the usual batch dyeing process a large vessel is filled with water (usual liquor ratios from 20 to 30:1), the textile product to be dyed is entered and wet out, auxiliary chemicals and dyes are added, and the batch raised to the boil (or above in the case of pressure dyeing) and held for the time required to complete the coloration process. At the conclusion of the dyeing the bath is dropped, the textile rinsed and removed for drying. The dyeing machine is now ready for a second batch and the entire cycle is repeated.

Comparison of the dyebath at the beginning and at the end of the dyeing reveals that the major change that has occurred during the dyeing is the transfer of dye from the bath to the fabric. The dyeing assistants, pH control agents and the water are essentially unchanged by the dyeing process. It should be possible, therefore, to analyze the bath following the dyeing process and to determine the quantity of dye which must be added to reconstitute the bath to the desired concentration for a subsequent dyeing. The advantages of reuse of the dyebath in this way are immediately obvious. First, a great reduction in the quantity of water required for subsequent dyeings should be realized due to reuse of water in the dyebath. Second, a significant reduction in the total quantity of chemicals required for dyeing is possible due to reuse of the dyeing assistants and pH control chemicals. Third, isothermal dyeing at 180°F dictates substantial energy savings connected with the procedure.
Beck dyeing of carpet was the first process selected for studying the technical feasibility of reconstitution and reuse of dyebaths. This area was selected for three reasons. First, beck dyeing of carpet is a major method for coloration of this large volume textile product (see Table III). Second, carpet beck dyeing is carried out with a relatively small number of dyestuffs. Approximately 12 dyes account for 65% of all dye used in carpet coloration. Third, shade matching requirements are much less stringent in carpet dyeing than in other types of textile processing. Carpet beck dyeing, therefore, provided an excellent opportunity to initially evaluate a dyebath recycle process.

Two main classes of dyes - disperse dyes and acid dyes - are used in carpet beck dyeing. In experiments recently concluded at Georgia Tech, carpet samples were dyed to the same shade with acid dyes with reuse of the dyebath up to five times. Dyeings in the recycle baths were only slightly less uniform than dyeings carried out in a fresh dyebath. Variations in color within a given sample and between samples dyed in recycled baths were generally within commercially acceptable color tolerances.

Success of these initial experiments, in addition to the noted production and energy consumption figures, led to the conclusion that dyebath reuse could conceivably be adapted to any batch dyeing procedure. A major portion of the Phase II investigation has thus been allocated to dyebath reuse.

During Phase I, work has continued on the carpet beck dyebath reuse area. It has recently been shown that a number of selected shades in a disperse dye color line can be sequentially applied to nylon carpet with
reuse of the bath for up to 10 cycles. The limiting factor in number of times a bath may be used appears to be the buildup in the bath of dispersing agents from the commercial dyestuffs. Experiments with reuse of both acid dyes and disperse dyes on the nylon carpet have progressed to a large pilot-scale basis (four-foot beck). The methods developed and equipment used in analysis were intentionally selected to be compatible with typical dyehouse practices. The carpet beck dyebath reuse study will be expanded to include polyester carpet (projected to grow substantially in relation to nylon carpet by 1980) in Phase II.

Pronounced energy savings have become apparent as the carpet dyebath reuse work has progressed. For the 5 successive dyeings of the nylon carpet with acid dyes to the same shade, an evaluation of the potential savings in water, energy, and chemicals of dyeing in recycled baths versus conventional beck dyeing have been carried out. In these calculations it was assumed that the bath was used for dyeing of 5 carpets before being replaced. Chemical cost for conventional beck dyeing was calculated at 3.74 cents per pound compared to 2.22 cents per pound for dyeing in recycled baths (a saving of 33%). Conventional dyeing required 3.6 gallons of water per pound compared to 1.5 gallons per pound with recycle (a reduction of 58%). Assuming that there are no heat losses, conventional dyeing of carpet would require 3,442.5 BTU per pound of carpet dyed. This simplified calculation assumes a 25:1 liquor ratio, a carpet and dyebath initial temperature of 70°F, a dyeing temperature of 205°F and a carpet specific heat of 0.5 BTU per pound. A similar calculation for dyeing in recycled baths assuming an entering temperature of 185°F for the last 4 dyeings in the series yields an energy requirement of 1,142.5 BTU/pound for an energy savings of 67%.
The dyebath reuse technology is also being transferred to other promising batch processes in Phase II. One area is hosiery dyeing. Men's and women's nylon hosiery use mainly acid and disperse dyes for coloration in machines similar in concept to atmospheric becks (called paddle machines). The transfer of the dyebath reuse technology to this area from the nylon carpet is thus promising and is expected to be straightforward. In addition, the shade variations in the nylon hosiery are small, with a limited number of dyes utilized. The system thus lends itself well to reuse studies.

Men's acrylic hosiery will also be investigated, but does not appear as promising a candidate as the nylon hosiery because of the different fibers in the construction. A typical acrylic construction consists of:

- 74% acrylic fiber
- 25% nylon fiber
- 1% elastomeric fiber

The acrylic fiber requires basic dyes, while the other constituents require acid or disperse dyes. The typical plant dyeing procedure for acrylic hosiery is thus more complicated than a one dye class system.

Greige men's and women's nylon hosiery, men's acrylic hosiery, and relevant procedures have been obtained from a leading manufacturer to facilitate the study and insure conformability. A hosiery dyeing machine has been fitted to conduct the studies.

Another major area being investigated for dyebath reuse adaptation is fabric dyeing. Several large volume utilizations of atmospheric becks for fabric are dyeing of 100% cotton and 50/50 cotton/polyester knit fabrics and woven 100% nylon upholstery fabrics. The cotton-containing fabrics offer a unique challenge in that many of the most commonly used cotton dye classes (reactive, vat, azoic, aftertreated directs, sulfur, etc.) require in situ
chemical reactions to develop the shade and/or "fix" the dye to the fiber. The dye classes chosen for the cotton component in Phase II reuse studies are reactive, premetallized directs, and aftertreated directs corresponding to the most frequently used procedures of the producer who has supplied the knit fabrics. The reactive dye requires base treatment for fixation. The base, in addition to affecting fixation, also attacks a portion of the dye to give colored by-products. The colored by-products interfere with the spectrophotometric analysis of the spent dyebath that is a critical part of the reuse technology. To bypass this problem in the current study, holding tanks will be utilized to separate the bath containing the parent reactive dye (the impregnation bath) and the bath containing the basic reagent (the fixation bath). The aftertreated direct requires a concentrated salt solution (sodium chloride) in the initial dyeing. Diazotization of a free amine group on the attached direct dye is then accomplished in situ, and a coupling agent added to complete the aftertreatment. In the case of the 50/50 polyester/cotton blend, the polyester component requires a disperse dye compared to the reactive or direct dye class of the cotton fiber. In these latter cases, holding tanks will also be necessary to separate the individual dye class baths and reagent baths to facilitate reuse.

The nylon upholstery fabric, similar to the nylon hosiery, offers unique potential for dyebath reuse. Since these fabric are dyed on atmospheric becks with acid and disperse dyes, transferral of the reuse technology from the nylon carpet should be straightforward. Negotiations are underway with a leading manufacturer for supply of the fabric with procedures for the Phase II studies.

-106-
The final major area selected for reuse technology transfer is pressure package dyeing. Of the three major pressure batch machines (package dyeing machines, pressure jet machines, and pressure becks), the largest volume of material is colored in the form of packages (see Table III). As the basic principles involved in these three processes are similar, with only the form of the textile structure being different, it was concluded that examination of reuse feasibility in one of the three would be sufficient for Phase II demonstration. A single-package machine has thus been modified for dye-bath reuse studies in Phase II. The fiber selected for initial study is 100% polyester (both staple and textured filament yarns), with disperse dyes comprising the only colorants used in the study. The chosen fiber-dye class combination corresponds one of the largest-volume systems dyed on package machines (Table II). The procedure supplied with the yarns by a southeastern plant calls for a 272°F holding temperature during the cycle, and thus holding tanks will also be required in the package studies to facilitate dropping the hot dyebath, bringing in afterscour or aftertreatment baths, and changing the package after cooling the yarn.

The question of materials handling will also be addressed during the dyebath reuse studies. On a plant scale, two possibilities exist: 1) coupling two or more batch machines together, and 2) setting up holding tanks for the various baths. The coupling concept suffers from the amount of scheduling required for plants which often change shades (the usual situation). The main advantage of coupling the machines is that capital investment would be minimal, requiring only a simple pumping system to "push" the baths from one machine to the next at the cycle completion. The holding tank concept,
though requiring more capital investment than the coupling approach, appears to have wider support in conversations with industry personnel due to lesser dependence on strict scheduling for maximum productivity. In addition, scour, finish, rinse, and other auxiliary baths can also be easily reused by simply installing additional tanks.

The dyeing procedures supplied by the manufacturers and utilized in the reuse studies are also being critically evaluated to determine minimum temperatures, times, number of rinses, and other factors that can maintain finished product quality while minimizing energy consumption. It has been discovered in Phase I that many of the dyeing procedures utilized today by the industry were devised in past years by dye and fiber manufacturers when energy was not a major consideration. As a result, excessive energy is often used to compensate for fiber irregularities and dye deficiencies (level, migration, fixation, etc.). The textile plants often do not possess the expertise or equipment to analyze the effects of variable changes in their dyeing procedures, and thus have not critically approached their current practices in view of the present energy situation.
Predryer and Dryer Modifications

During the drying of a textile fabric a heat transfer mechanism drives heat into fabric water to evaporate it and a mass transfer mechanism removes the evaporated water layer, which acts as an insulator, away from the fabric. Heat for evaporation is transferred to a unit area of cloth at a rate proportional to the heat transfer coefficient times the difference between the air dry bulb temperature and the adiabatic saturation (wet bulb) temperatures:

\[ H = h(T_d - T_s) = h \Delta T \]

Water vapor is transferred from a unit area of cloth surface at a rate proportional to the mass transfer coefficient times the difference between the cloth water's saturated partial pressure and the water vapor partial pressure of the dryer atmosphere:

\[ M = D (P_{ws} - P_{wd}) = D \Delta P \]

Since the evaporated water layer on the surface of a fabric acting as an insulator is an impedance to fabric drying, it can be expected that an increase in the mass transfer rate will result in a more efficient drying process. Correspondingly, the rate can be affected significantly by reducing \( P_{wd} \), water vapor partial pressure of the dryer atmosphere, to increase \( \Delta P \).

Currently, textile fabrics are dried thermally by one of two ways. The predominate method requires the fabric to be stretched by a set of traversing pins and passed through an oven. This oven is known throughout the textile industry as a tenter frame. The heat input to the frame is consumed three
ways: the essential heat requirement, the case loss, and the air loss.
The first of these components represents the heat that must be applied in
order to achieve drying, the second represents the losses by radiation and
convection from the machine casing, and the third the loss in hot exhaust air.

The essential heat requirement is dominated by the latent heat of water, but also includes relatively small contributions for raising the temperature
of the evaporated water to the air temperature in the oven and for heating
the fabric. It can be shown that this essential heat requirement is about
550 BTU's per pound of fabric which is mechanically dewatered to 35% moisture
content prior to entering the tenter.

The value of the case or housing loss obviously depends directly on the
efficiency of insulation of the oven casing. With effective insulation and
a small housing it can be reduced to the equivalent of about 17 BTU's per
pound to fabric produced and thus represents only a very small part of the
total energy consumption at the tenter.

The air loss arises from the fact that hot humid air is continuously
exhausted from the machine to be replaced by cold dry ambient air. The water
vapor produced during drying must be continuously removed and this removal
must be accompanied by the removal of hot air. In practice, this exhaust
serves to maintain the humidity in the enclosure at a certain level; for this
reason it affects both the thermal efficiency of the machine and its producti-
vity.

Unfortunately, large quantities of air are needed to remove a relatively
small quantity of moisture; specifically about 25 pounds of exhaust air are
used to remove one pound of evaporated water. Accordingly, it can be shown
that about 500 BTU's of energy from the makeup air are released to the ex-
haust for each pound of fabric passed through the tenter.
Looking at this data, one can easily conclude that a tenter frame is inherently only about 50% energy efficient since only about 50% of the required energy goes towards vaporizing the fabric water.

The second method of drying entails the use of steam heated cylinders or drying cans. Here a moving fabric which is to be dried is driven by hot rollers through the process. These rollers effect drying by conducting heat through the cylinder shell. Usually the fabric water then evaporates and just "steams" off the surface. This "steaming off" is usually not aided by auxiliary air flow and hence the mass flow rate from the fabric is not very rapid. Accordingly, air flow could be established by small fans, but these would also inadvertently cool the cylinders, increase energy consumption, and release wasted hot exhaust air. Of course this hot exhaust could be routed through heat exchangers to recover some energy. However, the entire mass transfer mechanism is questionable with regard to efficiency.

To overcome the foregoing shortcomings of conventional drying systems, this research is concerned with increasing the energy efficiency of the continuous textile drying process.

The main thrust involves looking at modifications to existing drying systems which have fast payback and can save large quantities of energy, and especially that which is derived from natural gas. These modifications are being developed with the concept that they may be easily connected in series with existing tenter frames.

The first modification involves the enhancement of the mass transport mechanism during drying, for if the mass transport rate can be increased, it is possible to assemble more compact and energy efficient drying systems.
The proposed modification consists of a porous heat conducting surface in a vacuum. The technique is illustrated in Figure 10.

Fabric which has been mechanically dewatered to about 35% moisture content is fed onto a steam can. The fabric is elevated to a temperature of about 150°F. Immediately upon reaching the desired temperature, it is passed between the porous cylinder and a thin, flexible, impermeable membrane. Here it is subjected to a vacuum and heat, which serve to flash the water off the fabric and which rapidly remove the vapor from the immediate area of drying. Of course, there is no energy saving with regard to the essential heat required to vaporize the water. However, the mass removal does not require large quantities of heated air which are required in the tenter. Accordingly, a 50% thermal energy savings with such a process can be expected. The electrical requirement to power a vacuum pump is a penalty. However, by rotating the impermeable seal with the porous surface, significant air flow and corresponding cooling is absent and hence the vacuum requirements are minimal. Therefore, considering the vacuum, a potential savings of about 40% of the total energy required for textile drying is estimated.

Currently, static tests are being carried out to determine the pressure - time - % moisture - temperature characteristics for wet fabrics. These experiments will determine the best set of operating conditions for a small scale dryer which will soon be constructed under the contract.

Ways to reduce the moisture content of incoming air to the tenter frame are also being investigated. For example, the industry norm for exhaust air is that it contain .042 pounds of water for each pound of dry air. If the
air taken from the finishing room is at 80°F and 80% RH it already contains
.017 pounds of moisture per pound of dry air and can only take on .025 more
lbs. of moisture before being exhausted. However, if air comes in at 70°F
and 50% RH the content is only .008 pounds of water and can hold an additional
.034 pounds of moisture. This represents about 14% less use of makeup air
or a total thermal energy savings of about 7% in an existing tenter operation.
If the air is dried entirely, the exhaust requirement can be reduced by 40%
and reduce the total thermal requirement of the frame reduced by 20%. Of course,
there is an energy cost for dehumidification. Finding this cost and exploring
feasible ways to dehumidify the air prior to entrance into the tenter frame
is within the scope of this investigation.
Fiber Preparation Modifications

In the processing of yarns into both woven and knit fabrics, and in the preparation, dyeing, and finishing of these fabrics, there are many steps in which the fabrics are treated with chemicals which in subsequent processes must be removed. For example, spun as well as continuous filament yarns which are to be converted into woven fabrics must be sized to provide protection of warp yarns from the abrasive action in weaving. Similarly, yarns which are converted into knit fabrics must be provided with a yarn finish, namely a good lubricant, to facilitate the knitting process. If there is a static problem in yarn manufacture as well as in fabric manufacture, a good antistatic agent must be used on the fiber to provide static protection. All of these fiber and yarn additives must be removed before the dyeing, printing, and finishing processes are encountered.

In addition to those impurities which are added to the fiber to improve performance in their conversion to yarn and fabrics, there are also impurities present in natural fibers which must be removed during preparation processes. For example, cotton always contains small bits of leaves from the cotton plant and so-called motes which originate from the cotton seed during the ginning process. Cotton fibers also have a waxy coating which is not easily wet by water.

Many other examples can be given in the dyeing and finishing of fabrics where complete preremoval of chemicals or impurities are required if a commercially acceptable product is to be achieved. Even in dyeing processes, after-cleaning is required to remove excess, unfixed materials not desirable in the final product.
Many steps are thus required in the wet processing of textiles in which cleaning is accomplished, accounting for large poundages of processed textiles (see Table III). Substantial energy is used in these cleaning processes. Consider the preparation of cotton and cotton/polyester woven fabrics for dyeing and finishing. The first step is fabric singeing. Thermal energy, supplied by natural gas, is required to burn off loose fibers from the surface of the fabric. In the desizing step, aqueous solutions of chemicals are applied to the fabric to facilitate the removal of size. Thermal energy is required to heat the impregnation bath. This is followed by washing with warm water. The most effective energy for the washing step is that of mechanical action. The water used in washing must also be heated. Mercerization is a process often used for cotton and cotton/polyester blends. It involves treatment of the fabric with a concentrated solution of sodium hydroxide. As the sodium hydroxide penetrates the fibers, the fabric is stressed. The action of sodium hydroxide on cotton converts the cellulose from one form of cellulose (Cellulose I) to a different crystallographic form (Celllose II). When this process is complete, the sodium hydroxide must be removed. Again, mechanical and thermal energy is used to remove the sodium hydroxide. The last two cleaning steps for cotton and cotton/polyester blends are scouring and bleaching. Scouring can be described as a hot treatment with an aqueous sodium hydroxide solution and bleaching as a hot treatment with an aqueous, alkaline solution of hydrogen peroxide (or other oxidant). It is quite common to scour in a steam atmosphere (at \( \geq 212^\circ F \)) for as long as one hour followed by bleaching under the same conditions, namely one hour steaming at 212\(^\circ\)F. The fabric is washed following the scouring steam treatment as well as after bleaching. Efficiency in washing depends strongly on mechanical action. After washing, water is removed by extraction and drying.
Much thermal as well as chemical energy is used in these preparative processes. The mechanical energy used is primarily in the washing of the fabric after it has been treated thermally and chemically. If more efficient mechanical and chemical means for removing impurities can be discovered, the thermal energy requirements could be reduced substantially. The objective of the proposed research is thus to demonstrate more efficient mechanical and chemical means for removing impurities, leading to less energy intensive fiber preparation processes.

In view of the large poundage of cotton and cotton/polyester woven fabrics which are continuously processed (see Table III), it is proposed that work be confined to these fabrics and to those processes which are used in the preparation of the fabrics for dyeing, printing, and finishing. The goals are twofold:

1. To investigate the application of sonic and supersonic vapor flows as a means for the more efficient removal of macro, micro, and chemical in cotton and cotton/polyester woven fabrics.

2. To determine the feasibility of combining preparative wet processes, and specifically combined desizing, scouring and bleaching.

A recent development is the Machnozzle, a device shown to be very effective for accelerating the removal of water and residual chemicals left after washing from fabrics.

"The Machnozzle is a device that blows steam at extremely high speed through the fabric. This system insures not only an optimal dewatering effect, but also an unrivaled
washing efficiency. The energy consumption is negligible because the thermal energy of the vapor can be completely recovered. Only the mechanical energy is used. In this way water and other residual matter entrained around and in the yarns are virtually blown out of the fabric."\(^{57}\)

The Machnozzle thus appears to remove water from wet fabric efficiently. In this work, the use of the Machnozzle will be investigated as a means for removing large-scale impurities present in woven fabrics, sizing materials and natural impurities (leaf, notes, insect parts, etc.) present in cotton and cotton/polyester fabrics. The technology used today for accomplishing this involves the totally chemical and/or biological attack and breakdown of impurities followed by washing. Two of the processes for cotton fabrics are very energy intensive, namely scouring and bleaching. Many mills traditionally steam cotton fabrics for one hour in the scouring operation and an additional hour in bleaching. Energy can be saved if the times of steaming were reduced (or eliminated completely) or if the processes were combined.

Four questions arise: 1) How can the Machnozzle be used effectively at every stage in fabric preparation?; 2) Will its use facilitate the combination of preparation processes?; 3) Can chemical combinations be devised to facilitate process combination?; 4) What energy savings will result? The experimental work undertaken will attempt to provide answers to these questions.
Atmospheric Dye Beck Equipment Modifications

Atmospheric dye becks consume over 5.5 million barrels of oil annually. Over 50% of this energy could be saved with design modifications. Differences in energy consumption verify that significant savings can be achieved by proper control of evaporative losses.

During Phase II of this program it is planned to systematically investigate all practical options concerning these becks. The following modifications in the basic design will be assessed:

- Cover sparge area
- Add door
- Add control damper to stack
- Add steam controls
- Desuperheat steam

Certain production procedure changes may be possible after the above tighter control of the equipment is accomplished. These operating modifications include:

- Decrease liquor ratio
- Reduce dye temperatures
- Reduce hold times
- Increase start temperatures

Exhaust Gas Heat Reclamation

Dryer and oven exhausts account for a considerable portion of waste heat in a textile mill. Standard heat recovery systems have been troubled by con-
densible organics in the exhausts. These condensibles coat the surface of heat exchangers making them ineffective and costly to operate. Several attempts at modifying these systems, such as in line steam cleaning, have been made but found unsuccessful.

In Phase II of this program EES proposes to recover the heat of these gases as well as the heating value of the condensible organics by incinerating the exhaust gases. Incineration could be done using a less premium fuel than the natural gas or propane now used in most dryers. Several versions of exhaust incineration are presently available, but are not in wide spread use. This study will concentrate on developing feasibility data and improving recovered heat distribution and reuse. Organic heat transfer fluids or a high temperature hot water system will be evaluated in order to reduce the size and cost of air-to-air systems.

Proposed Program:

- Investigate present systems
- Analysis of exhausts
- Build bench size test unit
- Determine fuel requirements
- Evaluate heat recovery potential
- Test on various units (carpet, knits, etc.)
Recent Advances in Energy-Efficient Equipment

Bibliography


37. C. Sommers, Engineering Department, West Point Pepperell, West Point, GA., private communication, 1976.


59. L. Gaddis, EPA Grant 803-875-01-5.
APPENDIX A
ATMOSPHERIC BECK

Sample 1a

Measured: Total Water Usage (one day): 1,000,300 Gallons
Total Steam Usage (one day): 375,000 pounds @ 125 psig
Requires orifice correction of .93
Includes deaerator and wet out box
Total Production: 111,640 pounds
55% polyester carpet
45% nylon carpet

Water Inlet Temperature: 77°F
Water Outlet Temperature: 120.6°F (average)
Beck Stack Exhaust Velocity: 2,500 ft/min
Beck Stack Diameter: 30 in.
Beck Stack Exit Temperature: 170°F

Sample 1b

Measured: Total water usage (one day): 1,042,500 Gallons
Total steam usage (one day): 1,336,700 pounds @ 125 psig
Requires orifice correction of .93
Includes deaerator and wet out box
Total production: 110,788 pounds
43% polyester carpet
45% nylon carpet
12% nylon and polyester carpet

Water Inlet Temperature: 77°F
Water Outlet Temperature: 119.9°F
\[ Q_{\text{beek}} = Q_{\text{H}_2\text{O}} + Q_{\text{Exh}} + Q_{\text{other losses}} \]

\[ Q_{\text{H}_2\text{O}} = C_p W \Delta T \]

\[ = 1 \cdot [1000800(8.34)](121 - 77) \]

\[ = 367.3 \times 10^6 \text{ BTU} \]

\[ Q_{\text{Exh}} = Q_{\text{air}} + Q_{\text{steam}} \]

\[ Q_{\text{air}} = \rho A V C_p \Delta T t \]

\[ A = \pi \left[\frac{30}{2(12)}\right]^2 = 4.91 \text{ ft}^2 \]

\[ V = 2,500 \text{ ft/min} \]

\[ p_s @ 170^\circ \approx 6 \text{ psi} \]

\[ p_{\text{air}} = p_{\text{atmos}} - p_s \]

\[ = 14.7 - 6 = 8.7 \text{ psi} \]

\[ p_v = RT \]

\[ v = \frac{RT}{p} \]

\[ \therefore \rho = \frac{1}{v} = \frac{\rho}{RT} = \frac{14.7(144)}{(53.3)(630)} = 0.063 \text{ lbs/ft}^3 \]

\[ q_{\text{air}} = (0.063)(4.91)(2500)(.24)(170-80) = 16,700 \text{ BTU/min} \]

(However only 8.7/14.7 or 60% of the exhaust stream is air)
\[
q_{\text{air}} = 0.6(16700) = 10000 \text{ BTU/min}
\]

\[
q_{\text{steam}} = \rho AV \Delta h
\]

\[
= (0.016)(4.91)(2500)(1134-178)
\]

\[
\therefore \rho = \frac{1}{v} = 0.016
\]

\[
= 0.19 \times 10^6 \text{ BTU/min.}
\]

(However only \(\frac{6}{14.7}\) or 40% of the exhaust stream is steam)

\[
\therefore q_{\text{steam}} = 0.4 \times (0.19 \times 10^6) = 75000 \text{ BTU/min.}
\]

\[
q_{\text{exh}} = (10000) + (75000)
\]

\[
= 85000 \text{ BTU/min. while @ boil}
\]

Assume 43 min. hold at boil average

\[
Q_{\text{Exh/Day}} = (80 \text{ Loads Day}) (85000 \text{ BTU/min.}) (43 \text{ min.}) = 292 \times 10^6 \text{ BTU/Day}
\]

Thermal Energy Consumption = \(\frac{665 \times 10^6 \text{ BTU}}{111640 \text{ lbs.}}\) = 6000 BTU/lbs.

\[
Q_{\text{H}_2\text{O}} = 367.3 \times 10^6 = \frac{367.3}{665} \times 100 = 55\%
\]

\[
Q_{\text{Exh}} = 292 \times 10^6 = \frac{292}{665} \times 100 = 44\%
\]

\[
Q_{\text{OL}} = 5.7 \times 10^6 = \frac{5.7}{665} \times 100 = 1\%
\]

\[
Q_{\text{Tot}} = 665 \times 10^6 \text{ BTU/Day}
\]

Electrical Energy Consumption:

\[
\frac{(10.5 \text{ H.P. Beck}) (20 \text{ Becks}) (20 \text{ HRS Day}) (0.7457 \text{ KW H.P.})}{111640 \text{ lbs. Day}} = 0.03 \text{ KW-HRS/1b.}
\]
Likewise for sample lb:

$$Q_{\text{beck}} = Q_{\text{net steam}}$$

$$Q_{\text{net steam}} = Q_{\text{total steam}} - Q_{\text{wet box steam}} - Q_{\text{deaerator steam}}$$

$$= [1336700 (.93)] (1000) - 1000(24)1000 - \frac{1336700(.93)(215 - 77)}{.9}$$

$$= 1028 \times 10^6 \text{ BTU}$$

$$\therefore \text{Consumption} = \frac{1028 \times 10^6 \text{ BTU}}{110,788 \text{ lbs.}} = 9279 \text{ BTU/lb.}$$

$$Q_{\text{H}_2\text{O}} = 1[1042500)(8.34)](119.9 - 77) = 373 \times 10^6 \text{ BTU}$$

$$\therefore \text{percentage of thermal energy consumption used to heat water} = \frac{373 \times 10^6}{1028 \times 10^6} \times 100 = 36\%$$

The difference between sample la and sample lb from the same plant could be caused by a number of factors. The most logical explanation is hold time at boil. Both samples consumed approximately the same amounts of water for similar production. However sample la utilized 55% of the heat in raising water temperature whereas sample lb utilized only 36%. Therefore, more energy was consumed in sample lb by exhaust and radiation losses due to longer dye cycle time. Dye cycle time is increased when dyeing polyester rather than nylon or when additional dye adds must be made in order to obtain correct color matching.

Similar data reduction from other measured samples and gathered beck data is summarized in Table A-I.
Table A-I

Summary of Atmospheric Dye Beck Thermal Energy Consumption

<table>
<thead>
<tr>
<th>Sample</th>
<th>Production weight, lbs.</th>
<th>Steam Consumed, lbs.</th>
<th>Utilization of Steam, %</th>
<th>Consumption, BTU/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heat Water</td>
<td>Exhausted</td>
</tr>
<tr>
<td>Carpet:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>111,640</td>
<td>813,800</td>
<td>55</td>
<td>44</td>
</tr>
<tr>
<td>1b</td>
<td>110,788</td>
<td>1,336,700</td>
<td>36</td>
<td>58</td>
</tr>
<tr>
<td>2a</td>
<td>3,440,000</td>
<td>26,700,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b</td>
<td>3,680,000</td>
<td>29,100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2c</td>
<td>4,260,000</td>
<td>35,200,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2d</td>
<td>4,050,000</td>
<td>33,100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3,152,600</td>
<td>42,876,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2,646,000</td>
<td>57,330,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1,350</td>
<td>17,872</td>
<td>37</td>
<td>61</td>
</tr>
<tr>
<td>2 (58)</td>
<td>N/A</td>
<td>N/A</td>
<td>23</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Avg)
Potential for Conservation:

Recovered from Waste Water: \(27362 \text{ lbs} \cdot H_2O(210 - 110)(100) = 273.6 \times 10^6 \text{ BTU}\)

Reduction of Exhaust: \(292 \times 10^6 (2/3 \text{ practical}) = 195 \times 10^6 \text{ BTU}\)

Radiation Losses:

\[ E = \varepsilon \sigma T_R^4 \]

\[ = 0.5(0.1714 \times 10^{-8})(460 + 210)^4 \]

\[ = 172.7 \text{ BTU/hr. - ft}^2 \]

\[ Q_R = E \cdot A = 172.7(766) = 132000 \text{ BTU/hr.} \]

Time @ temp. = \(\frac{45 \text{ min. (100)}}{60 \text{ min./hr.}} = 75 \text{ beck-hrs.}\)

\[ Q_R = 132000(75) = 9.9 \times 10^6 \text{ BTU/day (too low to be economically viable)} \]

Reduced or recovered = \(273.6 \times 10^6 + 195 \times 10^6 \approx 470 \times 10^6 \text{ BTU}\)

\[ \frac{470 \times 10^6}{665 \times 10^6} = 70\% \text{ potential} \]
APPENDIX B

Pressure Beck
(Sample Calculation)

Dark Shade with After Scour

<table>
<thead>
<tr>
<th>Recipe Steps</th>
<th>Weight of H₂O, lbs</th>
<th>ΔT, °F</th>
<th>Energy in from H₂O, BTU</th>
<th>Weight of Steam, lbs</th>
<th>Energy in from Steam, BTU</th>
<th>Energy Recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fill @ 100°F</td>
<td>11451</td>
<td>40</td>
<td>460,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. Hot Wash @ 120°F</td>
<td>11451</td>
<td>60</td>
<td>690,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. Hot Wash @ 120°F</td>
<td>11451</td>
<td>60</td>
<td>690,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4. Top Fill @ 120°F</td>
<td>2200</td>
<td>60</td>
<td>13,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5. Heat to 260°F</td>
<td>13651</td>
<td></td>
<td></td>
<td>2973</td>
<td>2,973,000</td>
<td>1.16</td>
</tr>
<tr>
<td>6. Hold at 260°F</td>
<td>13651</td>
<td></td>
<td></td>
<td>375</td>
<td>375,000</td>
<td>.48</td>
</tr>
<tr>
<td>7. Cool to 175°F</td>
<td>13651</td>
<td>85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Cool to 140°F</td>
<td>13651</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Overflow to 120°F</td>
<td>13651</td>
<td>20</td>
<td>273,000</td>
<td></td>
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</tr>
<tr>
<td>10. Drop and Refill at 110°F</td>
<td>11451</td>
<td>50</td>
<td>570,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Drop and Refill at 110°F</td>
<td>11451</td>
<td>50</td>
<td>570,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Drop and Refill at 100°F</td>
<td>11451</td>
<td>40</td>
<td>460,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{\textbullet\ Total Thermal Energy Used } (3.73 + 3.35) \times 10^6 = 7.08 \times 10^6 \text{ BTU}
\]

\[
\text{\textbullet\ Less Thermal Energy Recovered } (1.64 \times 10^6)
\]

\[
\text{\textbullet\ Thermal Energy Required } 5.44 \times 10^6 \text{ BTU}
\]

\[
\text{\textbullet\ Thermal Energy use per pound of Fabric: } \frac{5.44 \times 10^6 \text{ BTU}}{950 \text{ lbs}} = 5726 \text{ BTU/lb}
\]

\[
\text{\textbullet\ Electrical Use: } 15 \text{ H.P.} \times 6 \text{ hr Cycle} \times .7457 \text{ KW/H.P.} = 67 \text{ KW-HRS}
\]

\[
\frac{67 \text{ KW-HRS}}{950 \text{ lbs}} = .07 \frac{\text{KW-HRS}}{\text{lb}}
\]
Similarly, a medium shade dye cycle with no scour calculates to be 4,600 BTU/lb. and a light shade dye cycle including prescour calculates to be 5,300 BTU/lb. An independent analysis\(^{(58)}\) arrives at a 4,500 BTU/lb. requirement for pressure beck dyeing. Since, the amount of preparation (i.e., scouring) performed in pressure becks in addition to dyeing is unknown, 5,000 BTU/lb. will be used as the thermal energy consumption value for this process.
APPENDIX C

JET DYING MACHINE

(Based on Average Values Using Different Dyes)

THERMAL:

1. INITIAL FILL

1429 Pounds of Fabric
1173 Gallons of Cold Water (Assume 60°F Ambient H₂O)
532 Gallons of Hot Water (From Storage at 180°F)

\[ Q_{in1} = \frac{C \cdot WAT}{p} = 1(8.34)(532)(180-60) = 0.53 \times 10^6 \text{ BTU} \]

Approximate Temperature After Fill

\[ Q_{out} = \frac{C \cdot WAT}{p} \]

\[ 1173(60) + 532(180) = (1173 + 532) \cdot T \]

\[ T = 97^\circ F \]

2. INITIAL RINSE TO 150°F

1131 Gallons of Cold Water
1006 Gallons of Hot Water
582 Pounds of Steam (Assume h = 1000 BTU/1b)

\[ Q_{in2} = Q_{H_2O} + Q_{steam} = C \cdot WAT + Wh \]

\[ = 1(1006)(8.34)(180 - 60) + 582(1000) \]

\[ = 1.01 \times 10^6 + 0.58 \times 10^6 \]

\[ = 1.59 \times 10^6 \text{ BTU} \]

\[ Q_{out} = \text{Overflow to Drain at Avg. Temp.} \]

\[ = \frac{C \cdot WAT}{p} \]

Amount in Tank (From Step 1) = 1173 + 532 = 1705 Gallons

Amount Added = 1131 + 1006 = 2137 Gallons

Added Heat Remaining in Tank at 150°F:

\[ Q_T = 1(1705)(8.34)(150-60) + 0.5(1429)(150-80) \]

\[ = 1.28 \times 10^6 + 0.05 \times 10^6 \]

\[ Q_T = 1.33 \times 10^6 \text{ BTU} \]
Heat Exhausted to Drain: (Neglecting Radiation & Other Losses)

\[ Q_{T} = Q_{in_1} + Q_{in_2} - Q_{out} \]
\[ Q_{out} = Q_{in_1} + Q_{in_2} - Q_{T} \]

\[
= (.53 \times 10^6) + (1.59 \times 10^6) - (1.33 \times 10^6) \\
= .79 \times 10^6 \text{ BTU}
\]

3. HEAT TO 260°F

2360 Pounds of Steam REQD

\[ Q_{in_3} = wh = 2360(1000) = 2.36 \times 10^6 \text{ BTU} \]

THEORETICAL REQUIRED = \( C_{\text{H}_2\text{O}} + C_{\text{fabric}} \) (No Losses)

\[
= 1[(1705)(8.34)](260-150) + .5(1429)(260-150) \\
= 1.56 \times 10^6 + .08 \times 10^6 \\
= 1.64 \times 10^6 \text{ BTU}
\]
4. Cool to 180°F

\[
Q_{\text{out}} = \Sigma C_{p}W\Delta T
\]

\[
= 1[(1705)(8.34)](260-180) + .5(1429)(260-180)
\]

\[
= 1.14 \times 10^6 + .05 \times 10^6
\]

\[
- 1.15 \times 10^6 \text{ BTU}
\]

2118 Gallons of Cooling Water Reclaimed

\[
1.19 \times 10^6 = 1(2118)(8.34)(T-60)
\]

\[
T = 67.4 + 60 = 127^\circ\text{F}
\]

5. After Treatment

157 Pounds Steam Req'd

\[
Q_{\text{in}} = 157(1000) = .16 \times 10^6 \text{BTU}
\]

6. Final Rinse

5760 Gallons Cold Water

3130 Gallons Hot Water

\[
Q_{\text{in}} = 1(3130)(8.34)(180-60)
\]

\[
= 3.13 \times 10^6 \text{ BTU} \quad \text{(Also } Q_{\text{out}})\]

7. Drain

\[
Q_{\text{out}} = 1(1705)(8.34)(180-60) - .5(1429)(180-80)
\]

\[
= (1.71 + .07) \times 10^6
\]

\[
= 1.78 \times 10^6 \text{ BTU}
\]
<table>
<thead>
<tr>
<th>Steps</th>
<th>H₂O In</th>
<th>Steam In</th>
<th>H₂O Out</th>
<th>BTU Recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Initial Fill</td>
<td>.53 x 10⁶</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. Initial Rinse</td>
<td>1.01 x 10⁶</td>
<td>.58 x 10⁶</td>
<td>.79 x 10⁶</td>
<td>-</td>
</tr>
<tr>
<td>3. Heat to 260°F</td>
<td>-</td>
<td>2.36 x 10⁶</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4. Cool to 180°F</td>
<td>-</td>
<td>-</td>
<td>1.19 x 10⁶</td>
<td>1.19 x 10⁶</td>
</tr>
<tr>
<td>5. After Treatment</td>
<td>-</td>
<td>.16 x 10⁶</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6. Final Rinse</td>
<td>3.13 x 10⁶</td>
<td>-</td>
<td>3.13 x 10⁶</td>
<td>-</td>
</tr>
<tr>
<td>7. Drain</td>
<td>-</td>
<td>-</td>
<td>1.78 x 10⁶</td>
<td>-</td>
</tr>
</tbody>
</table>

\[
\text{Total BTU's Required: } 7.77 \times 10^6 - 1.19 \times 10^6 = 6.58 \times 10^6 \text{ BTU}
\]

**ELECTRICAL:**

\[
37.38 \text{ KW} \times 3 \text{ HRS} = 112 \text{ KW-HR} \quad \frac{112 \text{ KW-HRS}}{1429 \text{ lb}} = .08 \text{ KW-HRS/lb}
\]

(includes 44 H.P. of electric motors)

\[
\text{BTU} \text{ Equiv} = \frac{112(3412)}{.3} = 1.28 \times 10^6 \text{ BTU} \quad \frac{1.28 \times 10^6 \text{ BTU}}{1429 \text{ lbs}} = 890 \text{ BTU/lb}
\]

(conversion efficiency)

\[
\text{Thermal Elec} \quad [(7.77 - 1.19) + 1.28] \times 10^6 = 7.86 \times 10^6 \text{ BTU/Cycle}
\]

\[
\frac{7.86 \times 10^6}{1429} = 5500 \text{ BTU/lb}
\]
APPROXIMATE RADIATION & CONVECTION LOSS

2-JET DYEING MACHINE

Convection:

\[
\begin{align*}
    h_A &= .27 \left( \frac{\Delta T}{D} \right)^{1/4} \text{ (Laminar)} \\
    h_B &= .29 \left( \frac{\Delta T}{D} \right)^{1/4} \text{ BTU/} \text{MR-FT}^2 \circ \text{F} \\
    h_A &= .27 \left( \frac{260 - 80}{82} \right)^{1/4} = .61 \\
    h_B &= .29 \left( \frac{180(12)}{82} \right)^{1/4} = .66
\end{align*}
\]

\[
q_c = h_A A_A \Delta T + h_B A_R \Delta T
\]

\[
= .61 \left[ \pi \left( \frac{82}{144} \right)^{0.886} \right] 180 + (.66) \pi \left( \frac{4}{12} \right)^2 2 (180)
\]

\[
= 17404 + 8674 = 26080 \text{ BTU/HR}
\]

Radiation:

\[
E = .85 ( \cdot 1.714 \times 10^{-8} ) (720)^4
\]

\[
= 391.5
\]

\[
391.5 (232) = 90803 \text{ BTU/HR}
\]

\[
q_L = 26080 + 90803 = 116,883 \text{ BTU/hr}
\]

Avg. Time @ high temperature = 65.2 Min.

\[
\therefore Q = \frac{(117000 \text{ BTU})(65.2 \text{ Min})}{60 \text{ Min}} = .13 \times 10^6 \text{ BTU} \rightarrow \frac{.13 \times 10^6 \text{ BTU}}{1429 \text{ lbs}} = 91 \text{ BTU/lb}
\]

Actual Req'd - Theo Req'd = Losses

\[
(2.36 \times 10^6) - (1.64 \times 10^6) = .72 \times 10^6 \text{ BTU}
\]

Heat Exchanger Losses = Total Losses - RAD & CONV.

\[
Q_{HE} = (.72 \times 10^6) - (.13 \times 10^6)
\]

\[
= .59 \times 10^6 \text{ BTU}
\]
Measured Values for a 3-Tube Jet Dye Machine

696 gallons of steam condensate were collected for a complete dye cycle run on 602 pounds of product.

\[(696 \text{ gal})(8.34 \frac{\text{lbs}}{\text{gal}}) = 5,804 \text{ lbs of steam}\]

\[\therefore Q = \frac{5,804 \text{ lbs} (1,000 \text{ BTU/lb})}{602 \text{ lbs}} = \frac{5,804,000 \text{ BTU}}{602 \text{ lbs}} = 9641 \text{ BTU/lb}\]

An identical machine was insulated with 2 inches of foam glass. 600 gallons of condensate were collected on the same type dye cycle run on 600 pounds of product.

\[\therefore Q = \frac{(600)(8.34)(1,000)}{600} = 8340 \text{ BTU/lb}\]

Savings from insulation: 9641 - 8340 BTU/lb

Since the approximate radiation losses were only 91 BTU/lb and the experimental reduction in radiation was 1200 BTU/lb, the calculated losses will be ignored and the measured data considered accurate.

\[\therefore \frac{1300}{9641} = 13\%\]

The difference between the thermal energy consumption based on average values and an individual dye cycle measurement could be caused by a number of factors, such as weight of load (1429 vs. 602), type of fabric, type of dye, etc. A value of 7167 BTU/lb can be derived from a James Hunter Model VL Jet Dye Machine specification sheet. Since this value is close to the average of the two samples, it will be considered the typical energy requirement.
APPENDIX D

Package Dyeing

Given: Cold water supply @ 60°F
Average dye load in 1200 lbs.
Radiation and convection losses are nil
Running wash @ 1416 gpm average flow rate
Electrical energy required = .09 KW-HR/lb.

Assumptions:
Waste stream can preheat an equal volume of 60°F incoming water to within 20°F of waste water temperature

Direct Dyes

1. Standard wet out
   a) Fill with 1500 gal @ 160°F
      \[ Q_{in_1} = C_p W L \]
      \[ = 1 \times (8.34)(1500)(160 - 60) = 1.25 \times 10^6 \text{ BTU} \]
   b) Heat with steam to 192°F
      \[ Q_{in_2} = C_p W L \]
      \[ = 1 \times (8.34)(1500)(192 - 160) = 0.40 \times 10^6 \text{ BTU} \]
   c) Drain 192°F dye bath
      \[ Q_{out_1} = 1 \times (8.34)(1500)(60 - 192) = -1.65 \times 10^6 \text{ BTU} \]
   d) Running wash @ 120°F for 6 min
      \[ W = 1416 \frac{\text{gal}}{\text{min}} \times 6 \text{ min} \times 8.34 \frac{\text{lbs}}{\text{gal}} = 70857 \text{ lbs} \]
      \[ Q_{in_3} \text{ and } Q_{out_2} = 1 \times (70857)(60 - 120) = -4.25 \times 10^6 \text{ BTU} \]

2. Dye
   a) Fill with 3000 gal @ 120°F
      \[ Q_{in_4} = 1 \times ((3000)(8.34))(120 - 60) = 1.50 \times 10^6 \text{ BTU} \]
   b) Heat with steam to 192°F
      \[ Q_{in_5} = 1 \times ((3000)(8.34))(192 - 120) = 1.80 \times 10^6 \text{ BTU} \]
   c) Heat with steam to 210°F
      \[ Q_{in_6} = 1 \times ((3000)(8.34))(210 - 192) = 0.45 \times 10^6 \text{ BTU} \]
d) Cool with heat exchanger to 192°F
\[ Q_{exc} = 1[(3000)(8.34)](102 - 210) = -.45 \times 10^6 \text{ BTU} \]

e) Drain
\[ Q_{out} = 1[(3000)(8.34)](60 - 192) = -3.30 \times 10^6 \text{ BTU} \]

3. First Rinse
a) Fill with 1500 gal @ 75°F
\[ Q_{in} = 1[(1500)(8.34)](75 - 60) = .19 \times 10^6 \text{ BTU} \]

b) Heat to 100°F
\[ Q_{in} = 1[(1500)(8.34)](100 - 75) = .31 \times 10^6 \text{ BTU} \]

c) Drain
\[ Q_{out} = 1[(1500)(8.34)](60 - 100) = -.50 \times 10^6 \text{ BTU} \]

4. Second Rinse
a) Fill with 1500 gal @ 100°F
\[ Q_{in} = 1[(1500)(8.34)](100 - 60) = .50 \times 10^6 \text{ BTU} \]

b) Drain
\[ Q_{out} = -.50 \times 10^6 \text{ BTU} \]

5. Third Rinse
a) Fill with 1500 gal @ 100°F
\[ Q_{in} = .50 \times 10^6 \text{ BTU} \]

b) Drain
\[ Q_{out} = -.50 \times 10^6 \text{ BTU} \]
<table>
<thead>
<tr>
<th></th>
<th>Heat In</th>
<th>BTU x 10^6</th>
<th>Heat Added</th>
<th>Heat Out</th>
<th>Heat Exchanged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q_{in_1}</td>
<td>1.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q_{in_2}</td>
<td></td>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q_{out_1}</td>
<td>1.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q_{in_3}</td>
<td>4.25</td>
<td>1.80</td>
<td></td>
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</tr>
<tr>
<td>Q_{out_2}</td>
<td></td>
<td>4.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q_{in_4}</td>
<td>1.50</td>
<td></td>
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</tr>
<tr>
<td>Q_{in_5}</td>
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<td></td>
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</tr>
<tr>
<td>Q_{exc_1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.45</td>
</tr>
<tr>
<td>Q_{out_3}</td>
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</tr>
<tr>
<td>Q_{in_7}</td>
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<tr>
<td>Q_{in_8}</td>
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<tr>
<td>Q_{in_9}</td>
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<tr>
<td>Q_{out_5}</td>
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<td></td>
<td>0.50</td>
</tr>
<tr>
<td>Q_{in_10}</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q_{out_6}</td>
<td>8.19</td>
<td>2.96</td>
<td>10.70</td>
<td></td>
<td>0.45</td>
</tr>
</tbody>
</table>
\[
Q_{net} = Q_{in} + Q_{add} - Q_{recovered}
\]
\[
= 11.15 - .45 = 10.7 \times 10^6 \text{ BTU}
\]
\[.
\text{Required} \quad \frac{10.7 \times 10^6 \text{ BTU}}{1200 \text{ lbs}} = 8917 \text{ BTU/lb}
\]

With ideal recovery: (assuming all heat up to a 20°F differential can be recovered)

1500 gal @ 190°F = 1.63 \times 10^6 \text{ BTU}

1500 gal @ 172°F = 1.40

10000 gal @ 100°F = 3.34

4500 gal @ 80°F = \underline{.75} \\
\underline{7.12 \times 10^6 \text{ BTU}}

Potential required: \[
\frac{(10.7 - 7.12) \times 10^6 \text{ BTU}}{1200 \text{ lbs}} = 2983 \text{ BTU/lb}
\]
Package Dyeing

Fiber Reactive Dyes

1. Standard wet out
   \[ Q_{\text{in}} + \text{added} = 5.90 \times 10^6 \text{ BTU} \]
   \[ Q_{\text{out}} = \text{5.90} \times 10^6 \]

2. Scour
   a) Fill with 1500 gal @ 100°F \( .50 \times 10^6 \) BTU
   b) Heat to 140°F \( .50 \times 10^6 \) BTU
   c) Drain \( 1.90 \times 10^6 \) BTU

3. Rinse
   a) Fill with 3000 gal @ 120°F \( 1.50 \times 10^6 \)
   b) Drain \( 1.50 \times 10^6 \)

4. Rinse
   a) Fill with 3000 gal @ 120°F \( 1.50 \times 10^6 \)
   b) Drain \( 1.50 \times 10^6 \)

5. Circulate wash with @ 120°F for 6 min \( 4.25 \times 10^6 \)
   \[ l(1416 \times 6 \times 8.34)(120 - 60) = 4.25 \times 10^6 \]

6. Dye
   a) Fill with 3000 gal @ 120°F \( 1.50 \times 10^6 \)
   b) Heat to 200°F \( 2.00 \times 10^6 \)
   c) Drain \( 3.50 \times 10^6 \)
7. Dye

   a) Fill with 1500 gal @ 180°F \( 1.50 \times 10^6 \) gal
   b) Heat to 192°F \( .15 \times 10^6 \)
   c) Drain \( 1.65 \times 10^6 \) gal

8. Running wash @ 120°F for 12 min

\[
1(1416 \times 12 \times 8.34)(120 - 60) = 8.50 \times 10^6 \ \text{in and out}
\]

Total \( 27.80 \times 10^6 \)

Required \( 27.80 \times 10^6 \) BTU / 1200 lbs = 23167 BTU/lb.

With ideal recovery:

- 1500 gal @ 180 = \( 1.50 \times 10^6 \) BTU
- 3000 gal @ 172 = \( 2.80 \times 10^6 \) BTU
- 1500 gal @ 120 = \( .75 \times 10^6 \) BTU
- 33000 gal @ 100 = \( 11.01 \times 10^6 \) BTU
- 16.06 \( \times 10^6 \) BTU

Potential Required \( \frac{(27.80 - 16.06) \times 10^6}{1200} \) = 9783 BTU/lb.

**Blend 41 Bleach**

- fill 1500 @ 120
  - heat to 200
  - wash \( 1416 \times 8.34 \times 20(160 - 60) \) = \( 23.62 \)
  - fill 1500 @ 160
  - heat to 192
  - fill @ 180
  - heat to 192
  - fill @ 160
  - fill @ 160

\[
\begin{align*}
\text{fill} & \quad 1500(8.34)(200 - 60) = 1.75 \\
\text{heat to} & \quad 200 \\
\text{wash} & \quad 1416 \times 8.34 \times 20(160 - 60) = 23.62 \\
\text{fill} & \quad 1500(8.34)(192 - 60) = 1.65 \\
\text{heat to} & \quad 192 \\
\text{fill} @ & \quad 180 \\
\text{heat to} & \quad 192 \\
\text{fill} @ & \quad 160 \\
\text{fill} @ & \quad 1500(8.34)(160 - 60) = 1.25 \\
\end{align*}
\]

\[
\frac{1.25}{31.17}
\]
\[
\frac{31.17 \times 10^6}{1200} = 25,975 \text{ BTU/lb.}
\]

With ideal recovery:

\[
1500 \text{ gal @ 180} = 1.50 \times 10^6
\]
\[
3000 \text{ gal @ 172} = 2.80
\]
\[
29900 \text{ gal @ 140} = 19.95
\]
\[
1500 \text{ gal @ 100} = \frac{.50}{24.75 \times 10^6} \text{ BTU}
\]

\[
\frac{(31.17 - 24.75)(10^6)}{1200} = 5350 \text{ BTU/lb}
\]

\text{Napthol}

\[
\text{in} \quad \frac{40.86 \times 10^6}{1200} = 34,050 \text{ BTU/lb}
\]

With ideal recovery:

\[
1500 \text{ gal @ 172°} = 1.40
\]
\[
32900 \text{ gal @ 120°} = 16.96
\]
\[
21300 \text{ gal @ 100°} = 7.11
\]
\[
1500 \text{ gal @ 80°} = .25
\]
\[
28400 \text{ gal @ 70°} = \frac{2.37}{27.59}
\]

\[
\frac{(40.86 - 27.59)(10^6)}{1200} = 11,058 \text{ BTU/lb}
\]

\text{Disperse}

\[
\frac{22.74 \times 10^6}{1200} = 18,950 \text{ BTU/lb}
\]

-144-
With ideal recovery:

\[
\begin{align*}
1500 \cdot @160 &= 1.25 \\
19960 \cdot @140 &= 13.32 \\
1500 \cdot @120 &= 0.75 \\
5600 \cdot @80 &= \frac{0.93}{16.25} \\
\end{align*}
\]

\[
\frac{(22.74 - 16.25)(10^6)}{1200} = 5400 \text{ BTU/lb}
\]

38 Bleach

**IN:**

\[
\begin{align*}
14200(8.34)(80 - 60) &= 2.37 + 1500(8.34)(240 - 180) \\
14200(8.34)(140 - 60) &= 9.47 \\
31400(8.34)(160 - 60) &= 23.69 \\
1500(180 - 60) &= \frac{1.50}{39.53} \\
\end{align*}
\]

\[
\frac{39.53 \times 10^6}{1200} = 32,942 \text{ BTU/lb}
\]

**OUT:**

\[
\begin{align*}
1500(8.34) \cdot @220^\circ &= 2.00 \\
4500(8.34) \cdot @172^\circ &= 4.20 \\
28400(8.34) \cdot @140^\circ &= 18.95 \\
14200(8.34) \cdot @120^\circ &= \frac{7.11}{32.26} \\
\end{align*}
\]

-145-
41 Bleach

IN:

\[
\begin{align*}
1500(8.34)(200 - 60) &= 1.75 \\
3000(8.34)(192 - 60) &= 3.30 \\
29900(8.34)(160 - 60) &= 24.94 \\
1500(8.34)(120 - 60) &= .75 \\
30.74 &
\end{align*}
\]

OUT:

\[
\begin{align*}
1500(180 - 60) &= 1.5 \\
31400(160 - 60) &= 26.19 \\
3000(120 - 60) &= 1.5 \\
29.19 &
\end{align*}
\]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>8,900</td>
<td>7.6</td>
<td>(676)</td>
<td>3,000</td>
<td>(228)</td>
</tr>
<tr>
<td>Fiber Reactive</td>
<td>23,200</td>
<td>12.0</td>
<td>(2784)</td>
<td>9,800</td>
<td>(1176)</td>
</tr>
<tr>
<td>Blend 41 Bleach</td>
<td>26,000</td>
<td>4.0</td>
<td>(1040)</td>
<td>5,400</td>
<td>(200)</td>
</tr>
<tr>
<td>Napthol</td>
<td>34,100</td>
<td>1.2</td>
<td>(400)</td>
<td>11,100</td>
<td>(100)</td>
</tr>
<tr>
<td>Disperse</td>
<td>19,000</td>
<td>23.0</td>
<td>(4400)</td>
<td>5,400</td>
<td>(1200)</td>
</tr>
<tr>
<td>Blend: Disperse and Reactive</td>
<td>22,000</td>
<td>9.0</td>
<td>(1980)</td>
<td>7,500</td>
<td>(675)</td>
</tr>
<tr>
<td>38 Bleach</td>
<td>33,600</td>
<td>28.7</td>
<td>(9471)</td>
<td>7,000</td>
<td>(2009)</td>
</tr>
<tr>
<td>41 Bleach</td>
<td>30,000</td>
<td>7.5</td>
<td>(2250)</td>
<td>6,000</td>
<td>(450)</td>
</tr>
<tr>
<td>Vat</td>
<td>20,000</td>
<td>7.0</td>
<td>(1400)</td>
<td>5,000</td>
<td>(350)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22421</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5713</td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{5713}{22421} = 25\% \text{ of energy requirements for processes without heat recovery is possible with heat recovery.}
\]

Electrical: Given -- 100 H.P. motors

43307 gal water consumed in "typical" dye cycle

437 GPM pump capacity

\[
\frac{43307 \text{ gal}}{\frac{437 \text{ gal/min}}{60 \text{ min/hr}}} = 165 \text{ H.P. - HRS}
\]

-146-
(165 H.P. - HRS)(.7457 KW - HRS/H.P. - HR) = .10 KW - HRS

1200 lbs (avg. load)

(.10 KW - HRS/lb)(11,000 BTU/KW - HR) = 1,100 BTU/lb
APPENDIX E

SLASHING

The following information was obtained by letter from D. L. Nehrenberg of E. I. duPont de Nemours and Company based upon the production of a broad-cloth fabric (65/35 PE/C, 6000 ends, 50/1 count, 128 x 72. on a 10 can slasher operating at 90 ypm:

The thermal energy requirements of a slashing process can be divided into four areas:

A. Size preparation or cooking
B. Replacing heat losses
C. Heating of the warp yarns
D. Vaporizing water from the warp yarns

A. Size Preparation

1. Assume:
   100 lbs. PVA
   5 lbs. Wax
   1160 lbs. water (140 gallons)

2. BTU Required

   \[
   [(1160)(1.0) + 105 (.4)] [212° - 62°] = 180,000 \text{ BTU}
   \]

3. Steam Required

   185 Pounds

4. Finished: Weight = 1450 lbs.

   Volume = 172 gallons

   Solids = 7.1%

5. Heat Demand:

   1045 BTU/Gallon of Size

   16,000 BTU/100 Pounds of Yarn (at 130% Wet pick-up)
B. Heat Losses

1. Pipeline and Storage
   (12°F Loss, 130 WPU)
   
2. Size Box
   (Convection Losses)
   
3. Slasher Dry Can Losses
   (10 Can Slasher)
   
TOTAL HEAT LOSSES:

C. Heat Yarn

(100)(0.25)(235° - 75°) = 4,000

D. Heat to Vaporize Water

<table>
<thead>
<tr>
<th>Example</th>
<th>Solution Solids %</th>
<th>Add-On %</th>
<th>WPU %</th>
<th>BTU/100 Lbs. Yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7.1</td>
<td>9.2</td>
<td>130</td>
<td>160,000</td>
</tr>
<tr>
<td>B</td>
<td>3.7</td>
<td>4.6</td>
<td>125</td>
<td>160,000</td>
</tr>
<tr>
<td>C</td>
<td>10.3</td>
<td>13.9</td>
<td>135</td>
<td>160,000</td>
</tr>
<tr>
<td>D</td>
<td>3.7</td>
<td>4.8</td>
<td>130</td>
<td>166,500</td>
</tr>
<tr>
<td>E</td>
<td>10.3</td>
<td>13.4</td>
<td>130</td>
<td>154,000</td>
</tr>
</tbody>
</table>

Calculation:

\[(130)(0.929)(1000)(\frac{1}{0.75} \text{ Eff.}) = 160,000\]

Total: BTU/100 lbs. Yarn

<table>
<thead>
<tr>
<th>Example</th>
<th>BTU/100 Lbs. Yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>16,000</td>
</tr>
<tr>
<td>B</td>
<td>20,000</td>
</tr>
<tr>
<td>C</td>
<td>4,000</td>
</tr>
<tr>
<td>D</td>
<td>160,000</td>
</tr>
</tbody>
</table>

\[
200,000 \text{ or } \frac{200,000}{100} = 2000 \text{ BTU/lb}
\]
Comparison of Slashing Methods

<table>
<thead>
<tr>
<th></th>
<th>Dry Can Slasher</th>
<th>Hot Air Slasher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Dip</td>
<td>Double Dip</td>
</tr>
<tr>
<td>BTU lbs. Yarn</td>
<td>2,000</td>
<td>3,100</td>
</tr>
</tbody>
</table>

Communication from a different source indicated the following information. Most slashing is can dried and requires 1.6 pounds of steam per pound of yarn to process.

\[
\text{BTU/lb yarn} = 1.6 \times 1,000 = 1,600 \text{ BTU/lb}
\]

Since the amount of slashing samples is limited, a straight average will be assumed for process requirements except hot air slashing will be omitted.

\[
\frac{2,000 + 3,100 + 1,600}{3} = 2,233 \text{ BTU/lb}
\]
APPENDIX F

Continuous Preparation Range

<table>
<thead>
<tr>
<th>Source 1 (54)</th>
<th>Sample</th>
<th>Thermal, BTU/lb.</th>
<th>Electrical, BTU/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source 2 (59)</td>
<td></td>
<td>1,856</td>
<td>N/A</td>
</tr>
<tr>
<td>Source 3 (59)</td>
<td></td>
<td>2,365</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Since source 1 includes the drying step, it will not be included. Weight dried is included under dryers.

\[
\text{Average } \frac{1,856 + 2,365}{2} = 2,111 \text{ BTU/lb.}
\]
APPENDIX G

Fabric Dye Range

<table>
<thead>
<tr>
<th>Source 1 (54)</th>
<th>Sample</th>
<th>Thermal, BTU/lb.</th>
<th>Electrical, BTU/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,981</td>
<td>158</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6,737</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5,547</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>5,755</td>
<td>149</td>
<td></td>
</tr>
</tbody>
</table>

Source 2 (55)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thermal, BTU/lb.</th>
<th>Electrical, BTU/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3,330</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>4,830</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>3,660</td>
<td>-</td>
</tr>
<tr>
<td>Average</td>
<td>3,940</td>
<td></td>
</tr>
</tbody>
</table>

Source 3

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thermal, BTU/lb.</th>
<th>Electrical, BTU/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3,493</td>
<td>-</td>
</tr>
</tbody>
</table>

The straight thermal average of the three sources (4,400 BTU/lb.) will be employed as the process consumption along with 149 BTU/lb. for electrical requirement.
APPENDIX H

Continuous Finishing Range

Measured: 150 yd/min production speed
6.8 x 10^6 BTU/HR predryer consumption
2.7 x 10^6 BTU/HR tenter frame consumption
3.6 x 10^6 BTU/HR curing oven consumption

Given: weight of fabric: 1.59 lin. yds/lb

Assumed: 47-can pre-pad dryer consumes 1,200 BTU/lb

Production

(150 yrd/min)(60 min/hr)(\frac{1}{1.59} lbs/yd) = 5,660 lb/hr

Thermal energy consumption

(6.8 x 10^6) + (2.7 x 10^6) + (3.6 x 10^6) + (1,200)(5,660) = 19.89 x 10^6 BTU/hr

\frac{19.89 x 10^6 \text{ BTU/hr}}{5,660 \text{ lb/hr}} = 3,514 \text{ BTU/lb}

Similar measurements and calculations are summarized below under source 1.

<table>
<thead>
<tr>
<th>Source 1</th>
<th>Fabric Weight, lbs/yd</th>
<th>Production Speed, yd/min</th>
<th>Total Consumption, BTU/hr</th>
<th>BTU/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.63</td>
<td>150</td>
<td>19.89 x 10^6</td>
<td>3,500</td>
</tr>
<tr>
<td>2</td>
<td>.72</td>
<td>120</td>
<td>21.06 x 10^6</td>
<td>4,000</td>
</tr>
<tr>
<td>3</td>
<td>.63</td>
<td>95</td>
<td>13.42 x 10^6</td>
<td>3,800</td>
</tr>
<tr>
<td>4</td>
<td>.64</td>
<td>160</td>
<td>14.27 x 10^6</td>
<td>2,300</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>3,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source 2</th>
<th>Thermal, BTU/lb</th>
<th>Electrical, BTU/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3,837</td>
<td>242</td>
</tr>
<tr>
<td>2</td>
<td>6,129</td>
<td>305</td>
</tr>
<tr>
<td>3</td>
<td>3,066</td>
<td>219</td>
</tr>
<tr>
<td>Average</td>
<td>4,344</td>
<td>255</td>
</tr>
<tr>
<td>Source 3</td>
<td>Thermal, BTU/lb</td>
<td>Electrical, BTU/lb</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>4 oz PES/cotton shirting-dyed (42&quot;)</td>
<td>27,000</td>
<td>1,000</td>
</tr>
<tr>
<td>4 oz cotton shirting, dyed (42&quot;)</td>
<td>17,000</td>
<td>1,400</td>
</tr>
<tr>
<td>3 oz knitted nylon shirting-dyed (90&quot;)</td>
<td>8,000</td>
<td>600</td>
</tr>
<tr>
<td>6 oz PES/cotton sheeting-dyed (90&quot;)</td>
<td>22,750</td>
<td>800</td>
</tr>
<tr>
<td>8 oz cotton satin drill-dyed (36&quot;)</td>
<td>15,500</td>
<td>1,000</td>
</tr>
<tr>
<td>3 oz tubular knitted underwear, white</td>
<td>5,400</td>
<td>500</td>
</tr>
<tr>
<td>3 oz tubular knitted underwear, dyed</td>
<td>13,300</td>
<td>700</td>
</tr>
<tr>
<td>7 oz polyester textured jersey (54&quot;)</td>
<td>10,000</td>
<td>1,500</td>
</tr>
<tr>
<td>1-5 oz nylon taffeta (36&quot;)</td>
<td>8,000</td>
<td>1,000</td>
</tr>
<tr>
<td>4 oz PES/cotton print cloth (36&quot;)</td>
<td>25,400</td>
<td>1,600</td>
</tr>
<tr>
<td>4 oz cotton print cloth (36&quot;)</td>
<td>20,200</td>
<td>1,600</td>
</tr>
<tr>
<td>Average</td>
<td>15,686</td>
<td>1,064</td>
</tr>
<tr>
<td>Source Average</td>
<td>7,810</td>
<td>660</td>
</tr>
</tbody>
</table>
APPENDIX J

KUSTER CONTINUOUS DYE RANGE

The following table summarizes measured steam consumption for a Kuster and Tac. It includes flow to the wash box, the vertical, and the horizontal steamers.

**Thermal:**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>POUNDS DYED</th>
<th>STEAM USED, LBS</th>
<th>BTU/LB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>485,820</td>
<td>6,943,000</td>
<td>14,290</td>
</tr>
<tr>
<td>Feb.</td>
<td>818,823</td>
<td>11,549,000</td>
<td>14,100</td>
</tr>
<tr>
<td>Mar.</td>
<td>1,119,495</td>
<td>12,686,000</td>
<td>11,330</td>
</tr>
<tr>
<td>Apr.</td>
<td>998,916</td>
<td>9,741,000</td>
<td>9,750</td>
</tr>
<tr>
<td>May</td>
<td>1,439,382</td>
<td>12,398,000</td>
<td>8,610</td>
</tr>
<tr>
<td>June</td>
<td>939,100</td>
<td>8,986,000</td>
<td>9,570</td>
</tr>
<tr>
<td>July</td>
<td>608,585</td>
<td>4,514,000</td>
<td>7,420</td>
</tr>
<tr>
<td>Aug.</td>
<td>1,479,548</td>
<td>12,509,000</td>
<td>8,450</td>
</tr>
<tr>
<td>Sept.</td>
<td>1,365,570</td>
<td>10,815,000</td>
<td>7,920</td>
</tr>
<tr>
<td>Oct.</td>
<td>982,410</td>
<td>8,217,000</td>
<td>8,360</td>
</tr>
<tr>
<td></td>
<td>10,237,649</td>
<td>98,358,000</td>
<td>9,600</td>
</tr>
</tbody>
</table>

**Electrical:**

Given: 800 KW measured usage
2400 lbs/hr average production rate

While 800 KW was measured and assigned to the Kuster Dye Range, it includes agitators employed in dye preparation and other auxilliary equipment. Since other process measurements did not include equipment associated but not directly part of the process, only the directly related electrical requirements will be included. A motor load of 740 H.P., including 400 H.P. of vacuum extraction was directly associated with the range. An instantaneous load measurement indicated operation at approximately 50% of rating. Therefore, 283 KW will be used as an electrical requirement.

\[
\frac{283 \text{ KW}}{2400 \text{ lbs/hr}} = 0.12 \frac{\text{KW-HRS}}{\text{lb}}
\]
This dye range has six exhaust ducts joined to a common exhaust fan. Four of the ducts are from the vertical steamer and two from the horizontal steamer. All ducts are 16 inches in diameter. The following measurements were obtained:

- 1,000 feet per minute @ 101°F from both horizontal steamer ducts
- 400 feet per minute @ 170°F from two vertical steamer ducts
- 920 feet per minute @ 170°F from two vertical steamer ducts
\[ F_{HS} = AV = \frac{\pi(8)^2}{144} (1000)(2) = 2793 \text{ Ft}^3/\text{min} \]

\[ F_{VS} = AV = \frac{\pi(8)^2}{144} (400)(2) + \frac{\pi(8)^2(920)(2)}{144} = 3686 \text{ Ft}^3/\text{min} \]

\[ F_{TOT} = 2793 + 3686 = 6479 \text{ Ft}^3/\text{min} \]

\[ Q_{Exh} \text{ (assuming all flow which exits steamers is saturated steam @ 210°F)} \]

\[ V_g = 72.82 \, \text{Ft}^3/\text{lb} \]

\[ h_g = 1149.7 \, \text{BTU/ lb} = 1000 \, \text{BTU/ lb} \text{ (net)} \]

\[ q = \frac{F_h \cdot V}{V_g} = \frac{6479 \, \text{Ft}^3/\text{min}}{72.82 \, \text{Ft}^3/\text{lb}} \cdot \frac{1000 \, \text{BTU}}{\text{lb}} \approx 89,000 \, \text{BTU/ min} \]

Based upon a line speed of 2400 lbs/hr of product

\[ Q_{Exh} = 8900 \, \text{BTU/ min} \times \frac{60 \, \text{min}}{\text{hr.}} = 5.34 \times 10^6 \, \text{BTU/ hr} = 2225 \, \text{BTU/lb}. \]

\[ Q_{Exh} \text{ (assuming exhaust steam is diluted with air from enter and exit seals)} \]

\[ Q_{Exh} = Q_{Air} + Q_{Steam} \]

\[ q_{Air_{HS}} = \rho AVCp\Delta Tt \]

where: \[ \rho = \frac{1}{r} = \frac{p_a}{RT} \]

\[ p_a = \text{partial pressure of air @ 191°F,} \]

\[ p_a = 14.7 - 9.5 = 5.2 \, \text{psia} \]

\[ A = \text{area of duct, Ft}^2 \]

\[ V = \text{velocity, FT/ min} \]
\[ \text{Cp = specific heat} = 0.24 \frac{\text{BTU}}{\text{lb} \cdot ^\circ \text{F}} \]

\[ \Delta T = 191 - 75 = 116^\circ \text{F} \]

\[ t = \text{time} \]

\[ q_{\text{Air}_\text{HS}} = \frac{5.2(144)}{53.3(651)} \frac{\pi(8)^2}{144} (2793)(0.24)(116)(60) = 140600 \text{ BTU/HR} \]

\[ q_{\text{Stream}_\text{HS}} = \rho \text{AV} \Delta h t \quad \text{where: } \rho = 0.024 \odot 191^\circ \text{F} \]

\[ \Delta h \approx 1000 \]

\[ = 0.024 \frac{\pi(8)^2}{144} (2793)(1000)(60) \]

\[ = 5.62 \times 10^6 \text{ BTU/HR} \]

\[ q_{\text{Exh}_\text{HS}} = \frac{5.2}{14.7} (140600) + \frac{14.7 - 5.2}{14.7} (5.62 \times 10^6) = 3.68 \times 10^6 \text{ BTU/HR} \]

\[ q_{\text{Air}_\text{VS}} = \frac{8.7(144)}{53.3(630)} \frac{\pi(8)^2}{144} (3686)(0.24)(95)(60) \quad p_a @ 170^\circ \text{F} = 14.7 - 6 = 8.7 \text{ psia} \]

\[ = 262700 \text{ BTU/HR} \]

\[ q_{\text{Stream}_\text{VS}} = 0.016 \frac{\pi(8)^2}{144} (3686)(1000)(60) \quad \rho = 0.016 \odot 170^\circ \text{F} \]

\[ = 4.94 \times 10^6 \text{ BTU/HR} \]

\[ q_{\text{Exh}_\text{VS}} = \frac{8.7}{14.7} (262700) + \left(\frac{14.7 - 8.7}{14.7}\right)(4.9 \times 10^6) = 2.17 \times 10^6 \text{ BTU/HR} \]

\[ q_{\text{Exh}} = (3.08 + 2.17) \times 10^6 \frac{\text{BTU/HR}}{2400 \text{ lbs/HR}} = 2400 \text{ BTU/lb} \]

-158-
APPENDIX K

DRYER CALCULATION

Given: Fabric Dry Weight: .77 lb/Lin Yd.
Fabric Width:
Fabric Entering Moisture & Temp: 30% & 70°F
Fabric Speed 1380 lbsF/Hr.; 414 lbs/Hr water
Drying Temp.: 350°F

1. Heat Required to Remove Water

\[ Q_{H_2O} = Q_{Heat \ H_2O} + Q_{EVAP} + Q_{Temp \ Rise} \]
\[ = C_{Pw} \Delta T + Q + C_{Pw} \Delta T \]
\[ = 1(1)(212-70) + 970 + .48(1)(350-212) \]
\[ = 142 + 970 + 66 = 1178 \text{ BTU/lb}_w \]

\[ \frac{1178 \text{ BTU/lb}_w}{1380 \text{ lb}_F/\text{HR}} \times \frac{414 \text{ lb}_w}{\text{HR}} = 353 \text{ BTU/lb}_F \]

2. Heat Required to Raise Temperature of Fabric

\[ Q_F = C_{Pw} \Delta T \]
\[ = .5(1)(350-70) \]
\[ = 140 \text{ BTU/lb}_F \]

3. Heat Required to Make up for Losses

\[ q_L = UA\Delta T \]
\[ q_L = .1(2000)(350-80) \]
\[ q_L = 54000 \text{ BTU/HR} \]
\[ \frac{54000 \text{ BTU/HR}}{1380 \text{ lb}_F/\text{HR}} = 39 \text{ BTU/lb}_F \]

4. Heat Required to Raise Temperature of Exhaust Air

Assume: 24 lbAir/lbH2O
150 lbAir/lbOil

\[ \frac{1380 \text{ lb}_F}{\text{HR}} \times \frac{414 \text{ lb}_w}{\text{HR}} = 13.8 \text{ lbs}_\text{Oil}/\text{HR} \]
Air Required = 24(414) + 150(13.8)
           = 9936 + 2070 + 12006 lb\_air/HR

\[ Q_{\text{Air}} = C \cdot W \cdot A \cdot T \]
\[ = 0.24(12006)(350 - 70) \]
\[ = 80700 \text{ BTU/HR} \]
\[ = \frac{80700}{1380} = 585 \text{ BTU/lb}_F \]

By varying the amount of incoming moisture and the exit humidity ratio, the following table can be constructed for the other given conditions with like calculations. The tabulated results are illustrated in Figure 10.
<table>
<thead>
<tr>
<th>$\text{lbs}_{\text{H}<em>2\text{O}}/\text{lbs}</em>{\text{F}}$</th>
<th>$\text{BTU/\text{lbs}_{\text{F}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>.01</td>
<td>.02</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
<td>140</td>
</tr>
<tr>
<td>Losses</td>
<td>39</td>
</tr>
<tr>
<td>Air</td>
<td>1109</td>
</tr>
<tr>
<td>Total</td>
<td>1465</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
<td>140</td>
</tr>
<tr>
<td>Losses</td>
<td>39</td>
</tr>
<tr>
<td>Air</td>
<td>604</td>
</tr>
<tr>
<td>Total</td>
<td>960</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
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<tr>
<td>Losses</td>
<td>39</td>
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<tr>
<td>Air</td>
<td>343.7</td>
</tr>
<tr>
<td>Total</td>
<td>698</td>
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<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
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</tr>
<tr>
<td>Losses</td>
<td>39</td>
</tr>
<tr>
<td>Air</td>
<td>302.4</td>
</tr>
<tr>
<td>Total</td>
<td>658</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
<td>140</td>
</tr>
<tr>
<td>Losses</td>
<td>39</td>
</tr>
<tr>
<td>Air</td>
<td>201.6</td>
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<tr>
<td>Total</td>
<td>557</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
<td>140</td>
</tr>
<tr>
<td>Losses</td>
<td>39</td>
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<tr>
<td>Air</td>
<td>168</td>
</tr>
<tr>
<td>Total</td>
<td>523</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>176.5</td>
</tr>
<tr>
<td>Fabric</td>
<td>140</td>
</tr>
<tr>
<td>Losses</td>
<td>39</td>
</tr>
<tr>
<td>Air</td>
<td>151</td>
</tr>
<tr>
<td>Total</td>
<td>506</td>
</tr>
</tbody>
</table>
QUARTERLY PROGRESS REPORT
June 1, 1976 to September 1, 1976

Energy Conservation in the
Textile Industry

Contract No. E(40-1)-5099
Research Project A-1853 & E-27-642

Prepared For
The Energy Research and Development Administration
Buildings and Industry Conservation
Washington, D. C.

by
The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

September 1, 1976
INTRODUCTION

Research Project A-1853 & E-27-642 is being conducted for the Energy Research and Development Administration pursuant to contract E(40-1)-5099 by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. The purpose of this research project is to identify and demonstrate process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies. This will include development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements and dissemination of the research results throughout the industry.

Phase I of the project has the specific objectives of:

1) Identifying major energy intensive processes which may be subject to energy conserving modifications and to determine the energy conservation potential for these process modifications and

2) Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:

1) Developing and demonstrating, on a pilot or full scale basis, energy conserving modifications for selected processes identified in Phase I,

2) Examining cost/benefit relationships of proposed process modifications and

3) Disseminating the results of the research to industry.

This quarterly progress report describes the activities and accomplishments relative to this project for the time period from June 1, 1976 to September 1, 1976.

RESEARCH ACTIVITIES

Phase I

In order to define energy used in the wet processing segment of the textile industry in a manner which has practical utility, a definition of the energy used in major processes was required. Industry energy usage could then be estimated by summing specific process usage to an overall quantity or by reducing each process to an energy per pound basis and then multiplying by the number of pounds utilizing the specific process. The acquisition of data has proceeded in three areas--literature search, company audits, and process measurements. In addition,
a matrix has been completed to facilitate the use of the data. The matrix details the end use of all major raw material and the processes required for each end use.

In order to derive an industry-wide matrix in BTU's/lb. of material/process utilizing the data collected in Phase I, a detailed breakdown of production characteristics was required. To accomplish this, data is being obtained that details poundage for types of fibers and types of textile structures and matches poundage with the wet process used in dyeing the material. For example the matrix shows that out of 1077 million pounds of continuous polyester filament consumed by apparel in 1973, 90 percent went into knitted yarns and most of these knits were dyed by pressure-batch processes.

Efforts to date have uncovered some unexpected results. First, almost no information has been published concerning energy usage of specific wet processing textile equipment. It is suspected that the lack of detailed data obtainable from a literature search is because of the historically low cost of energy as a percentage of sales and therefore a lack of energy management. Also, a specific equipment design is employed for the manufacture of myriad end products. Each end product generates its own parameters which differently affect energy usage in the particular wet processing equipment. Therefore, very little data can be extracted from a literature search.

Secondly, the technical expertise required to generate energy data at textile mills has not existed. Therefore, the data necessary to define a textile wet process energy usage must be acquired by a direct working relationship with individuals in those mills which have recently begun to install instrumentation and to acquire energy use data.

It has been found during this first quarter's effort that equipment manufacturers do not consider energy as an engineering criterion in equipment design because their customers do not demand it. Of primary interest to the customer is the flexibility of each piece of new equipment to adapt to different fibers, fabrics, weaves, etc. Therefore no energy consumption data is available for process equipment from the equipment manufacturers.

To acquire the necessary energy use data contact has been established with the major textile companies located in the Southeast. Where the conditions were favorable visits were made to operating facilities to determine the processes utilized and the energy use data available. Results to date indicate a high degree of cooperation from industry members but a small amount of useful data available. The very large companies indicate they have the data but are reluctant to release it for fear of loss of competitive advantage. Personal relationships with individual members of firms have worked best in acquiring these data.

To date visits have been made to the following equipment manufacturers and textile mills:

-2-
<table>
<thead>
<tr>
<th>Company</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaston County Dyeing Machine Co.</td>
<td>Equipment manufacturer (wet process)</td>
</tr>
<tr>
<td>Burlington Engineering Co.</td>
<td>Equipment manufacturer (wet process)</td>
</tr>
<tr>
<td>Marshall and Williams Co.</td>
<td>Equipment manufacturer (dryers)</td>
</tr>
<tr>
<td>Southern Phoenix</td>
<td>Finishing, slashing, drying</td>
</tr>
<tr>
<td>Columbus Mills</td>
<td>Atmospheric becks, Kuester (carpets)</td>
</tr>
<tr>
<td>West Point Pepperill</td>
<td>Atmospheric becks, rotary printing (carpets)</td>
</tr>
<tr>
<td>Springdale Mill</td>
<td></td>
</tr>
<tr>
<td>West Point Pepperill Opelika</td>
<td></td>
</tr>
<tr>
<td>Lyman Print Co.</td>
<td></td>
</tr>
<tr>
<td>Hanes Dyeing &amp; Finishing Co.</td>
<td></td>
</tr>
<tr>
<td>Shaw Industries, Star #4</td>
<td></td>
</tr>
<tr>
<td>Spring Mills, Inc.</td>
<td></td>
</tr>
<tr>
<td>Deering Milliken</td>
<td></td>
</tr>
<tr>
<td>Burlington Industries</td>
<td></td>
</tr>
<tr>
<td>Union Underwear</td>
<td></td>
</tr>
<tr>
<td>Standard Coosa Thatler</td>
<td></td>
</tr>
<tr>
<td>Graniteville Sibley</td>
<td></td>
</tr>
<tr>
<td>Graniteville Gregg</td>
<td></td>
</tr>
<tr>
<td>J. P. Stevens</td>
<td></td>
</tr>
<tr>
<td>Collins and Aikman Albermarle</td>
<td></td>
</tr>
<tr>
<td>Mobil Textile</td>
<td></td>
</tr>
<tr>
<td>Trend Mills</td>
<td></td>
</tr>
<tr>
<td>Thomaston Mills</td>
<td></td>
</tr>
</tbody>
</table>

Major wet processes for which sufficient data to calculate an energy balance is being acquired are as follows:

- Atmospheric beck dyeing
- Jig dyeing
- Pressure beck dyeing
- Jet dyeing
- Package yarn dyeing
- Beam dyeing
Energy, fuel and product through-put data are beginning to flow to the investigators and calculations of energy use per pound of product are in progress. It is anticipated that sufficient sets of data for each process listed above will be acquired to give a meaningful average for each process. Then from these averages with the information from the industry fabric usage matrix will be determined the by-process industry energy usage. This in turn will help determine those areas for further energy conservation research.

Phase II

Because of the previous experience of investigators in the School of Textile Engineering and because of related research being conducted into atmospheric beck dyeing of carpets, it was known that a major energy consuming process in the textile industry is atmospheric beck dyeing. Therefore, it was decided to continue current research on dye bath reuse under Phase II efforts of the project concurrently with the Phase I efforts.

Work has continued on the dye bath reuse with emphasis being placed on beck dyeing of carpet. In the process instead of dumping the spent dyebath at approximately 200°F after dyeing is complete, the temperature is lowered only slightly, analysed for chemical content, dye stuffs replenished to the proper level and material introduced and returned to boil. Obviously this results in much less energy usage as well as less usage of water and chemicals. Detailed energy calculations of the method have concluded a 67 percent savings in energy over the conventional drop-fill procedures assuming the use of five consecutive batches before the bath is expended. Laboratory experiments have shown that by adding the replenishment dye in increments over a fifteen minute period and by use of a commercial leveling agent, level, non-streaked dyeings can be accomplished while entering the bath at 175°F in a one foot wide beck. A four foot beck has been installed for scale-up of the process and preliminary dyeings have been carried out with excellent results. To adapt to industry conditions a 700 pound roll of carpet, dyeing procedures, dyestuffs and formulas have been obtained from a large company. This dyed carpet using the reuse method will be compared with the company dyed product.

FUTURE ACTIVITIES

It is planned that during the next period the majority of energy use data available will be obtained and the process energy balances calculated.
Also to be completed are the production and machinery-in-place matrices. Combining these will result in the by-process industry energy use and therefore recommendations for Phase II energy modification studies. During this period it is also anticipated that Phase II effort will be begun into an assessment of methods to improve predrying to include coupling of vacuum extraction with other techniques to decrease energy expenditure in drying/curing ovens. Phase II efforts will also continue into dye bath reuse with transfer of the demonstrated principles in carpets to fabrics and to package dyeing.
QUARTERLY PROGRESS REPORT
September 1, 1976 to December 1, 1976

Energy Conservation in the
Textile Industry

Contract No. E(40-1)-5099
Research Project A-1853 & E-27-642

Prepared For
The Energy Research and Development Administration
Buildings and Industry Conservation
Washington, D. C.

by
The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

December 6, 1976
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3. Disseminating the results of the research to industry.

This quarterly process report describes the activities and accomplishments relative to this project for the time period from September 1, 1976 to December 1, 1976.

RESEARCH ACTIVITIES

Phase I

As reported earlier, the lack of previously generated data from textile wet processing required an extension of Phase I of three months. Field trips have continued in coordinating equipment and instruments with major
companies so that the appropriate measurements can be obtained to meet this schedule.

Sufficient measurements have been accomplished to define energy consumption in the following processes:

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electrical</td>
</tr>
<tr>
<td>Atmospheric Dye Beck</td>
<td>.03 KW-Hrs/1b</td>
</tr>
<tr>
<td>Pressure Beck</td>
<td>.06 KW-Hrs/1b</td>
</tr>
<tr>
<td>Jet Dyeing</td>
<td>.08 KW-Hrs/1b</td>
</tr>
<tr>
<td>Package Dyeing</td>
<td>.09 KW-Hrs/1b</td>
</tr>
<tr>
<td>Continuous Carpet Dyeing</td>
<td></td>
</tr>
<tr>
<td>Drying and Heat Setting</td>
<td></td>
</tr>
</tbody>
</table>

The range of thermal energy consumption for a particular process is the result of variations in the product, process, or equipment utilized within a plant or among different plants. To illustrate, the kind of raw material (i.e., nylon, polyester, cotton, blends), the types of dyes (direct, fiber reactive, disperse, acid, etc.), specific dye recipes (highest temperature required, time at temperature, dye liquor ratio, number of prerinses, rinses, scour, etc.), the individual equipment configuration (accuracy of controls, power ratings of pumps and exhaust fans, conditions of seals, etc.), and the end product (weight per unit area, whether woven, tufted or knitted, esthetic qualities, chemical additives, etc.) all affect the amount of energy required to produce a pound of finished textile product.

Insight into the energy conservation potential for a particular process is obtained from measuring and calculating the energy flows sufficiently to define consumption. This insight, coupled with actual conservation results from different sources, enables the energy conservation potential for each process or equipment modification to be estimated.
A matrix has been compiled that details weights of various types of fiber processed by the textile industry in the base year 1973, the final textile forms of the fibers (knitted, broadwoven, etc.), and the weight of each that is manufactured by a particular textile wet process. The first two compilations were derived mainly from Textile Economics Bureau and Department of Commerce statistics, with some advice on nonaccessible information from knowledgeable experts in the textile and polymer industries. The base year of 1973 was chosen in that production in that period corresponded roughly with present production, with the period 1974-1976 showing marked decline in production followed by an upswing to earlier levels in the latter part of the span.

The weight of each textile form of the various fiber manufactured by a particular textile wet process was derived totally by communications with industrial experts in the textile-polymer fields and from the project participants' experience. No governmental or industrial organizations have compiled such data as confirmed by the American Textile Manufacturers Institute. Considering the scarcity of available data, however, the figures are considered adequate and will provide a beginning reference base.

A 1973 summary of equipment-in-place in the textile industry has been obtained from the Commerce Department. Based on a compilation made every ten years, the summary is the only information of its type available. The fiber consumption matrix, equipment-in-place data, and BTU per pound data from Phase I will be utilized to derive a BTU per process matrix for the entire industry. This BTU per process matrix and each estimate of process conservation potential will be combined to define the potential for energy conservation in manufacturing wet processes.

Explanation of the conditions and procedures which generated these results will be included in a formal report along with the other relevant wet processes at the end of Phase I.

Phase II

Certain processes have been identified during the close interaction with various textile plants where successful development of equipment and/or procedures would result in large energy savings. Therefore, the following areas have already been defined and effort initiated for Phase II development.
Atmospheric Dye Becks

Atmospheric dye becks (kettles) are common in the textile industry. The operation is fairly simple. Fabric to be dyed is placed in a large vessel to which water, dye and any supplemental chemicals are added. Generally the dyes require temperatures near the boiling point of water for setting. Water is normally heated by direct injection (sparging) of steam into the vessel. The type material, color and type dye determines the time held at elevated temperatures. One of the largest uses of atmospheric becks is in the carpet and rug industry.

Some generalizations apply to dyeing with atmospheric becks. First, electrical energy consumption is not only proportionately small but is constant and cannot readily be significantly reduced. Other than reducing exhaust fan power (for thermal reasons), potential savings of electrical energy are not considered sufficient to justify further investigation.

Secondly, the amount of thermal energy consumed in the form of hot water and steam can vary widely in any specific atmospheric dye beck cycle due to previously discussed variables. In general, energy consumption is proportional to the following:

- Dye liquor/fabric ratio
- Hold time at dye set temperature
- Number of adds and redyes
- Type of material being dyed

Outlined are our proposed equipment modifications for energy conservation in atmospheric dye-becks. It is necessary that this program be completed on the same piece of equipment for comparative analysis of each modification. Therefore, a program has been coordinated with a major carpet manufacturer to field test and obtain operating data on the effects of equipment modifications utilizing existing dye procedures. This program would obviously be subject to alterations depending on the outcome of proceeding steps.
A. Dye-Beck Energy Conservation from Minimal Equipment or Procedure Modifications

1. Cover for steam sparge chamber (this should eliminate the low pressures observed in this area and reduce direct superheated steam loss).

2. Steam sparge flow modifications
   a. Controls to regulate steam flow during dye cycle.
   b. Desuperheater and nozzle changes to optimize heat transfer.

3. Exhaust vent modifications
   a. Exhaust fan controls and modifications (change drive and add damper).
   b. Dye-beck door to reduce air available to beck and carpet.

4. Dye liquor ratio and temperature study
   a. Vary loading of beck to determine effect.
   b. Vary temperature set points for various products to determine effect throughout dye-beck.

Field measurements have indicated that 40%-60% of the thermal energy presently required in this process is being exhausted to the atmosphere unnecessarily. Completion of the outlined program should significantly reduce this waste and also the input demand for thermal energy. Considering present dyeing procedures and practical limitations upon obtaining all benefits, it is estimated that approximately 50% near term reduction in energy consumption is practicable with minimal modification to existing atmospheric dye becks.

B. Dye-Beck Energy Conservation from Dyebath Reuse in Carpet Beck Dyeing

In a separate program, a reduction in the requirements for water, energy and chemicals has been achieved on a pilot plant scale in the Georgia Tech laboratories by changes in carpet beck dyeing procedures. Instead of discharging the dyebath following each dye cycle, the hot, spent bath is
spectrophotometrically analyzed, reconstituted to the desired concentration of dyes and auxiliary chemicals, and reused.

Major effort this quarter in carpet dyebath recycle has been concentrated on preparations for a series of large pilot scale dyeings in a four-foot beck. Preliminary equipment check-out has been completed and dyeing formulas for the experiments on disperse dyeing of nylon carpet have been established. Test dyeings on two carpet styles have been completed and evaluated and indicate that the system will produce commercially acceptable carpet dyeings. A 650 pound roll of undyed commercial carpet is being used for experiments to demonstrate commercial quality disperse dyeing of nylon carpet to the same shade five times with reuse of the dyebath. These dyeings will be evaluated by Georgia Tech and by carpet manufacturers.

Laboratory work on acid dyeing with dyebath reuse has continued this quarter. A number of dyeing auxiliaries have been surveyed and an effective retarder system selected for use in the large scale dyeings. Similar experiments to select appropriate dyestuffs are now underway. Preliminary dyeings in a four-foot beck with acid dyes are being carried out to evaluate the acid dyeing system.

A number of discussions have been held this quarter with carpet dyers to consider problems in scale-up of the dyebath recycle system to commercial production. The principal problems appear to be in materials handling and at least two possible solutions to these problems are under active consideration. The major approach at this time is to couple two dye becks together, with the hot dye liquor pumped back and forth between becks in order to afer scour, change carpet batches, etc. Production speeds should be increased due to immediate reuse of the bath for each new batch.

Transfer of Dyebath Reuse Technology to Package and Fabric Dyeing

Efforts are underway to transfer the dyebath reuse technology to pressure package dyeing and atmospheric beck dyeing of fabrics. A one-pound Morton Laboratory Pressure Package Dyeing machine is being utilized in the yarn package studies. Packages of 100% polyester yarn are being investigated in the first stage. The undyed yarn, dyeing procedures, and dyed yarn color standards have been obtained from a large commercial plant. The yarn will
be dyed with disperse dyes using the reuse system via utilization of the machine's flow tank. To convert to other large-volume yarns that require ionic-type dye classes, such as polyester/cotton or 100% cotton, designs are being formulated to modify the machine with addition of two holding tanks. The holding tanks are necessary to pump the hot dye and auxiliary chemical baths back and forth. Mixing these in the dye chamber itself would degrade part of the dye to colored by-product, which prohibits the spectrophotometric analysis inherent in the dyebath reuse technology.

The fabric to be initially investigated will be nylon upholstery fabric with acid dyes. This system should correlate closely with the earlier dyebath reuse work on nylon carpets. Work will proceed initially on a one-foot beck to correlate with the carpet results, followed by scale-up to a four-foot beck. Other fabric systems requiring auxiliary holding tanks for the package dye system will also be investigated. These include 50/50 cotton/polyester and 100% cotton, both from a single plant. Designs are being formulated for the equipment modifications.

Dryer Fume Incineration

Dryers and tenter frames are utilized to remove moisture from the fabric and for heat setting. The wet fabric enters and is dried and heat set before exiting. Most have temperature controllers and exhaust ducts in each of several zones coupled to individual burners. The dryers fall into two main classes according to the internal air circulation configuration. A flow-through (transportation) dryer forces the hot air through the fabric with its internal fans while an impingement dryer directs high velocity air onto both surfaces of the fabric.

Since most dryers were installed prior to the swift jump in fuel prices, the design criterion was production rates and not energy efficiency. Hence, most existing dryers achieve production rates by "brute force" rather than matching production goals and equipment design. Therefore, an inexpensive method to reduce fuel consumption in existing dryers is to "tune" the dryer for the specific job. One way is to reduce exhaust air flow and force an increase in its humidity ratio. So doing eliminates the energy required to
heat up excess ambient air to dryer exhaust temperature. Unfortunately, the amount of exhaust reduction possible cannot be calculated on a general basis. Oils and resins are evaporated along with water causing varying amounts of smoke. Reducing exhaust increases the tendency of this smoke to blow out the entrance and exit slots which imposes a practical limit on exhaust reduction. Also, a limit is imposed based upon insurance regulations if combustibles are being evaporated.

Dryer exhaust temperatures vary with type of product; however, all dryers exhaust at temperatures high enough to warrant heat recovery. Conventional heat reclaiming devices such as heat wheels, heat pipes or finned tubes are rapidly fouled by the condensing oils and resins. Some schemes have been attempted to recover the oils but these generally lose the sensible heat. The combustible vapors are present in an air rich mixture, if these could be incinerated in a fume type incinerator the condensible problem would be eliminated and heat recovery would be enhanced.

This concept can be tested with a portable bench scale working model. This model can then be tested at various plants to determine the feasibility and applications criteria. The Phase II work will consist of constructing and testing the potential of fume incineration with heat recovery as an energy conservation system for textile plants.

Investigation of Low-Energy Methods of Predrying

Removing water from fabric with heat, and the conveying away of evaporated water requires large quantities of heat energy. Present mechanical devices such as squeeze rolls and vacuum slots are more efficient than heat for removing water down to about 30% to 40% moisture content in fabrics. However, indications are that 30% to 40% water removal via mechanical interaction is only the frontier. Accordingly, a portion of Phase II effort will be devoted to the design and development of methods to pre-dry fabrics prior to final drying in the tenter frame.

There are several ways in which this "ultra-predrying" may be performed. One method, currently being investigated is the use of continuous vacuum drying. This is similar to that which occurs with a vacuum oven. That is water is driven from a textile fabric when it "flashes" off at temperatures below 212°F. A series of experiments are in progress at this time in which
the feasibility of vacuum drying is being determined. In these experiments, we are determining residual moisture content in fabrics as a function of time at constant partial pressures and temperatures. Our target is those combinations of pressure and temperature which yield residual moisture contents of below 35% in less than 30 seconds. When these experiments are completed, the economics of this proposed pre-drying system will be evaluated. If the economics are favorable, as they are expected to be, work will commence on a continuous process.

Another method of drying fabrics would entail the use of a "machnozzle". This method has been described by Theusink of Holland. Essentially, this method is employed to accelerate the mass transport mechanism during drying. High pressure steam is forced through the fabric and in turn it drives off adherent water. Residual moistures from 0-25% for polyester have been reported. Also, extra savings could be maintained through the use of the exhausted steam. This steam could be used as process steam. As a note, it is important to realize that all advances in predrying will serve to limit the voracious energy appetite of tenter frames.

In the quarter just completed, a course entitled "Energy Considerations in the Textile/Polymer Industry" was taught to textile engineering students. Seminars dealing with the subject were presented at several short courses and professional meetings. An energy conservation workshop featuring several of the project's personnel was conducted in Dalton, Georgia with 46 representatives from the textile industry attending. An energy short course is scheduled for January.
QUARTERLY PROGRESS REPORT

December 1, 1976 to March 1, 1977

Energy Conservation in the
Textile Industry

Contract No. E(40-1)-5099
Research Project A-1853 & E-27-642

Prepared For
The Energy Research and Development Administration
Buildings and Industry Conservation
Washington, D.C.

by
The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

March 10, 1977
INTRODUCTION

Research Project A-1853 and E-27-642 is being conducted for the Energy Research and Development Administration pursuant to contract E(40-1)-5099 by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. The purpose of this research project is to identify and demonstrate process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies. This will include development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements and dissemination of the research results throughout the industry.

Phase I of the project has the specific objectives of:

1. Identifying major energy intensive processes which may be subject to energy conserving modifications and to determine the energy conservation potential for these process modifications and

2. Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:

1. Developing and demonstrating, on a pilot or full scale basis, energy conserving modifications for selected processes identified in Phase I,

2. Examining cost-benefit relationships of proposed process modifications and

3. Disseminating the results of the research to industry.
This quarterly progress report describes the activities and accomplishments relative to this project for the time period from December 1, 1976 to March 1, 1977.

RESEARCH ACTIVITIES

Phase I

During this period, field trips to textile processing facilities and data acquisition were completed for the Phase I effort. Analysis of all data has been completed and the preparation of the Phase I technical report is in progress. The actual report preparation and construction is essentially complete and the report is in process of review.

Enclosed is a copy of the executive summary to be found in the Phase I report, detailing the conclusions that approximately 41,000,000 barrels of oil-equivalent energy is consumed by the wet-processing segment of the textile industry. Also concluded is that approximately 12,500,000 barrels or 31 per cent of the consumed energy can be conserved via procedural and engineering modifications. This is approximately 19 per cent of the total industry energy consumption. The executive summary details the textile industry energy consumption by major wet processes and by types of fiber.

This report will essentially conclude the Phase I requirements under the Textile Energy Conservation Project and report preparation will continue into the next period.

Phase II

During this period there was little Phase II progress because of the emphasis put on completing the Phase I Technical Report. Now that this report has been essentially completed, the Phase II work described in the previous Quarterly Report will be accelerated to develop energy saving modifications in the defined areas of high energy use and high conservation potential.
I. EXECUTIVE SUMMARY

The textile industry is a major sector of the United States industrial economy. Although one of the oldest industries, the textile industry has exhibited drastic technological changes, progressing from an extremely labor-intensive production orientation to one which can be considered primarily capital-intensive. While still employing over one million people, the added machinery and production volume has increased the fuel consumption considerably. Presently the competing demands for fuels and chemical feedstocks as well as the diminishing supply, has focused attention on energy considerations in the textile industry.

The industry consumed over 67 million barrels of oil equivalent energy in 1971 and is ranked in the top ten in industrial energy use. Because of its relative ranking, the Energy Research and Development Administration contracted with the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech to study energy consumed by various processes within the industry. The contracted research was to concentrate on the finishing or wet processing energy consuming segment of the industry which previous study had indicated used 60% of the total. The approach was to gather process energy consumption data from available literature and selected companies and to develop a matrix of production by each wet process within the industry. Comparison of process energy consumption with the production matrix would then identify major energy intensive processes. Energy conservation potential of each major process would be estimated in order to complete Phase I. Additionally, in Phase II, equipment and procedure modifications would be developed to demonstrate energy savings. This report
completes Phase I and identifies the major energy consuming wet processes within the industry and estimates their conservation potential.

Plant visits indicated the engineering capabilities were considerably better at large facilities as was expected. The small plants in general are dependent upon natural gas and the majority have not experienced significant difficulty in obtaining necessary quantities until recently. When combined with the economies of scale and the declining price of natural gas with volume, energy conservation engineering and implementation has been difficult to economically justify at small installations.

The medium to large installations have started comprehensive energy conservation programs. All of the companies were interested in any assistance Georgia Tech could provide. Some of the more attractive concepts have been implemented by various plants and the technology made available for others to consider. The approach taken by Georgia Tech to address both the equipment and its application by industry was well accepted. However, energy use data by process was generally unavailable or in a form such that different processes could not be accurately compared. Sufficient data was obtained by working closely with individual mills to identify relative energy consumption of major wet processes and estimate their conservation potential.

The major energy consuming equipment in the industry includes boilers, dryers, climate control systems, and product construction machinery. Climate control and product construction equipment are utilized in dry processing (spinning, knitting, weaving, tufting, etc.) and have benefited from extensive engineering. Most of the energy required in dry processing or the manufacture of textile structures is in the form of electricity.
Wet processing (dyeing, drying, finishing, etc.) on the other hand utilizes energy predominately in its thermal form. Energy in fuel is either transformed and utilized as steam (heating dye liquors) or directly combusted (drying operations). The thermal uses of energy, influenced by low cost, has not yet developed comparable engineering sophistication to the electrical uses found in dry processing.

It was found that approximately 41 million barrels of oil equivalent energy (BOE) is consumed by the wet processing segment. Of that, an estimated 12.5 million barrels can be eliminated by conservation via procedural and engineering modifications which is approximately 31% of the wet processing segment and 19% of the total industry consumption. The results for the major wet processes investigated are shown in Table I.

The results indicate two major areas where conservation should be most productive. Drying and heat setting operations waste the largest amount of energy due to the weight processed and the required repetition (It should be noted that drying operations account for most of the energy consumption shown for continuous dye ranges, finishing ranges and printing ranges). Atmospheric dye becks and related atmospheric equipment consume an inordinate amount of energy due to their design and, therefore, also appear especially suited for conservation efforts. Accordingly, Georgia Tech will concentrate research and development efforts in these two areas during the Phase II effort.
### TABLE I - PROCESS CONSUMPTION AND CONSERVATION POTENTIAL

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Consumption:</th>
<th>Energy Per Cent of Total</th>
<th>Estimated Savings, BOE</th>
<th>Estimated Application, %</th>
<th>Conservation Potential, BOE</th>
<th>Per Cent of Total Conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal BTU/lb.</td>
<td>Electrical BTU/lb.</td>
<td>Fiber lbs. x 10^6</td>
<td>Consumed, BOE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Beck</td>
<td>Carpet</td>
<td>13,300</td>
<td>330</td>
<td>605</td>
<td>1,400,000</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Fabric</td>
<td>23,500</td>
<td>600</td>
<td>1,095</td>
<td>4,220,000</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Hosiery</td>
<td>23,500</td>
<td>600</td>
<td>465</td>
<td>1,907,000</td>
<td>5</td>
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<tr>
<td></td>
<td>Jig</td>
<td>2,700</td>
<td>670</td>
<td>448</td>
<td>257,000</td>
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<tr>
<td></td>
<td>Pressure Beck</td>
<td>6,400</td>
<td>660</td>
<td>534</td>
<td>641,000</td>
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<tr>
<td></td>
<td>Jet</td>
<td>9,200</td>
<td>880</td>
<td>431</td>
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<tr>
<td></td>
<td>Package/beam</td>
<td>17,300</td>
<td>1,980</td>
<td>1,018</td>
<td>3,340,000</td>
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<td>Stock</td>
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<td>1,426</td>
<td>375</td>
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<tr>
<td>Continuous</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Slashing</td>
<td>2,900</td>
<td>-</td>
<td>3,905</td>
<td>1,900,000</td>
<td>6</td>
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<tr>
<td></td>
<td>Singe</td>
<td>200</td>
<td>-</td>
<td>3,717</td>
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<td></td>
<td>Preparation Range</td>
<td>2,100</td>
<td>150</td>
<td>3,863</td>
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<td></td>
<td>Mercerize</td>
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<td></td>
<td>Fabric Dye Range</td>
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<td>150</td>
<td>2,493</td>
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<td>Finishing Range</td>
<td>7,800</td>
<td>660</td>
<td>3,207</td>
<td>4,612,000</td>
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<td></td>
<td>Carpet Dye Range</td>
<td>12,300</td>
<td>1,300</td>
<td>351</td>
<td>826,000</td>
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<tr>
<td></td>
<td>Printer</td>
<td>9,300</td>
<td>230</td>
<td>1,018</td>
<td>1,656,000</td>
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<td></td>
<td>Predryer</td>
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<td></td>
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<tr>
<td></td>
<td>Infra-red</td>
<td>900</td>
<td>-</td>
<td>7,528</td>
<td>1,152,000</td>
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<td></td>
<td>Mechanical</td>
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<td>200</td>
<td>4,895</td>
<td>166,000</td>
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<td></td>
<td>Steam Cans</td>
<td>1,600</td>
<td>-</td>
<td>4,124</td>
<td>1,122,000</td>
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<tr>
<td></td>
<td>Dryers</td>
<td>2,100</td>
<td>200</td>
<td>16,471</td>
<td>6,331,000</td>
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<td>Sub Total</td>
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<td>Continuous Idle time (.2 x 22,870,000)</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
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</table>

Conservation Potential = 12,545,000/40,804,000 = 31%
QUARTERLY PROGRESS REPORT
March 1, 1977 to June 1, 1977

Energy Conservation in the
Textile Industry

Contract No. E(40-1)-5099
Research Project A-1853 & E-27-642

Prepared For
The Energy Research and Development Administration
Buildings and Industry Conservation
Washington, D.C.

by
The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

June 28, 1977
INTRODUCTION

Research Project A-1853 and E-27-642 is being conducted for the Energy Research and Development Administration pursuant to contract E(40-1)-5099 by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. The purpose of this research project is to identify and demonstrate process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies. This will include development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements and dissemination of the research results throughout the industry.

Phase I of the project has the specific objectives of:

1. Identifying major energy intensive processes which may be subject to energy conserving modifications and to determine the energy conservation potential for these process modifications and

2. Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:

1. Developing and demonstrating, on a pilot or full-scale basis, energy conserving modifications for selected processes identified in Phase I,

2. Examining cost-benefit relationships of proposed process modifications, and

3. Disseminating the results of the research to industry.

Phase I of this project has been completed and the Phase I report has been submitted to the ERDA Program Manager for approval. When that approval is forthcoming, the suggested modifications will be incorporated and the document formally submitted.
This quarterly activity report describes the Phase II activities relative to this project for the time period from March 1, 1977 to June 1, 1977.

Phase II RESEARCH ACTIVITIES

Atmospheric Dye Beck Equipment Modification

A full-scale production dye beck located in a Georgia carpet mill has been instrumented in order to document equipment modification effects on energy consumption. Preliminary tests have been conducted to obtain baseline consumption data. A cover has been fabricated for the sparge area to determine temperature gradient effects and heat transfer efficiency. A door has been fabricated in order to enclose the beck. A multispeed exhaust fan has been installed to quantify exhaust flow effects. Preliminary design of a desuperheat system has been completed.

Field testing of individual and cumulative modifications will proceed next quarter with the installation of a calibrated primary flow element in the steam supply line.

Dryer Exhaust Heat Reclamation

Standard heat exchange surfaces employed in heat exchangers, heat pipes, heat pumps, etc., have exhibited fouling problems when employed in oily waste gas streams from tenter frame dryers. Since Phase I showed dryer exhaust accounts for one of the largest waste energy streams in wet processing, investigation in this area was warranted. Investigation indicated that fume incineration prior to heat recovery is technically feasible and several companies manufacture equipment for this purpose. Additional study has indicated that the energy conserved is not sufficient to economically justify the installed equipment cost when the incineration fuel is included. Therefore, additional effort will not be expended in Phase II to pursue research into incineration/
heat recovery. However, it should be noted that where environmental regulations require pollution control of dryer exhausts, this type of system can alleviate the energy penalty.

**Carpet Dyebath Reuse**

Reuse of the bath in beck dyeing of carpet was scaled up to dyeing of 35-50 pound samples in a four-foot beck. Dyeing of nylon carpet with disperse dyes to the same shade five times was the first experiment conducted on the larger scale equipment. The carpet for the study was obtained from a carpet plant of a major textile company. Initial dyeings in the four-foot beck indicated that some modifications in the dye analysis technique would be necessary to obtain sufficiently accurate results (less than ± 3% variation in dye concentrations) for "no-add" dyeings. Procedural changes were required in the extraction step of the analysis procedure. These changes gave analytical results well within the required accuracy.

Five carpets were dyed a light green shade with the first carpet dyed in the conventional manner (to serve as a control) and four subsequent dyeings carried out in the used dyebath for a total of 5 dye cycles in the same dyebath. Visual inspection of the dyeings indicated that good within-sample and between-sample shade uniformity was achieved in these dyeings. This conclusion has been confirmed by having the samples examined by 3 carpet mill dyers at various plants. These professional dyers have indicated that all 5 samples would be acceptable as first quality commercial carpet.

The second large scale equipment experiment will be an attempt to dye 8 nylon carpet samples to 4 different shades in a color line with disperse dyes utilizing reuse of the dyebath. Shades have been selected and dyeing recipes established in laboratory dyeings. Analysis of the residual dyebaths suggest
that no problems should be encountered in the large scale dyeing in going from light samples to dark samples in the series.

Extension of the dyebath recycle concept to polyester carpet was also begun this quarter. A suitable carpet was obtained from a second major manufacturer and 3 shades have been selected for initial dyeing trials. Plant production samples of these three shades are being collected by the plant and sent to Georgia Tech to be used as a benchmark for "average" commercial production color variability.

Completion of pilot scale work on disperse dyeing of both nylon and polyester carpet is planned for next quarter. Pilot scale studies on acid dyeing of nylon carpet will also be carried out.

Hosiery Dyebath Reuse

Women's Nylon Pantyhose

Reuse studies on hosiery were centered initially on women's nylon pantyhose. Working with a leading manufacturer, it was discovered that the shade variation for pantyhose was narrow (only 3 colors marketed) and that the shades were all in a single color line, i.e., the 3 shade variations were obtained by altering the proportions of three specific disperse dyes. Since the pantyhose system was well suited for reuse adaptation due to its lack of procedural variability from batch-to-batch, transfer of the dyeings from a beaker scale to pilot scale was rapid. The pilot scale dyeings were conducted in a rotating drum hosiery machine requiring eight pounds of material. Four pounds of nylon carpet yarn was used as "filler" in the dyeings to minimize the amount of hosiery used in the experiments, with the carpet yarn and hosiery located in separate compartments of the machine's drum. Since the three shades were derived from a color line, the investigators decided to change from shade-to-shade on the initial set of experiments, rather than dye a series of batches using a
single shade. The sequence followed is listed in Table I. Shade variation went from Light Beige (light shade) to Suntan (medium shade) to Coffee (dark shade), and finally back to Light Beige in the final two dyeings, all out of the same bath of water. Unlike the carpet reuse studies, in which the material was removed by hand from the hot (180°F) bath, the hosiery baths were pumped at 180°F from the rotating drum machine into holding tanks. A finish was then applied to the hosiery, the cooled material removed, and the spent dyebath analyzed spectrophotometrically. The hot bath was then pumped into the machine, brought back to 180°F to adjust for radiation-convection cooling, and the next material batch entered by hand. The reconstitution chemicals (consisting of dye and approximately 10% of the original auxiliary chemicals) were added slowly to the hot bath with agitation, and the cycle repeated. Using standards for each of the shades supplied by the manufacturer, MacAdam Unit color variations were determined for the dyed hosiery using the FMC Color Difference Metric on a Diano/LSCE Automate System. Five readings were obtained at fixed positions along each hose leg, and three randomly-selected hose from each lot were measured. The results of the measurements are located in Table I. All of the dyeings were "one-shot" procedures, i.e., with no adds. The widest MacAdam Unit variation from the standard was recorded for the light beige (3-5 units).

To determine if the dyeings were within acceptable company tolerances, samples of "barely passible" as first quality Suntan and Coffee hosiery (one hose of each shade) was obtained from the manufacturer, and color differences between the commercial hosiery and the supplied standards were obtained. The results are shown in Table II. In comparison to the Table II figures, the Suntan shade on the reuse runs was well within the 4-unit tolerance range indicated by the company samples, whereas the Coffee shade showed about one MacAdam Unit more variation on the reuse samples than on the company sample. The single hose supplied by the company was not as statistically valid as the random sampling
Table I

Color Variation from Standard
Dyebath Reuse Lots-Nylon Pantyhose

<table>
<thead>
<tr>
<th>Shade</th>
<th>Run No.</th>
<th>MacAdam Unit Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lt. Beige</td>
<td>1²</td>
<td>3.681</td>
</tr>
<tr>
<td>Lt. Beige</td>
<td>2³</td>
<td>5.144</td>
</tr>
<tr>
<td>Lt. Beige</td>
<td>4</td>
<td>5.571</td>
</tr>
<tr>
<td>Suntan</td>
<td>5</td>
<td>1.522</td>
</tr>
<tr>
<td>Suntan</td>
<td>6</td>
<td>2.439</td>
</tr>
<tr>
<td>Coffee</td>
<td>7</td>
<td>3.631</td>
</tr>
<tr>
<td>Coffee</td>
<td>8⁴</td>
<td>3.967</td>
</tr>
<tr>
<td>Light Beige</td>
<td>9⁵</td>
<td>4.801</td>
</tr>
<tr>
<td>Light Beige</td>
<td>10⁵</td>
<td>4.957</td>
</tr>
</tbody>
</table>

¹The MacAdam Unit Variation is in relation to a standard supplied by the sponsoring plant, and was determined by the FMC Color Difference Metric on a Diano/LSCE Automatic System. Five readings were obtained at set positions down the length of the hose leg, and three random pairs of hose from each lot were measured. All of the measurements were then averaged to provide the numbers shown in Table I.

²Dyed by the standard procedure provided by the sponsoring company.

³In Run 3, a technician's mistake in weighing make-up dye resulted in severe shade change (see Text).

⁴An alkaline rinse at pH of 8, 150°F for 15 minutes was necessary to reduce "dullness".

⁵Dyed at a pH of 8 to prevent lignin sulfonate "dulling" of the shade.
from the Georgia Tech runs, therefore, collection of samples from batches deemed "first quality" at the plant are being collected for a time-averaged determination of the tolerance levels for the three shades investigated.

A technician's weighing error in reconstitution of Reuse Bath No. 3 resulted in gross shade deviation from the standard. The dyebath analysis technique, however, was versatile enough to compensate for the error, and Batch 4 was brought back within shade tolerance levels.

The Light Beige Run 9 appeared "dull" in appearance in comparison to the standard and to Runs 1, 2, and 4. It was postulated that colorless lignin sulfonate, which is a major "filler" (50-70% by weight) of commercially-available disperse dyes, was building in concentration in successive baths, moving onto the fiber, and becoming fixed to the fiber similar to a dye. The lignin sulfonate could cause dulling by light scattering. From chemical considerations, it was concluded that if the sulfonate group could be ionized by a base without affecting the disperse dye, the impurity chemical could be "backed off" the fiber. The Light Beige Run No. 9 was thus reentered into the hosiery machine and rinsed at 150°F for 15 minutes at a pH of 8. The resulting bath was cloudy, indicating that impurity chemicals had released from the fiber. There was no

---

Table II

<table>
<thead>
<tr>
<th>Shade</th>
<th>MacAdam Unit Variation</th>
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</thead>
<tbody>
<tr>
<td>Suntan</td>
<td>4.894</td>
</tr>
<tr>
<td>Coffee</td>
<td>2.534</td>
</tr>
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</table>

1 See Note 1, Table I. Only one hose for each shade was available from the manufacturer at the date of reporting.
evidence of dye release from the fiber under the rinse conditions. The rinse hosiery was much brighter than the original Run 9 batch, matching in appearance Run 1. A final dyeing was then conducted from the reused bath at a pH of 8 (attained by addition of 0.05 g/l of monohydrated monosodium phosphate and 2.50 g/l of dodecahydrated disodium phosphate); the hosiery from Run 10 matched that attained from Run 1 in brightness without alkaline rinse.

The conclusions drawn from the ladies' nylon pantyhose experiments were as follows:

1. Demonstrations proved that the hosiery could be dyed on a large scale in matching shades, and with randomly changing shades, by the dyebath reuse technique without adversely affecting product quality.

2. Dropping the bath hot (175-185°F) and reentering subsequent batches hot does not affect product quality if precautions are taken (slow chemical adds, proper leveling agents, etc.).

3. Build up of auxilliary chemicals included in commercial disperse dye formulations and subsequent "dulling" of shades on > 10 reuse cycles can be alleviated by slightly alkaline dyeing conditions (pH 8) which does not affect the dyeing behavior.

The women's nylon hosiery Phase II research is nearing completion at this date. A meeting has been scheduled with the sponsoring company to formulate plans for the Phase III (In-Plant Demonstration) proposal.

Men's Nylon and Acrylic Hosiery

The shades supplied by the plant as their three largest volume shades on men's nylon hosiery were Black, Navy, and Cheviat Green. The Black consisted of a single dye, while the Navy consisted of the dye for the Black shade plus a blue dye. The Black and Navy thus presented good potential for reuse, as changing from shade-to-shade out of the same reuse bath appeared feasible. Initial
beaker-scale dyeings have confirmed that the Black shade lends itself well to reuse. Absorptivity constants have been determined for the Navy shade dyes, and beaker experiments are under way to determine the feasibility of switching from shade-to-shade in the same bath. The sequence to be followed will be 3 Blacks, followed by 3 Navies, and the sequence ended with 3 additional Blacks. If the beaker experiments are successful, machine dyeing of the sequence will follow.

The Cheviat Green shade was found to contain 3 dyes which had overlapping peaks in the visible spectra. The overlap in the dye absorption peaks rendered the simple analytical scheme used in earlier studies inoperative. Analysis of the largest-volume procedures provided for the men's acrylic hosiery (Black, Navy, and Brown) revealed a similar problem. The acrylic socks consisted of 3 fibers: acrylic (Basic Dyes), and nylon and Spandex (Acid Dyes). As a result, some of the procedures' absorbance spectra were extremely complicated. Figure 1 shows the absorption curves of the individual dyes used in the Navy coloration in equal concentrations, and dyebath curves in the correct relative concentrations called for by the procedure. The analysis problem is obvious due to the complexity. It was thus concluded that reuse studies on the Cheviat Green shade of the men's nylon hosiery and the Black, Navy, and Brown shades of the men's acrylic socks required an alternate analytical scheme to determine dyebath exhaustion and dye requirements. Potential schemes being examined by the investigators include High Speed Liquid Chromatography utilizing a UV-Visible detector, and a more sophisticated absorption curve analysis than has been utilized in the past. Success of the analytical development will determine if dyebath reuse can be applied to these particular systems.
Fig. 1  Absorption Characteristics of Dyes Utilized in Navy Coloration of Men's Acrylic Socks.
Yarn Package Dyebath Reuse

Both textured filament and spun staple 100% polyester package yarn was obtained from a major finishing plant, and reuse studies were conducted on a Morton Single Package Dyeing Machine. The packages were dyed under pressure at 245-260°F. The machine was fitted with a valve system that allowed dropping the depressurized bath after cooling below 212°F. The dyebath was held in a stainless steel tank while the dyed package was subjected to a reduction cleaning with hydrosulfite followed by removal. A fresh package was mounted in the machine, the hot bath reentered, the temperature raised to 175-180°F with circulation, and the dye add for reconstitution made slowly. Shades of Pink (1 dye), Green (2 dyes), and Grey (3 dyes) were supplied as the largest-volume products by the cooperating company. All of the dyes were disperse dyes. In the initial experiments, eight spun polyester packages were dyed with the Pink shade in the single package machine from the reused bath. Three textured polyester packages were also dyed singly from a second reuse bath in the pink shade. Using a single reuse bath, five textured yarn packages followed by three spun yarn packages were then dyed consecutively using the two-dye Green shade. For the three-dye Grey shade, five spun yarn packages and three textured yarn packages were dyed consecutively from a single reuse bath.

To analyze through-package uniformity and shade matching with standards, five fabrics were knitted on a FAK unit from each package using yarn taken at set points throughout the diameter of the package (going from the outer, three-fourths, midway, one-fourth, and inner areas). The fabrics were then analyzed for MacAdam Unit color differences from standards by the FMC II program. The uniformity and shade variation in the Pink and Green shades were deemed within industrial tolerance levels. The Gray shade, however, showed nonuniformity as well as pronounced shade variation from the outer to the inner portion of the
package. The nonuniformity was attributed to the plastic spool of the package collapsing during dyeing due to yarn pressure. The Morton machine was fitted with a metal sleeve to prevent spool collapse. To correct the shade variation, dye reconstitution adds were made much slower over long periods of time. At the reporting date, final instrumental analysis on the modified Gray dyeings were not complete. Visual inspection of the fabrics, however, indicate substantial improvement over the earlier runs.

Conclusions derived from the polyester yarn package dyebath reuse are as follows:

1. Dyebath reuse is adaptable to batch pressure dyeing, with results appearing to be as good as those observed earlier in atmospheric systems.

2. Good outer-to-inner package uniformity and package-to-package shade uniformity is obtained by the reuse technique.

3. No adverse effects were observed on dropping the bath hot (~212°F) and entering the subsequent package at 185°F if sufficient precautions were taken to minimize dye strike, i.e., slow make-up dye addition.

4. Variability appeared to be less on spun staple polyester yarns than on textured filament yarns. The modified techniques, however, appear to have minimized variations in the textured yarns.

Analysis will be completed shortly on the single shade dyebath reuse runs. The feasibility of switching from shade-to-shade in successive reuse baths will next be investigated. One dye is common to all three shades, and the disperse dyes are exhausted to 90-95% levels. Switching from shade-to-shade on successive switches thus appears feasible, with the sequence followed being Pink (light shade) to Green (medium shade) to Gray (dark shade). Converting from Gray back to Pink does not appear promising but will be attempted. Studies will also be conducted to determine the feasibility of analyzing, reconstituting,
and reusing the hydrosulfite reduction bath for further energy, chemical, and water savings. A larger pilot scale pressure dyeing unit (5-10 package capacity) than is available to Georgia Tech is also being sought to better define procedural variables before Phase III proposal submission. Scale-up from a one-package machine to an industrial operation is considered too severe, so trials on an intermediate level are desired first.

Fabric Dyebath Reuse

**Underwear Knit Fabrics**

Experiments were conducted on 100% cotton knit fabric to determine if the hydrolysis of the reactive dye in the impregnation bath by $\text{H}_2\text{SO}_4$ would interfere significantly in reuse shade matching. (See Phase I report for problems presented by reactive dyes.) The modified procedure was to impregnate the fabric with the reactive dye solution at 100°F, remove the bath for analysis, and pump into the fabric container sodium carbonate base fixation bath. The reactive dye shade initially investigated, Scarlet Red, consisted of 3 closely associated red Procion dyes that had nearly identical peaks in the absorption spectra, making simple spectrophotometric analysis difficult. Therefore, the studies to determine if a split-bath technique could be utilized in reactive dyebath reuse were conducted with the major red dye that constituted 80% of the shade. A standard was prepared by the usual single bath technique. Initial split-bath runs gave lighter shades, due to the fixation of dye in the one-bath system resulting in a dye solution-fiber equilibrium shift to drive more dye from the solution reservoir onto the fabric. Also, dye bleed-off in the fixation bath before fixation also contributed to a lighter shade. To counter the equilibrium effects of fixation in the one-bath system, a higher concentration of dye in the impregnation bath than called for by the company procedure is being investigated. To prevent bleed-off in the fixation bath of the split-bath system, the base
solution is being made up initially with a high concentration of hydrolyzed dye in addition to base. The hydrolyzed dye, being similar in chemical structure to the parent reactive dye, prevents dye migration off the fabric as the base is entered, and therefore provides adequate fixation time without bleed-off. Increased salt concentration in the fixation bath did not adequately prevent bleed-off.

A reuse sequence of 4 dyeings of 100% cotton knit have been conducted on a beaker scale with the split-bath technique. The major dye component of the Scarlet Red shade was utilized as the single reactive dye. The first dyeing was lighter than the standard prepared by the conventional single-bath technique, and the three subsequent batches dyed in reused impregnation and fixation baths were progressively lighter. Studies are under way to determine if a cumulative mistake in dyebath analysis was being made each bath, or if the residual dye (~60% exhaustion) in the impregnation bath was being progressively hydrolyzed as the sequence was conducted.

A literature procedure based on a colored sodium hydroxide/pyridine complex of the reactive dye offered the possibility of quantitatively "shifting" the three overlapping peaks of the tricomponent Scarlet Red shade so that spectrophotometric analysis would be simplified. Investigation showed, however, that the shifts of the colored complexes of the 3 dyes were basically the same, and thus the peaks of the 3 complexes overlapped as had those of the original dyes. It thus appears that High Speed Liquid Chromatography or a more sophisticated spectrophotometric-based analysis will be necessary to analyze the 3-component impregnation baths of the company's Scarlet Red shade.

In summary, dyebath reuse applied to reactive dye systems has been as was expected the most difficult system encountered to date. Work will be concentrated initially on the 100% cotton fabrics, as the 50/50 cotton/polyester knit
fabric presents a challenge only as far as the cotton component is concerned. The polyester component, dyed with disperse dyes as a separate step of the procedure, will be a straightforward extension of the dyebath reuse work already done or underway on 100% staple spun polyester yarn and on polyester carpets (see the relevant sections of this report). Once the problems presented by dyeing 100% cotton with reactive dyes are overcome, the dyeing of the 50/50 cotton/polyester analog with reactive and disperse dyes should proceed rapidly.

**Nylon Upholstery Fabric**

Nylon velour automobile upholstery fabric has recently been obtained from a quality manufacturer, along with five largest-volume procedures and color matching standards. Due to strenuous color matching requirements of this section of the textile industry, and due to multicomponent dye procedures, reuse studies will proceed slowly on the upholstery fabric until critical problems have been solved in the other reuse systems detailed herein. Other problems presented by the upholstery system include a rayon backing (requiring direct dyes) and a polymeric adhesive that binds the backing to the face fabric, causing the fabric solution to be strained. In summary, the nylon upholstery fabric presents the greatest challenge offered by the industry to dyebath reuse due to the complexity of the fabric structure, the dyeing procedure and the rigidity of the color matching standards.

**Preparation Modifications**

The emphasis in this work is on process modifications which will make possible a reduction in the temperature and/or amount of water used in the washing and the combining of processes, thus decreasing the number of washings required. The first goal is to investigate the application of sonic and supersonic vapor flows as a means for the more efficient removal of impurities (macro, micro, and molecularly dispersed) in cotton and cotton/polyester woven fabrics. A
device which provides the means for accomplishing this is the Machnozzle, developed by Brugman Machine Fabriek, Almelo, Holland. We are now negotiating with Brugman to obtain a Machnozzle. If one is obtained, a study will be made to determine its effectiveness in increasing washing efficiencies. Also, it may be possible to eliminate the washing step in desizing if sufficient impurities can be removed using the Machnozzle.

In attempting to combine desizing, scouring, and bleaching processes, the question arises as to their compatibility. It is obvious that enzymatic degradation of starch cannot be accomplished effectively under the conditions of high alkalinity and high temperature used in scouring cotton and bleaching it with hydrogen peroxide. However, if the film former in the size is polyvinyl alcohol instead of starch, it may be feasible to combine desizing, scouring, and bleaching. It is often stated that chemical costs will be much higher if processes are combined. For example, the amount of hydrogen peroxide required will be greater if the size is not removed prior to bleaching.

Initial efforts will be directed toward determining the feasibility of combined processes from the standpoint of chemical costs and bleach quality. A large textile manufacturing firm has agreed to work with Georgia Tech in this program to discover means for reducing energy requirements in fabric preparation.

Thermomechanical Drying

This segment of the project is concerned with the reduction of energy use during thermomechanical dewatering of fabric. The focus is on the development of an innovative dryer which has been described in the Phase I report.

During the last quarter, several mechanical problems have been encountered with the equipment. The flexible plastic belt which provides a moving seal to prevent a vacuum loss was not tracking straight on the drying cylinder. Accordingly, the drying cylinder was modified with a set of tracking lips (teflon
coated) to enhance the system stability. This modification allows a much higher vacuum to be developed on the underside of a fabric to be dried and hence increases the torque drive requirements on the feed system. The system had to be modified with a new chain drive to accommodate this new load. This effort is in progress at the time of this writing. Also, a laboratory infrared heater which can be tuned to the correct wavelength for efficient drying is being fitted on the dryer.

In an attempt to preheat the fabric prior to vacuum application, several rotating cans which will be filled with hot water are being integrated into the system. An important feature of this addition is the fact that the hot water for these cans can be obtained from warm (160°F) wastewater which is normally expelled from a dyehouse.

Within several weeks the entire system should be assembled and ready for an intensive series of experiments which will include the effects of vacuum, temperature, and process speed. The next quarterly report should include these results. The Machnozzle described earlier under Preparation Modifications will also be used in conjunction with the dryer.

Last month, a laboratory device secured by the IMMS Company of Greenville, South Carolina, was donated to this department for conducting drying experiments. This device, called an Infravac, has a high fabric velocity (700 feet/minute) through the dryer. IMMS, which built this machine in 1973, had never completed an intensive experimental program with this device due to a lack of internal research funds. However preliminary results indicated that the dryer could be made energy efficient. Accordingly, Georgia Tech is determining its usefulness and making appropriate modifications to further its effectiveness.
QUARTERLY PROGRESS REPORT

June 1, 1977 to September 1, 1977

Energy Conservation in the
Textile Industry

Contract No. E(40-1)-5099
Research Project A-1853 & E-27-642

Prepared For
The Energy Research and Development Administration
Buildings and Industry Conservation
Washington, D.C.

The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

September 2, 1977
INTRODUCTION

Research Project A-1853 and E-27-642 is being conducted for the Energy Research and Development Administration pursuant to contract E(40-1)-5099 by the Engineering Experiment Station and the School of Textile Engineering At Georgia Tech. The purpose of this research project is to identify and demonstrate process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies. This will include development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements and dissemination of the research results throughout the industry.

Phase I of the project has the specific objectives of:

1. Identifying major energy intensive processes which may be subject to energy conserving modifications and to determine the energy conservation potential for these process modifications and

2. Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:

1. Developing and demonstrating, on a pilot or full-scale basis, energy conserving modifications for selected processes identified in Phase I,

2. Examining cost-benefit relationships of proposed process modifications, and

3. Disseminating the results of the research to industry.

Phase I of this project has been completed and the Phase I report has been reviewed, modified and transmitted to the ERDA program manager. Phase II of this
effort was initiated early in 1977 and this quarterly activity report describes these activities for the time period from June 1, 1977 to September 1, 1977.

**ATMOSPHERIC DYE BECK TESTS**

An atmospheric dye beck used for batch dyeing of carpets is illustrated in Figure 1. Carpet is introduced into the beck around the reel and the ends sewn together to form a continuous loop. The beck is filled with water and appropriate chemicals added from a separate tank for pH control, antifoaming, leveling, etc. according to the dye recipe. Continuous agitation is provided by the action of the carpet being pulled out of the water over the reel. Approximately 3% of the carpet is out of the water as it traverses the reel. Dye is added according to the production recipe and the direct injection of steam begun in order to heat the dye bath. The steam enters the water through piping containing several holes and is prevented from directly contacting the carpet by a perforated false front. Steam flow is regulated by an air-actuated flow valve, controlled by a remote temperature feedback servo system. The controller incorporates a temperature rate of rise command in addition to temperature set point command.

During initial loading of the carpet into the beck, the water quantity is controlled manually to an approximated level regardless of the weight of carpet entered. During our test, carpet weight varied from 1171 pounds to 2172 pounds while water ranged from 3500 to 4000 gallons per cycle. The liquor ratio (weight of water to weight of carpet) therefore varied between 14:1 and 25:1.

On occasion, the water fill valve is left open causing the beck to overflow. When this condition is discovered, the operator will close the fill valve and open the drain valve until the approximate water level is reestablished. This inattention in one instance drained a portion of the auxiliary chemicals and another time drained a portion of the incoming dye. One other consideration
Atmospheric Dye Beck
with respect to water level if lint is trapped at the seal interface. The subsequent loss of dye necessitates later dye adds and prolongs the dye cycle.

The dye cycle ceases to be typical after the bath is raised to its commanded temperature. The different accuracies and deadbands in the temperature controllers require different settings in order to achieve the desired temperature, in this case boiling at 210°F. Obviously, the higher the command set point above the maximum feedback signal at 210°F, the greater the resulting error signal which determines steam valve opening. Therefore, the amount of steam required to maintain the dye bath at 210°F, is to a large extent a function of controller accuracy and set point rather than cooling due to heat transfer.

Another dye cycle variable with a significant effect on energy consumption is time. Whereas some carpets achieve correct color after a one-hour dye cycle, others require a series of dye adds which may extend dyeing time to over 12 hours. In addition, it is necessary in some cases to drain the hot dye bath containing in-exhausted dye, refill with cold water, add more dye, reheat, refill with cold water, add more dye, reheat and maintain at boiling until the correct color has been obtained. Some of the factors which affect dye cycle time include color, dye variation, pH and other chemical variations, liquor ratio, temperature gradients, agitation, and yarn variations.

Existing beck design appears to have resulted in order to satisfy personnel requirements at the expense of energy consumption. Doors which enclose the loading/unloading area either remain open or do not exist. In order to prevent steam from escaping the beck, relatively high capacity exhaust fans are operated continuously. Not only does this mode of operation increase thermal losses through the stack, it also wastes electricity.

Objective: To determine the energy consumption required in a typical atmospheric beck carpet dye cycle and the extent of conservation possible with low cost equipment modifications.
Method: A 15 foot atmospheric beck was instrumented in order to measure steam flow during production carpet dyeings. Additionally, temperature sensors were placed around the beck to obtain dye bath temperature gradients and an instrument was provided to measure exhaust flow from the stack. Water quantities were obtained from water level measurements and vessel geometry. Product information for each test run was gathered from normal production records.

By attempting to vary only one parameter during each dye cycle, the benefit of each change from the standard present dye cycle can be compared with its cost of implementing, thereby generating the economic information required to optimize atmospheric beck dyeing.

Discussion:

Figure 2 indicates temperature sensor locations from which temperature gradients were determined. Temperature differences up to 40°F were recorded from front to back of the beck. Also of note was a 25°F temperature rise in about 15 seconds caused by the carpet entraining hotter water from the front sparge area and carrying it over the reel to a back temperature sensor.

Figure 3 illustrates steam consumption during a "typical" dye cycle up to the point of the first sample to determine color match. The one condition of note is the command set point on the temperature controller.

The first change from baseline dye cycle was to set the controller at 210°F. Figure 4 illustrates the results. Steam requirements were reduced by over 1000 pounds of steam for the first 90 minutes of the dye cycle. Additionally, over a million Btu's are saved for each hour at boil as a result of controller adjustment. Since average hold time at boil exceeded seven hours for the test beck, significant savings would result from implementing this modification on a general basis.

Observations indicated that some steam was not condensing during a normal
THERMOCOUPLE LOCATIONS

8, 9, 15 in WATER
Rest are OUTSIDE

Atmospheric Dye Beck
Figure 3
dye cycle. Rather then yielding its latent heat to the dye bath, it remained as a vapor and was exhausted to the atmosphere. It was believed that covering the area over the sparge tubes would eliminate it as a low pressure escape route. Therefore a prototype sparge area cover was built and installed to force more steam into the main dye bath, thereby increasing the superheated steam's retention time and enhancing condensation. The results of the test runs with the sparge area covered are presented in Figure 5. Although the sparge cover exhibits more influence on steam flow reduction at excessive temperature commands, those results are not presented since a lower control set point is assumed to be the new standard. As indicated in Figure 5, the first 90 minutes required approximately 5600 pounds of steam, which is an additional decrease of about 800 pounds of steam over the command correction savings.

A front door was fabricated and installed to document the magnitude of anticipated energy reduction effected by eliminating the exhaust fan during a dye cycle. The usual exhaust fan motor was replaced with a two-speed motor in case the lack of a fan allowed steam to escape into the production area. The steam required during the initial portion of a dye cycle with the fan off and the door closed is shown in Figure 6. An extrapolated 5200 pounds would be required for this condition even though the command set point was 215°F. The fan off-door closed condition did not result in steam escaping to the dye room so the low-speed fan condition was not tested.

Several test runs will be repeated next quarter since production problems created variables which lessened comparison accuracy.

Figure 7 summarizes steam consumption for different conditions. Energy balances for these conditions are being calculated. Preliminary estimates indicate $180,000 per year fuel savings for this company.

Of special interest relative to energy consumption in carpet back dyeing
TEMP.

COMMAND AT 210° F
DOOR OPEN
FAN ON
SPARGE AREA COVERED

TEMPERATURE - F

FLOW RATE - LBS. X 10^-3/HR.

TOTAL FLOW

FLOW RATE

ELAPSED TIME - MIN.
STEAM CONSUMPTION - VARIOUS CONDITIONS

- COMMAND AT 210°F
  Door Open
  Fan On

- COMMAND AT 210°F
  Door Open
  Fan On

- COMMAND AT 215°F
  Door Closed
  Fan Off

- BASELINE COMMAND AT 218°F
  Door Open
  Fan On

ELAPSED TIME - MIN

TOTAL FLOW - LBS X 10^-3
is the variation in dyeing time. In eight days of production on the test beck, energy required ranged from 5000 Btu/lb to 16,000 Btu/lb. Quality control and dye procedures coupled with beck equipment modifications and the analysis techniques developed for bath reuse will be investigated during the next quarter. Preliminary estimates indicates a potential savings of $3.5 \times 10^{12}$ BTU/year in carpet dyeing alone. The desuperheat experiments designed last quarter have not been tested because we have been unable to find a manufacturer willing to work with us in setting up an actual in-plant installation to date. Efforts to secure such cooperation will continue next quarter.

Case Studies

Compilation of the cost/benefit relationships for energy conservation projects funded and installed by textile companies is in progress. It is expected that this documentation will aid in the transfer of existing conservation technology.
The color differences between the dyed pantyhose of the 10-run series and company standards that were contained in the previous report were recalculated using a corrected color difference program. The corrected values are shown in Table I.

Table I

<table>
<thead>
<tr>
<th>Run</th>
<th>Shade</th>
<th>Color Difference Versus Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Light</td>
<td>4.36</td>
</tr>
<tr>
<td>(conventional)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Light</td>
<td>6.15</td>
</tr>
<tr>
<td>III</td>
<td>Light</td>
<td>-</td>
</tr>
<tr>
<td>IV</td>
<td>Light</td>
<td>6.35</td>
</tr>
<tr>
<td>V</td>
<td>Medium</td>
<td>2.53</td>
</tr>
<tr>
<td>VI</td>
<td>Medium</td>
<td>3.30</td>
</tr>
<tr>
<td>VII</td>
<td>Dark</td>
<td>4.06</td>
</tr>
<tr>
<td>VIII</td>
<td>Dark</td>
<td>4.48</td>
</tr>
<tr>
<td>IX</td>
<td>Light</td>
<td>6.04</td>
</tr>
<tr>
<td>X</td>
<td>Light</td>
<td>5.64</td>
</tr>
<tr>
<td>Medium Limit*</td>
<td>Medium</td>
<td>7.78</td>
</tr>
<tr>
<td>Dark Limit</td>
<td>Dark</td>
<td>2.89</td>
</tr>
</tbody>
</table>

*Hoisery samples supplied by the participating company and termed "just passable as first quality" by plant personnel.

At the end of Table I, the color differences between "just passable as first quality" hosiery samples supplied by the company and its standards are shown for the Medium and Dark shades. The data shows that the shades on the reuse
runs were within the tolerance ranges required commercially by pantyhose producers.

Run III color difference was omitted from the table due to a technician weighing error on reconstitution of the bath, resulting in gross visual shade variations. The reuse analysis system was versatile enough, however, to allow continued use of the bath with correction of shade on Run IV.

A 2-sequence reuse series was run on the Light Shade to determine the feasibility of dropping the baths at 200°F. The color difference calculations were derived as for the earlier sequence, with a difference of 5.47 and 6.08 MacAdam units for the runs.

The experiments confirmed that the reuse technique could be applied readily to hosiery dyeing, that randomly switching from shade-to shade in a color line was feasible, and that level dyeings could be obtained by dropping baths and entering goods at high temperatures ($175^\circ$ - $200^\circ$F). The actual chemical and water savings for the 10 run reuse sequence over conventional procedures are shown in Table II, along with the calculated energy savings based on a 200°F drop.

Table II
Chemical, Water, and Energy Savings in Application of Dyebath Reuse to Disperse Dyeing

<table>
<thead>
<tr>
<th>Dyed Material</th>
<th>Dye Cost (%)</th>
<th>Auxiliary Cost (%)</th>
<th>Water (%)</th>
<th>Energy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon Pantyhose 1</td>
<td>5.2</td>
<td>86</td>
<td>90</td>
<td>35</td>
</tr>
<tr>
<td>Polyester Yarn 2</td>
<td>1.5</td>
<td>82</td>
<td>81</td>
<td>42</td>
</tr>
</tbody>
</table>

1. Based on the 10 cycle dyeing sequence with a 200°F drop of bath.
2. Based on the 9 cycle multi-color dyeing sequence on spun yarn. For a comparable 9 cycle sequence on filament yarn, a 50% BTU savings is calculated.

The hosiery dyed in the 10-run reuse sequence were returned to the company, and has been graded "first-quality" by plant personnel. Plans are to sell the goods
through normal channels.

Negotiations are underway with the participating company and ERDA to submit a Phase III In-Plant Demonstration proposal. As part of the proposal preparation, available company data was utilized to estimate the savings involved in incorporation of dyebath reuse to a 10 machine section of the company's hosiery dyeing operation. The savings were calculated as follows:

Table III
Estimated Company Savings
Pantyhose/Dyebath Reuse

A. Chemical Savings (Dyes, Auxiliaries, Finish)
   Basis: 10 runs
   3 Light
   3 Medium
   4 Dark
   OVERALL: 1.08¢/lb

B. Water/Sewer Savings
   Basis: $980.57/month
   OVERALL: $618/month

C. Energy Savings
   OVERALL: 0.67 of steam now used

D. Personnel Cost Savings due to Increased Productivity
   Basis: $592.00/30 runs
   12.5% increased productivity
   (with same personnel)

   OVERALL ESTIMATED COMPANY SAVINGS: 2.8¢/lb

The chemical and water/sewer savings were well defined based on the pilot scale runs. The energy savings were roughly estimated, as the company has no steam flow meters in place at the present. The increased productivity was based on elimination of the heat-up cycle during dyeing from 60°F (incoming water tem-
perature) to 170°F (dyeing temperature at which bath is held) and also on a re-
duction in the number of dye adds required due to better control.

**Men's Nylon Hosiery**

As stated in the previous report, dyebath reuse on the Black shade with
acid dye (single commercial dye consisting of a blend) appeared feasible. The
color difference results between the socks dyed in the reuse sequence (beaker
scale) and the company standard are in Table IV:

<table>
<thead>
<tr>
<th>Run</th>
<th>Sock Section</th>
<th>Color Difference Versus Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Smooth</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>Ribbed</td>
<td>3.06</td>
</tr>
<tr>
<td>II</td>
<td>Smooth</td>
<td>3.33</td>
</tr>
<tr>
<td></td>
<td>Ribbed</td>
<td>2.70</td>
</tr>
</tbody>
</table>

The Navy shade consisted of the black dye used on the Black shade, as
well as a blue dye. The black dye was an obvious blend of mainly an orange
component (absorbance max. at 440 nm) and a blue component (absorbance max.
at 580 nm). The blue dye was a homogeneous dye with an absorbance max. at
590 nm. Analysis of the black dye on attempted bath reuse was made on the
orange component due to the overlap in the 580-590 nm range of the blue dye
with the blue component of the black dye. A switch to the Navy shade was
attempted from the same bath on a beaker scale after a Black shade run. The
Navy run came too far toward blue, giving a MacAdam unit difference of 7.77 on
color difference calculation with the Navy standard from the company. The
orange component was shown by spectrophotometric analysis to be exhausting much
slower than blue component of the Black dye, and thus reuse analysis based on
the orange peak gave a smaller amount of Black dye to be added than was actually
needed. Efforts to obtain the dye structures of the 2 components of the blend from the manufacturers are underway. In addition, an 18-point computer program is under development that will allow reuse analysis of dyes that have overlapping spectrophotometric curves.

A dyeing was conducted on the Navy shade in the conventional manner from a fresh bath to try and match the company standard. The runs and adjustments made are in Table V:

<table>
<thead>
<tr>
<th>Route</th>
<th>Color Difference Versus Company Standard (MacAdam Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>2.34</td>
</tr>
<tr>
<td>5% Black increase</td>
<td>2.54</td>
</tr>
<tr>
<td>10% Black increase</td>
<td>3.20</td>
</tr>
</tbody>
</table>

The conventional route appeared "too blue", and increasing Black concentration was added in the following 2 fresh-bath runs. The color difference increased, however, due to an increasing depth of shade (darkness due to dye buildup). Therefore, experiments are underway to hold the Black dye at its original concentration and to decrease the Blue dye of the shade until a match is attained.

**Men's Acrylic Socks**

Reuse work on the acrylic hosiery has been postponed until sufficient progress has been made on the nylon socks. Specifically, the 18-point computer program described in the previous section must be developed before beginning the experiment, as the 3 supplied shades on the acrylics all have overlapping dyes.
Polyester Yarn Packages

Several single-shade and multi-shade sequences have been dyed on the 1-package Morton dyeing machine in the reporting period. The 9 Pink I spun yarn packages dyed in the initial reuse sequence were backwound and fabrics knitted on a FAK laboratory unit from yarn corresponding to the outer, three-fourths, one-half, one-fourth, and inner portions of each package. The tristimulus values for the sets of 5 package samples were determined, the values averaged, and the averages utilized in color difference calculations against the average tristimulus values of the initial (conventional) dyed package. The results are shown in Table VI.

Table VI

Lot-to-Lot Color Differences in MacAdam Units of Spun Polyester Yarn Dyed with Pink Disperse Dye

<table>
<thead>
<tr>
<th>Pink I Shade Color Difference Versus Standards</th>
<th>Run (Series A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Standard</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>1.61</td>
</tr>
<tr>
<td>III</td>
<td>4.40</td>
</tr>
<tr>
<td>IV</td>
<td>6.71</td>
</tr>
<tr>
<td>V</td>
<td>0.68</td>
</tr>
<tr>
<td>VI</td>
<td>8.06</td>
</tr>
<tr>
<td>VII</td>
<td>7.95</td>
</tr>
<tr>
<td>VIII</td>
<td>6.44</td>
</tr>
<tr>
<td>IX</td>
<td>8.07</td>
</tr>
</tbody>
</table>

The remainder of the package series that were dyed from company procedures, the yarn construction, and the number of cycles per bath are listed in Tables VII and VIII. The Green series G examined if the yarn construction could be switched during a series without detrimental effect. The multicolor series E and G were run to determine if shades that were not part of a color line,
but which shared 1 or 2 dyes and had high exhaustions, could be dyed in sequence if judiciously selected. The color differences between the series packages and the corresponding standards are also shown in Tables VII and VIII.

Table VII
Lot-to-Lot Color Differences in MacAdam Units of Polyester Yarn Dyed in Single-Shade series

<table>
<thead>
<tr>
<th>Series</th>
<th>Shade</th>
<th>Number of Dyes</th>
<th>Yarn Construction</th>
<th>Package in Series</th>
<th>Color Difference Versus Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Pink I</td>
<td>1</td>
<td>Filament</td>
<td>1</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>0.54</td>
</tr>
<tr>
<td>C</td>
<td>Green</td>
<td>2</td>
<td>Filament</td>
<td>1</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spun</td>
<td>6</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>1.30</td>
</tr>
<tr>
<td>D</td>
<td>Gray</td>
<td>3</td>
<td>Spun</td>
<td>1</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>3.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>4.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>6.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5.56</td>
</tr>
<tr>
<td>E</td>
<td>Gray</td>
<td>3</td>
<td>Filament</td>
<td>1</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>3.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>5.55</td>
</tr>
</tbody>
</table>
Table VIII
Lot-to-Lot Color Differences in MacAdam Units of Polyester Yarn Dyed in Multi-Shade Series

<table>
<thead>
<tr>
<th>Series</th>
<th>Shade</th>
<th>Number of Dyes</th>
<th>Yarn Construction</th>
<th>Package in Series</th>
<th>Color Difference Versus Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Pink II</td>
<td>1</td>
<td>Spun</td>
<td>1</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>3</td>
<td>Spun</td>
<td>2</td>
<td>3.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>2</td>
<td>Spun</td>
<td>4</td>
<td>2.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1.48</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>2</td>
<td>Spun</td>
<td>6</td>
<td>24.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>Gray</td>
<td>3</td>
<td>Spun</td>
<td>8</td>
<td>5.17</td>
</tr>
<tr>
<td>G</td>
<td>Pink II</td>
<td>1</td>
<td>Filament</td>
<td>1</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>2</td>
<td>Filament</td>
<td>2</td>
<td>2.79</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>3</td>
<td>Filament</td>
<td>3</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>2</td>
<td>Filament</td>
<td>4</td>
<td>2.84</td>
</tr>
<tr>
<td></td>
<td>Gray</td>
<td>3</td>
<td>Filament</td>
<td>5</td>
<td>4.33</td>
</tr>
<tr>
<td></td>
<td>Maroon</td>
<td>2</td>
<td>Filament</td>
<td>6</td>
<td>8.47</td>
</tr>
</tbody>
</table>

The color differences for the single-shade series A through E were deemed commercially acceptable, although the differences for series A, Table VI were considered marginal for several runs. In the initial multi-color series F, obvious visual and quantitative problems arose in converting from Green to Yellow (Table VIII). The color difference of the final Gray run in the series (Package 9) was likely due to technician error, as the earlier single-shade Gray runs shown in Table VII gave closer results. The multi-color series G, Table VIII, proved to be a wiser 6-shade selection sequence for filament yarn, resulting in acceptable color differences from the standards with the possible exception of Gray to Maroon (Package 6), with the Maroon being marginal.
To check through-package uniformity, the color differences between the tristimulus values of each sample knit fabric and the average of the tristimulus values of the 5 fabrics of the standard were calculated. For example, the color differences between packages of the Green shade from series C are shown in Table IX. The color differences of each of the fabric samples of the standard against the average for the sample are shown for comparison.

Table IX
Through Package Color Differences in MacAdam Units of Polyester Yarn Dyed in Green Shade Series

<table>
<thead>
<tr>
<th>Series</th>
<th>Package in Series</th>
<th>Yarn Construction</th>
<th>Position in Package</th>
<th>Color Difference Versus Standard Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1</td>
<td>Filament</td>
<td>Outer</td>
<td>4.38</td>
</tr>
<tr>
<td></td>
<td>(Standard)</td>
<td></td>
<td>3/4</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/2</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/4</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inner</td>
<td>1.43</td>
</tr>
<tr>
<td>5</td>
<td>Filament</td>
<td>Outer</td>
<td>3/4</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/2</td>
<td>2.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/4</td>
<td>1.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inner</td>
<td>2.86</td>
</tr>
<tr>
<td>6</td>
<td>Spun</td>
<td>Outer</td>
<td>3/4</td>
<td>3.11</td>
</tr>
<tr>
<td></td>
<td>(Standard)</td>
<td></td>
<td>1/2</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/4</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inner</td>
<td>2.46</td>
</tr>
<tr>
<td>8</td>
<td>Spun</td>
<td>Outer</td>
<td>3/4</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/2</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/4</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inner</td>
<td>1.57</td>
</tr>
</tbody>
</table>


The polyester yarn experiments demonstrated that dyebath reuse is adaptable to pressure dyeings, that lot-to-lot and through-package shade uniformity is acceptable in single shade sequences, and that, if exhaustion is high, multi-color sequences not in a color line can be dyed satisfactorily if at least 1 dye overlaps and if the shade series are chosen judiciously. The actual chemical and water savings and the calculated energy savings for the 9-run, multi-color series F are shown in Table II.

**Underwear Knit Fabrics**

Using the "split-bath" technique described in the previous quarterly report and employing a single Procion reactive dye, 100% cotton knit underwear fabric has been dyed on a beaker scale 5 times from the same impregnation and fixation baths. The reactive dye in the impregnation bath was apparently stable for long periods at room temperature and at a slight acidic pH, as the final 2 dyeings without drop in quality. The color differences between the fabrics and a standard dyed by the conventional technique were within the 2-4 MacAdam unit range desired. It has thus been demonstrated that dyebath reuse is adaptable to reactive dyeing of cotton if certain precautions are taken (split bath, slightly acidic dye impregnation bath, etc.).

The 18-point computer program described earlier is now being investigated to aid in analysis of the full company dyeing procedure, which included 3 spectral overlapping Procion reactive dyes. Once the reactive dyes on cotton have been demonstrated at the 1-foot beaker stage, the system will be adapted to reactive/disperse dyeing of 50/50 cotton/polyester knit underwear fabric. With the expertise built to date on disperse dyeing of polyester yarn and carpet, the transfer of the technology to cotton/polyester blends should be straightforward. Studies will also be conducted on the feasibility of using a
high-temperature stable reactive with a disperse dye in a single impregnation bath to give a simpler system for dyeing the cotton/polyester blends.

**Polyester Carpet**

Work continued this quarter to extend dyebath recycle to carpet procedure from polyester face yarn dyed with disperse dyes. This work will essentially complete the application of dyebath recycle to all types of carpet currently dyed in fabric form.

A working relationship with a large Georgia carpet plant has been established for this part of the study. A suitable carpet has been selected and plant procedures for dyeing of this carpet in 3 large volume colors have been obtained.

Extensive data on color differences in production runs of polyester carpet have been collected to provide a benchmark for comparison with pilot scale dyeings using recycle. These recent data suggest that color tolerances are becoming more critical in the carpet industry. Differences of the order of 3 to 4 MacAdam units are common with a few samples showing differences of 5 or 6 MacAdam units. These data covering a 3 month production period will be very valuable in assessing the recycle dyeings.

Development of the analytical procedures for polyester disperse dyes in spent dyebaths is underway and pilot scale dyeings are planned for early next quarter.

**Nylon Carpet-Disperse Dyes**

Preliminary work for the pilot scale dyeings of nylon carpet to 4 different colors with disperse dyes with reuse of the dyebath have been completed. In this experiment we will dye 30-40 pound carpet samples beige, blue, green, and rust shades with reuse of the bath for 8 dyeings. This series will com-
plete laboratory work on dyeing of nylon with disperse dyes.

A more extensive analysis of the economic and energy conservation potential of disperse dyeing of nylon carpet with recycle has been carried out based on the 5 run pilot scale experiment. Results show that savings of 4% in dye cost, 65% in auxiliary costs, 65% in water requirements and 15% in energy requirements are possible with recycle in this system.

Evaluation of the uniformity and reproducibility of the pilot scale recycle dyeings has also been carried out. Ten samples were cut at random along the length of each of the 5 dyeings. Color differences between each of the 10 samples and the average of the 10 measurements are given in Table X. Only 3 of the 50 samples gave values greater than 4 MacAdam units indicating that very good uniformity was achieved in the dyeings.

Color differences between the average of the 10 measurements for each sample and the average of the 10 measurements for the control dyeing (Run 1) were used to assess the reproducibility. The results are shown in Table XI. The color differences are much smaller than those observed for typical commercial practice.

Samples of the carpets dyed in recycled baths have been submitted for visual examination to several experienced plant dyers. The dyers were unanimous in confirming that the dyeings were first quality.

Nylon Carpet-Acid Dyes

Dyeing of nylon carpet with acid dyes has not been actively pursued this quarter. The currently available carpet samples are not suitable for pilot scale runs. A second manufacturer has agreed to supply a suitable carpet and dyeing recipes in the near future.

Several laboratory experiments to investigate control of leveling by
adjustment of dyebath pH were carried out and show promise for acid dyeing of nylon.

Table X
End-to-End Color Differences in MacAdam Units of Nylon Carpet Dyed with Disperse Dyes

<table>
<thead>
<tr>
<th>Position</th>
<th>Run I</th>
<th>Run II</th>
<th>Run III</th>
<th>Run IV</th>
<th>Run IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.68</td>
<td>0.76</td>
<td>2.61</td>
<td>1.81</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>0.67</td>
<td>1.33</td>
<td>4.02</td>
<td>5.16</td>
<td>0.40</td>
</tr>
<tr>
<td>3</td>
<td>1.04</td>
<td>3.90</td>
<td>0.97</td>
<td>3.17</td>
<td>1.30</td>
</tr>
<tr>
<td>4</td>
<td>1.99</td>
<td>1.82</td>
<td>1.00</td>
<td>1.90</td>
<td>1.13</td>
</tr>
<tr>
<td>5</td>
<td>0.35</td>
<td>3.57</td>
<td>3.75</td>
<td>1.61</td>
<td>2.14</td>
</tr>
<tr>
<td>6</td>
<td>1.60</td>
<td>2.38</td>
<td>3.15</td>
<td>2.11</td>
<td>0.69</td>
</tr>
<tr>
<td>7</td>
<td>0.72</td>
<td>3.21</td>
<td>1.41</td>
<td>0.76</td>
<td>0.46</td>
</tr>
<tr>
<td>8</td>
<td>3.39</td>
<td>0.84</td>
<td>4.17</td>
<td>1.55</td>
<td>1.79</td>
</tr>
<tr>
<td>9</td>
<td>0.98</td>
<td>2.53</td>
<td>1.96</td>
<td>3.59</td>
<td>2.09</td>
</tr>
<tr>
<td>10</td>
<td>1.10</td>
<td>5.78</td>
<td>1.23</td>
<td>1.52</td>
<td>1.64</td>
</tr>
</tbody>
</table>

Table XI
Lot-to-Lot Color Differences in MacAdam Units of Nylon Carpet Dyed with Disperse Dyes

<table>
<thead>
<tr>
<th>Run</th>
<th>Color Difference Versus Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>-</td>
</tr>
<tr>
<td>(Standard)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>1.31</td>
</tr>
<tr>
<td>III</td>
<td>0.44</td>
</tr>
<tr>
<td>IV</td>
<td>0.45</td>
</tr>
<tr>
<td>V</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Preparation of Cotton-Containing Fabrics

The objective of this work is the reduction in the energy and chemical re-
requirements in the preparation of cotton and cotton/polyester blend fabrics through modifications of existing preparation procedures. These procedures include singeing, desizing, scouring, bleaching and mercerization. The process of singeing is not being considered. Desizing, scouring and bleaching are all cleaning processes whereas mercerization is a process involving basic structural changes in the cotton fiber. It has estimated that the thermal energy requirements for the continuous preparation of cotton fabrics including desizing, scouring, and bleaching (with hydrogen peroxide) exclusive of drying is 2370 BTU's and 1860 BTU's per pound of fabric for open-width and rope form processes, respectively. Further, 70-75 percent of the thermal energy requirement for heating the water is used in washing the fabric following each step in the process. Approximately 20 percent of the energy in the rope process is steam used in connection with the caustic scour and peroxide J boxes. In view of these considerations, work is underway to determine the feasibility of combining preparation processes. The obvious processes to combine are scouring and bleaching. This would eliminate one J-box steaming and one washing as well as reduce the amounts of chemicals required. Substantial savings of energy and chemicals should result.

The impurities in cotton and cotton/polyester blend woven fabrics which must be removed in fabric preparation include:

1. warp size
2. natural impurities in cotton
   These impurities include wax, pectic substances, proteins, sample organic acids such as malic and citric acids, sugars and mineral matter. In addition, all cotton fabrics contain impurities known as motes which come from the seed of the cotton bale. Motes are the small dark specks seen in unbleached cloth.
3. producer finish
These impurities are applied to polyester fiber by the fiber producer to facilitate the processing of the fiber through yarn manufacture.

4. miscellaneous impurities including picker oils and greases, rust, chalk, etc.

In this work, attention will be focused initially on the removal of the impurities associated with cotton and polyester and not those impurities associated with the warp size. This is normally accomplished in two separate processes, namely scouring and bleaching. The feasibility of combining these processes will be explored. A description of accomplishments to date and future work follows:

I. Identification of Fabrics

The experimental work on a combined scouring and bleaching process will be performed on fabrics furnished by a quality manufacturer are described as follows:

Fabric 1. 50/50 polyester/cotton (51½" wide)
Twill Style 5554

Fabric 2. 50/50 polyester/cotton (61" wide)
Style 180 Sheeting

II. Analysis of Warp Size

The twill fabric was found to have starch-based warp size and the sheeting fabric only polyvinyl alcohol. The quantity of size was not determined.

III. Preparation of Desized Fabrics

Fabric 1 was desized as follows:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Concentration (o.w.f.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brine (28%)</td>
<td>0.89%</td>
</tr>
<tr>
<td>Enzyme-Rapidase</td>
<td>0.14%</td>
</tr>
<tr>
<td>Griffwet NB-106</td>
<td>0.06%</td>
</tr>
</tbody>
</table>
The desizing process was carried out in a sample beck at 170°F for one (1) hour with a liquor ratio of 40:1. This treatment was followed by hot rinsing. Tests indicated the complete removal of starch.

Fabric 2 will be desized in a similar manner except brine and enzyme will be omitted.

These fabrics will be used in the scouring and bleaching studies.

IV. Preparation of Bleached Reference Fabrics

In order to provide a reference against which can be judged the quality of samples scoured and bleached in a one-step process, two procedures will be followed:

1. Two-step commercial procedure
   This procedure will be that which is representative of commercial practice.

2. One-step experimental procedure
   This procedure will be essentially the same as the two-step commercial procedure except that the chemical agents required for the two-step process will be combined in one step.

These reference standards will be evaluated by standard procedures (AATCC) used for determining bleached quality:

1. water absorbency
2. brightness - whiteness
3. strength
4. extractables
5. mote removal

V. Problem of Mote Removal

The severity of the scouring treatments used for cotton is undoubtedly associated with the problem of the removal of motes. There are references in old textbooks, to the use of various organic solvents
which appear to promote mote removal (*). Therefore, experiments will be carried out to determine the effectiveness of selective reagents in removing motes. These include such materials as ethylene glycol, diethylene glycol, triethanolamine, N,N-dimethylformamide, triacetone, trichloroethylene and perchloroethylene. Solutions of these reagents will be applied to the desized fabric either by padding or spotting followed by steaming. Visible inspection of the fabrics should reveal the effectiveness of the reagent. This will be followed by a combined scouring and bleaching procedure to determine the effectiveness of the reagents.

VI. Exploratory One-Step Scouring and Bleaching Experiments

In this work, the variables studies will be

1. The type and amount of chemical agent found to be effective in removing motes.
2. The type and amount of peroxy compounds (other than hydrogen peroxide).

The resulting samples will be subjected to the same tests for bleach quality as described above.

VII. Establishment of a One-Step Process for Mill Treatment

The variables in this phase of the work will include:

1. Concentration of peroxy compound (other than hydrogen peroxide) found to be effective.
2. Ratio of sodium hydroxide to sodium silicate
3. The total amount of sodium hydroxide and sodium silicate.
4. The concentration of the reagent found to be effective in removing motes.
5. The time of bleaching at 100°C.

The resulting fabrics will be evaluated with respect to bleach quality as described above. These experiments should provide the optimum one-step scouring and bleaching procedure.
THERMOMECHANICAL PREDRYING

During the last quarter, thermomechanical vacuum drying was studied. Problems with maintaining a vacuum prevented any real progress towards determining the effectiveness of the technique presented in the last report. However, during the study, some interesting and important observations with regard to cylinder drying were made. Accordingly, in this report these observations are discussed.

Steam charged drying cylinders are commonly employed in the textile finishing industry to dry fabrics. These cylinders are used in a continuous fashion on ranges which might include tenter frames, vacuum nozzles, and mangles for drying. Their main advantage is that the rate of heat transfer to the fabric may be considerably more rapid than for convection or radiation heating. A limitation of steam can drying is the necessity of having a solid surface in physical contact with the fabric which may cause damage to the fabric.

As with tenter frames the greatest portion of energy consumption derives from energy for water evaporation (latent heat of vaporization) and that for heating of the air used to carry away water vapor. The latent heat of vaporization remains relatively constant over a large range of pressure and temperatures for water (about 1000 BTU per pound of water). However, the energy required to heat the air used to remove water vapor can be affected by the humidity of the exhaust air and the difference between air input and exhaust temperature. This relationship is presented in Figure 8.

In a typical textile mill, minimum theoretical steam requirement to heat one pound of water from 90°F to 212°F and evaporate it at atmospheric pressure is about 1.09 pounds of steam per pound of water. Added to this requirement is the steam usage to heat the air. It can be observed from Figure 8 that if the exhaust air is rich in moisture, less steam is used. But this argument has a fault since a high exhaust air humidity will cause a dramatic slow down in
difference between air input and exhaust temp.

100° F

80° F

60° F

STEAM USAGE - lbs steam / lb exhausted water

HUMIDITY OF EXHAUST AIR - lbs water / lb dry air

Figure 8
production speed and the opportunity cost for equipment will rise dramatically. On the other hand, if the difference between air input and exhaust temperature can be reduced, the steam usage will drop dramatically. Accordingly, an effort has been made this last quarter to determine if lower drying can temperatures may be employed to effect drying.

An experimental rig consisting of two aluminum drying cans was assembled. A schematic of this assembly is given in Figure 9. Each can has an inside diameter of 6", a length of 15" and a 1/4" wall thickness. Hot water to heat the cans is supplied by a portable hot water heater. Three water temperatures were studied: 120°F, 140°F and 160°F. The corresponding can surface temperatures were measured with a thermocouple. Bleached, unfinished 50% cotton 50% polyester sheeting samples (4.75 oz/yd²) were wetted thoroughly, wrung and subsequently exposed to the can surfaces for periods ranging from 10 to 40 seconds per side of fabric. The results of these experiments are presented in Table XII.
I CAN

I CAN HOT WATER HEATER

-35-

Figure 9
Table XII

<table>
<thead>
<tr>
<th>Water Temp °F</th>
<th>Can Temp °F</th>
<th>Exposure</th>
<th>Dry Wt. oz/yd²</th>
<th>Wet Wt. g/yd²</th>
<th>Moisture Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>120°F</td>
<td>100°F</td>
<td>10 sec/side</td>
<td>4.75</td>
<td>8.13</td>
<td>71%</td>
</tr>
<tr>
<td>120°F</td>
<td>100°F</td>
<td>20 sec/side</td>
<td>4.75</td>
<td>7.58</td>
<td>60%</td>
</tr>
<tr>
<td>120°F</td>
<td>100°F</td>
<td>30 sec/side</td>
<td>4.75</td>
<td>7.41</td>
<td>56%</td>
</tr>
<tr>
<td>120°F</td>
<td>100°F</td>
<td>40 sec/side</td>
<td>4.75</td>
<td>7.13</td>
<td>50%</td>
</tr>
<tr>
<td>140°F</td>
<td>126°F</td>
<td>10 sec/side</td>
<td>4.75</td>
<td>7.99</td>
<td>68%</td>
</tr>
<tr>
<td>140°F</td>
<td>126°F</td>
<td>20 sec/side</td>
<td>4.75</td>
<td>7.55</td>
<td>59%</td>
</tr>
<tr>
<td>140°F</td>
<td>126°F</td>
<td>30 sec/side</td>
<td>4.75</td>
<td>7.55</td>
<td>59%</td>
</tr>
<tr>
<td>140°F</td>
<td>126°F</td>
<td>40 sec/side</td>
<td>4.75</td>
<td>7.21</td>
<td>52%</td>
</tr>
<tr>
<td>160°F</td>
<td>126°F</td>
<td>10 sec/side</td>
<td>4.75</td>
<td>7.80</td>
<td>64%</td>
</tr>
<tr>
<td>160°F</td>
<td>126°F</td>
<td>20 sec/side</td>
<td>4.75</td>
<td>7.55</td>
<td>59%</td>
</tr>
<tr>
<td>160°F</td>
<td>126°F</td>
<td>30 sec/side</td>
<td>4.75</td>
<td>6.79</td>
<td>43%</td>
</tr>
<tr>
<td>160°F</td>
<td>126°F</td>
<td>40 sec/side</td>
<td>4.75</td>
<td>6.36</td>
<td>34%</td>
</tr>
</tbody>
</table>

From the results in Table XII, one can conclude that drying can be accomplished without the use of high temperature steam thereby eliminating the high energy usage that arrives from heating makeup air. In the next quarter this technique will be studied extensively to determine its economic and technical practicality.

Predrying

Substituting mechanical water removal for phase-change drying has been shown to be more energy efficient. Vacuum slots driven by electric suction pumps are commonly employed to predry carpet and fabric. A Machnozzle was ordered which, employing steam "blows" water from the fabric rather than "sucking" it out. Preliminary design of the test setup is in progress. It is anticipated that tests to determine energy savings will begin early next year.
QUARTERLY PROGRESS REPORT

September 1, 1977 through November 30, 1977

Energy Conservation in the
Textile Industry

Contract No. E(40-1)-5099
Research Project A-1853 & E-27-642

Prepared For

The Energy Research and Development Administration
Buildings and Industry Conservation
Washington, D.C.

The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

January 1978
INTRODUCTION

Research Project A-1853 and E-27-642 is being conducted for the Energy Research and Development Administration pursuant to contract E(40-1)-5099 by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. The purpose of this research project is to identify and demonstrate process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies. This will include development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements, and dissemination of the research results throughout the industry.

Phase I of the project had the specific objectives of:
1. Identifying major energy intensive processes which might be subject to energy conserving modifications and determining the energy conservation potential for these process modifications
2. Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:
1. Developing and demonstrating, on a pilot or full-scale basis, energy conserving modifications for selected processes identified in Phase I,
2. Examining cost-benefit relationships of proposed process modifications, and
3. Disseminating the results of the research to industry.

Phase I of this project has been completed and the Phase I report has been reviewed, modified and transmitted to the ERDA program manager. Phase II of this effort was initiated early in 1977 and this quarterly activity report described these activities for the time period from September 1, 1977 through November 30, 1977.

CASE STUDIES

Compilation of cost/benefit relationships for energy conservation projects funded by textile manufacturers continues.
DYEBATH REUSE IN DYEING OF FABRICS, HOSIERY, YARN PACKAGES, AND CARPETS

FABRICS

Cotton and Cotton/Polyester Knits

A system for effectively utilizing dyebath reuse reactive dyeing of 100% cotton knit fabrics and reactive/disperse dyeing of 50/50 cotton/polyester blended knit fabrics has been developed and demonstrated on a small scale. The initial objective was to color 100% cotton fabric with a single Procion MX reactive dye to determine if the problems inherent in reusing the bath with this class of dyes were soluble. The "splitbath" technique described in the previous report was utilized. The dyes were stable in aqueous solution at a pH of 6-6.5, and the impregnation bath was held at this pH level to avoid dye hydrolysis. A "step-up" in exhaustion inherent in base fixation in the conventional system, but which is absent in the split-bath technique, was compensated for by using a higher concentration of dye in the impregnation bath. Bleeding of dye on introduction of the caustic fixation bath was minimized by utilizing salt and deliberately hydrolyzed reactive dye in the bath. Both the impregnation dyebath and the fixation bath were thus successfully reused in the experiments. A total of 5 fabrics were dyed on a large beaker scale in the reuse sequence. The final fabric was dyed several days after the initial dyeing to demonstrate the hydrolytic stability of the reactive dye in the slightly-acid impregnation bath. The shade variations were determined by the techniques described in previous reports utilizing three reflectance measurements at three points randomly chosen from each dyed fabric. Color difference calculations between the reuse-dyed samples and the first dyed material (taken as the standard) revealed that the MacAdam unit variation through the series was 1.5 to 2.9 units. Efforts are underway to obtain a statistical sampling of fabrics dyed to a single shade from the participating plant's first quality production in order to get an acceptable MacAdam-unit range for the product line. From earlier commercial samples of textile structures (carpets, hosiery, etc.) the obtained range appears well within industrial tolerances.
The next investigation was to utilize a multicomponent Procion reactive dye system that corresponded to a large-volume recipe utilized by the company. The recipe consisted of four distinct reactive dyes, two of which were contained in a single package as a blended dye. The dye manufacturer, ICI Inc., provided the researchers with a detailed analysis of the dye blend, which consisted of two commercially available components. Using a 20-point computer program developed on the project for accurate analysis of complex dye systems with overlapping spectrophotometric curves (see previous report), accurate analysis of the spent dyebath was possible. A total of six fabrics were dyed utilizing the "split bath" dyebath reuse technique developed for the single-dye system, and the fabrics analyzed for color differences. The color differences between the average of all the reflectance measurements obtained for the six samples (18 total), and the individual dyed fabrics ranged from 0.3 to 1.5 MacAdam units. The color difference between the first dyed sample and the following five reuse-dyed samples ranged from 1.0 to 3.1 MacAdam units. All of the samples thus fell within predicted lot-to-lot shade variation tolerance ranges, and thus demonstrated the accuracy of the 20-point program in analyzing multicomponent dye systems. The program thus aids considerably in broadening the potential applicability of dyebath reuse.

The final area of knit fabric research was to adapt dyebath reuse to the coloration of 50/50 cotton/polyester blends. Traditionally, two complete cycles have been required to dye the individual components for no single dye class has been developed that will color adapt the natural and synthetic fibers. Such cycles are extremely energy inefficient, requiring approximately 12 hours time and consuming 16 - 20,000 BTU's/lb. of finished goods. Recent development of high temperature stable reactive dyes by ICI (Procion HE series) offered the possibility of applying both reactive and disperse dyes from the same bath, while the reactive dye research on 100% cotton indicated that the baths could be reused. The dyebath at a pH of 6.0-6.5 thus consisted of a base-stable disperse dye (also by ICI), a Procion HE series reactive dye, and all of the relevant auxiliaries for both classes. The fabric was submerged in the bath, the solution brought to the boil, and the polyester component was disperse dyed. After cooling to 175°F, the dyebath solution was removed and the caustic fixation bath for the reactive dye was entered into the fabric container and raised to 175°F. The fixation bath was then removed hot, and both the fixation bath and the dyebath were
subsequently reused to dye a total of six samples. To analyze the dyebath containing the relatively water-insoluble disperse dye and the soluble reactive dye, benzene extraction was utilized to separate the dye classes. The disperse dye was found to be extracted into the benzene layer, while the more polar reactive dye remained in the aqueous layer. The color differences between the average of all the reflectance measurements obtained for the six samples (18 total) and the individual dyed fabrics ranged from 0.7 to 1.5 MacAdam units. The color differences between the first dyed sample and the following five reuse dyed samples ranged from 1.0 to 3.1 MacAdam units. All of the samples thus fell within predicted lot-to-lot shade variation tolerance ranges, and thus demonstrated the feasibility of dyeing cotton/polyester fabrics from a single dyebath with both the dyebath and caustic fixation bath reused.

Calculations are being performed to roughly determine the energy and mass balances for the reuse system on the knits versus the conventional systems, and to decipher the percent savings in energy, chemicals, and water.

**Nylon Upholstery**

Work on the nylon upholstery fabric has been delayed to allow development of the 20-point computer program necessary for analysis of the multi-component dye systems. Due to the success with the developed program for the reactive dye analyses, work will now begin on the upholstery fabric.

**Hosiery**

To insure a minimum of problems in the in-plant demonstrations, the Investigators have continued pilot-scale hosiery dyeing research in Phase II of DOE Contract No. E-(40-1)-5099. Dyeings have been conducted to simulate exactly the procedure formulated by the Georgia Tech investigators and the sponsoring company for in-plant dyebath reuse. The procedure, detailed in Table I, differs in several respects from the current one-bath procedure utilized by the company (Table II). Since the initiation of Phase II, Adams-Millis has lowered the holding temperature in the hosiery dyeings to 170°F, and this change has been incorporated in the reuse procedure. The finish bath for the dyed hosiery in the modified procedure will also be used as a prescour bath for the subsequent batch. The mild prescour was placed in the reuse procedure in order to eliminate gross quantities of spin oils, oligomers, and other detrimental chemicals inherent with the fiber that could interfere with the dyeing behavior in long-run reuse sequences. No additional
water, energy, or chemical costs are incurred by incorporation of the prescour. The scour chemical costs are incurred by incorporation of the prescour. The scour chemical is placed in the dyebath at a 2% owf concentration in the conventional procedure. In the modified procedure, the scour chemical is added at a 1% owf concentration to the dyebath and at a 1% owf concentration in the separate scour bath, so that there is no overall chemical volume increase. The required dyebath analysis time (approximately 15-30 minutes) is concurrent with the 36 minutes necessary to finish Batch I and to prescour Batch II.

In discussing Phase III, the company expressed doubt that sufficient quantities of Nylon 66 pantyhose to be dyed in the in-plant demonstration would be required by customers in the season in which the demonstrations were planned (April-September). In addition, Nylon 6-based pantyhose had overtaken Nylon 66-based pantyhose as the company's largest volume style.

The Georgia Tech investigators thus agreed to conduct a 13-cycle reuse sequence that would incorporate both Nylon 6 and Nylon 66 pantyhose in a range of five shades utilizing the proposed procedure detailed in Table I. The Nylon 66 batches were subsequently dyed by the three shades utilized previously in the Phase II 1-cycle reuse sequence, and the Nylon 6 batches were dyed by two different shades supplied by the company that incorporated the same three disperse dyes used to attain the Nylon 66 shades.

The sequence, detailed in Table III, was conducted using the Table I procedure at Georgia Tech on the 2-foot Smith Rotary Drum machine. No unexplained problems were encountered during the sequence, and the hosiery quality was judged visually acceptable. Quantitative color difference calculations using the Diano LSCE Automate R System and the FMC II Color Difference Metric Program confirmed that the hosiery fell within the 3-7 MacAdam unit tolerance range that had been deciphered for Adams-Millis (Table IV). The sequence thus confirmed that on a pilot-scale basis the modified procedure is practical, that random switching of the two fiber types and the selected five shades within the sequence is possible, and that commercial quality pantyhose can be obtained utilizing multicycle reused baths. No further nylon pantyhose experiments are planned at Georgia Tech until the beginning of the Phase II in-plant demonstration project, at which time the check-out of the purchased analytical equipment for dyebath analysis will be conducted.
TABLE I
Modified Procedure for Dyebath Reuse
Pantyhose Operations

I. Dyeing Batch I

1. Load machine
2. Fill with cold water, raise to 90°F
3. Add auxiliary chemicals, run 10 minutes
4. Add dyes
5. Raise temperature at ca. 3°F/minute to 170°F
6. Run 20 minutes at 170°F
7. Sample; make add if necessary
8. Dump the bath to holding tank when correct shade is obtained

II. Finishing Batch I

9. Refill with cold water
10. Inject steam rapidly to achieve 110°F
11. Add finish chemical and run 10 minutes at 110°F
12. Unload the pantyhose

CYCLE I TOTAL: 119 minutes

III. Dyeing Batch II

1. Load machine
2. Add prescour chemical to exhausted finish bath at ambient temperature, run 10 minutes
3. Dump prescour bath to drain
4. Refill with the analyzed dyebath from holding tank at ca. 150°F*
5. Add the necessary auxiliaries to reconstitute the bath, run 10 minutes
6. Add the necessary dyes to reconstitute the bath slowly over a 10 minute period
7. Raise temperature at ca. 3°F/minute to 170°F
TABLE I (con't)

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Run 30 minutes at 170°F</td>
</tr>
<tr>
<td>9. Sample; make add if necessary</td>
</tr>
<tr>
<td>10. Dump the bath to holding tank when correct shade is obtained</td>
</tr>
</tbody>
</table>

IV. Finishing Batch II

1. Repeat steps 9 through 12, Batch I | 20 |

**CYCLE II TOTAL:** | **103 minutes**

**TOTAL TIME, CYCLES I and II:** | **3.7 hours**

*Analysis of the spent dyebath is done during the 20 minute finishing cycle of Batch I and the 16 minute prescour cycle of Batch II, and thus no additional cycle time is charged to the analysis which is conducted on equipment not required for simultaneous dye machine operation.*
**TABLE II**

Conventional Company Procedure for Dyeing Pantyhose

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Dyeing Batch I</strong></td>
<td></td>
</tr>
<tr>
<td>1. Load machine</td>
<td>3</td>
</tr>
<tr>
<td>2. Inject live steam 10 minutes at 200°F</td>
<td>12</td>
</tr>
<tr>
<td>3. Fill with cold water, and raise to 90°F</td>
<td>7</td>
</tr>
<tr>
<td>4. Add auxiliary chemicals, run 10 minutes</td>
<td>10</td>
</tr>
<tr>
<td>5. Add dyes</td>
<td>1</td>
</tr>
<tr>
<td>6. Raise temperature at 3°F/minute to 170°F</td>
<td>45</td>
</tr>
<tr>
<td>7. Run 20 minutes at 170°F</td>
<td>20</td>
</tr>
<tr>
<td>8. Sample; make add if necessary</td>
<td>10</td>
</tr>
<tr>
<td>9. Dump the bath to drain when correct shade is obtained</td>
<td>3</td>
</tr>
</tbody>
</table>

| **II. Finishing Batch I** |       |
| 10. Refill with cold water, rinse 10 minutes, and dump the bath | 20    |
| 11. Refill with cold water | 3     |
| 12. Inject steam rapidly to achieve 110°F | 4     |
| 13. Add finish chemical and run 10 minutes at 110°F | 10    |
| 14. Dump the bath to drain | 3     |
| 15. Unload the pantyhose | 3     |

**CYCLE I TOTAL:**

154 minutes

| **III. Dyeing and Finishing Batch II** |       |
| 1. Repeat steps 1 through 15 |   |

**CYCLE II TOTAL:**

154 minutes

**TOTAL TIME, CYCLES I and II:**

308 minutes

5.1 hours
TABLE III

Pilot Scale Dyebath Reuse Sequence
Performed on Nylon 6 and Nylon 66 Pantyhose

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Shade*</th>
<th>Nylon Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>Medium I</td>
<td>66</td>
</tr>
<tr>
<td>3</td>
<td>Medium II</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Dark II</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Dark I</td>
<td>66</td>
</tr>
<tr>
<td>6</td>
<td>Light</td>
<td>66</td>
</tr>
<tr>
<td>7</td>
<td>Medium I</td>
<td>66</td>
</tr>
<tr>
<td>8</td>
<td>Medium II</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Dark II</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>Dark I</td>
<td>66</td>
</tr>
<tr>
<td>11</td>
<td>Light</td>
<td>66</td>
</tr>
<tr>
<td>12</td>
<td>Medium II</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>Light</td>
<td>66</td>
</tr>
</tbody>
</table>

* A total of 5 shades were utilized. The numeral I refers to a Nylon 66 shade, and the numeral II refers to a Nylon 6 shade.
Polyester Yarn Packages

The polyester yarn pressure package dyeing experiments were completed by determining the feasibility of recycling the caustic/hydrosulfite reduction clearing bath in addition to the dyebath. No simple procedure could be found for analyzing accurately the hydrosulfite concentration in an aqueous solution, so hydrosulfite was added back at 10% of the original weight without analysis. After hydrosulfite was added, a pH meter was used to easily decipher the pH drop on reduction clearing, and sufficient sodium hydroxide was added to adjust the pH to the initial level. The shade series conducted, the color differences at each position through the dyed packages, and the average color difference from the standard are given in Table V. A single shade (blue) composed the first five runs, while shade-to-shade switching was accomplished in the last four runs for a total of nine cycles. Both the dyebath and reduction clearing bath were reused. As shown in Table V, the through-package uniformity and lot-to-lot shade variations were within limits observed in earlier single-shade reuse runs (see previous report). The gray shades deviated the farthest from the standard but the large deviation had also been observed in the single shade gray dyeing. Light fastness and crockfastness tests were performed on standard dyed fabrics, reuse-dyed fabrics, and fabrics which had been colored utilizing reused dye and reduction baths. Lightfastness was performed according to AATCC Test method 16A-1974, and crockfastness was performed according to AATCC Test Method 8-1972. All of the fabrics knitted from the yarns were unaffected by the tests (test ratings of 5), and thus the reused reduction bath did not adversely affect the products' fastness qualities.
TABLE IV
Lot-to-Lot Color Differences in MacAdam Units
of Nylon 66 and Nylon 6 Pantyhose Dyed
With Disperse Dyes

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Fiber Type</th>
<th>Shade *</th>
<th>Color Difference Versus Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66</td>
<td>Light</td>
<td>1.96</td>
</tr>
<tr>
<td>2</td>
<td>66</td>
<td>Medium I</td>
<td>4.21</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>Medium II</td>
<td>2.87</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Dark II</td>
<td>1.93</td>
</tr>
<tr>
<td>5</td>
<td>66</td>
<td>Dark I</td>
<td>2.79</td>
</tr>
<tr>
<td>6</td>
<td>66</td>
<td>Light</td>
<td>1.95</td>
</tr>
<tr>
<td>7</td>
<td>66</td>
<td>Medium I</td>
<td>2.98</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>Medium II</td>
<td>2.16</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>Dark II</td>
<td>2.41</td>
</tr>
<tr>
<td>10</td>
<td>66</td>
<td>Dark I</td>
<td>2.36</td>
</tr>
<tr>
<td>11</td>
<td>66</td>
<td>Light</td>
<td>2.99</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>Medium II</td>
<td>3.37</td>
</tr>
<tr>
<td>13</td>
<td>66</td>
<td>Light</td>
<td>4.21</td>
</tr>
</tbody>
</table>

*A total of 5 shades were utilized. The numeral I refers to a Nylon 66 shade, and the numeral II refers to a Nylon 6 shade.
<table>
<thead>
<tr>
<th>Package Number</th>
<th>Shade</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Average Color Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blue</td>
<td>3.21</td>
<td>2.31</td>
<td>1.84</td>
<td>1.30</td>
<td>1.41</td>
<td>1.87</td>
</tr>
<tr>
<td>2</td>
<td>Blue</td>
<td>4.12</td>
<td>3.06</td>
<td>1.74</td>
<td>1.37</td>
<td>1.17</td>
<td>1.77</td>
</tr>
<tr>
<td>3</td>
<td>Blue</td>
<td>7.38</td>
<td>5.05</td>
<td>4.43</td>
<td>3.73</td>
<td>4.11</td>
<td>4.90</td>
</tr>
<tr>
<td>4</td>
<td>Blue</td>
<td>4.17</td>
<td>2.37</td>
<td>1.02</td>
<td>1.57</td>
<td>0.65</td>
<td>1.35</td>
</tr>
<tr>
<td>5</td>
<td>Blue</td>
<td>1.48</td>
<td>1.40</td>
<td>1.31</td>
<td>0.65</td>
<td>1.99</td>
<td>1.30</td>
</tr>
<tr>
<td>6</td>
<td>Green</td>
<td>2.82</td>
<td>3.23</td>
<td>2.97</td>
<td>2.68</td>
<td>3.29</td>
<td>2.82</td>
</tr>
<tr>
<td>7</td>
<td>Blue</td>
<td>10.40</td>
<td>4.47</td>
<td>5.39</td>
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<td>8.53</td>
<td>4.21</td>
</tr>
<tr>
<td>9</td>
<td>Maroon*</td>
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<td>5.61</td>
<td>4.94</td>
<td>4.41</td>
<td>4.50</td>
<td>4.68</td>
</tr>
</tbody>
</table>

*Dyed on spun yarn.
Overall energy, chemical and water savings for the dyebath reuse adaption to pressure package dyeing, for the reduction bath reuse, and overall savings for the two combined procedures over conventional techniques are detailed in Table VI. The percent energy savings are considerably higher than with atmospheric carpet or hosiery dyeing, for the pressurized package dye machines are essentially adiabatic systems with no vapor or undissipated steam losses. The energy figures were thus calculated for an adiabatic system. The chemical and water savings constitute "hard" data that was taken directly from the pilot-scale experiment.

The overall conclusions from the polyester yarn reuse research were therefore that the reuse technique was adaptable to pressure dyeing systems and reduction clearing operations, that energy, chemical, water, and sewer savings were substantial, and that industrial quality standards could be maintained.

Cotton and Cotton/Polyester Yarn Packages

A meeting has been held with the participating yarn dyeing company to discuss the feasibility of a Phase III in-plant demonstration of polyester package reuse system. Due to the recent increase in the volume of 100% polyester knit fabrics dyed on jet machines, the general depression in the polyester apparel market, and the corresponding decrease in the volume of polyester yarn package dyed, 100% polyester packages presently constitute less than 1% of the volume of material dyed by the company. Future improvement in the polyester area was not foreseen. The company therefore requested that, in view of the success obtained in the reactive dyeing of the cotton/polyester knit underwear fabrics, Georgia Tech investigate transfer of the reuse technology to package dyeing of yarn containing cotton in Phase II before a decision is reached on an in-plant demonstration. As cotton/polyester yarn now accounts for approximately 70% of the company production, a high-volume procedure was obtained from the plant and efforts are underway to devise a reuse system for the cotton-containing packages. The company now uses a conventional 2-cycle procedure for dyeing the different fiber components. The approach will be two-fold. The first will attempt to use the high-temperature stable Procion reactive dyes so that the dyeing can be accomplished in one cycle with reuse of the bath. The second approach will be to retain the two cycles, but will adapt bath reuse to both cycles.
TABLE VI

Chemical, Water, and Energy Savings in Application of Dyebath Reuse to Package Dyeing

<table>
<thead>
<tr>
<th>Procedure Used</th>
<th>Dye Cost (%)</th>
<th>Auxiliary Cost (%)</th>
<th>Water (%)</th>
<th>Energy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyebath Reuse</td>
<td>2.2</td>
<td>82.0</td>
<td>81.0 250°F</td>
<td>56.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>272°F</td>
</tr>
<tr>
<td>Reduction Bath Reuse</td>
<td></td>
<td>76.2</td>
<td>89.0</td>
<td>74.0</td>
</tr>
<tr>
<td>Dyebath and Reduction Bath Reuse</td>
<td>2.2</td>
<td>77.8</td>
<td>85.0 250°F</td>
<td>63.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>272°F</td>
</tr>
</tbody>
</table>
CARPETS

Polyester Carpet

Details of the system for analysis of spent dyebaths used in dyeing polyester carpet with disperse dyes are essentially complete. Several problems were encountered in the procedure which required modifications in the system used previously for disperse dyes in nylon dyeing. The antifoaming agents and large quantities of carriers used in polyester dyeing gave difficulty in separating the benzene and aqueous layers in the dye extraction step. This gave a cloudiness in the benzene extract that interfered with spectrophotometric analysis. This problem was circumvented by exposing the benzene extract briefly to calcium chloride.

A data base for polyester disperse dyes has been generated in a form compatible with the new computer software (see below). Absorption measurements have been made at wavelengths in the visible spectrum on 7 different standard concentrations (1, 2, 5, and 10 ppm) of each dye. These data were used to generate the constants for the Lambert-Beer equation. The constants have been checked by analysis of several dye solutions of known concentration.

A new computer program has been developed which can analyze for up to six different dyes in mixtures. Previous analyses were limited to 3 or 4 dyes using simultaneous linear equations. The new program performs a least square fit to up to 20 points on the absorption curve of a dye mixture. The system will be compatible with new computer color matching systems now being installed in some textile plants.

Nylon Carpet

A working relationship has been established with a carpet manufacturer to work on acid dyeing of nylon carpet. A large volume of carpet, plant dyeing recipes, and example production standards for large volume colors have been obtained.

The data base for acid dyes used has been generated and test dyeings with the acid system are underway.
PREPARATION OF COTTON - CONTAINING FABRICS

The research objective is the reduction in the energy and chemical requirements in the preparation of cotton and cotton/polyester blend fabrics through modifications of existing procedures. Specifically, effort has been directed to determine the feasibility of combining the scouring and bleaching processes.

The severity of the scouring treatments normally used for cotton and cotton/polyester blend fabrics is without question associated with the problem of removing solid impurities called motes and shives. These impurities require more severe conditions for their removal than those for the removal of impurities associated with the fiber itself, principally cotton wax. Therefore, experiments have been carried out to determine the effectiveness of selected organic compounds in removing motes. These include the following:

- diethylene glycol
- triethanol amine
- tetrachloroethylene
- dimethylformamide
- tetraethylene glycol
- ethylene carbonate
- ethylene glycol
- dimethylacetamide
- decalin
- tetralin
- pine oil soap
- urea

These chemicals exhibit a wide range of properties. The procedure used in screening these chemicals was to "spot" the motes in the desized 50/50 cotton/polyester tanker fabric with the chemical followed by a steaming for one (1) hour. After steaming, the fabrics were examined usually to determine the effect of the chemical on the removal of motes. Another type of screening was carried out in which the desized fabric was treated for one (1) hour at 100° C. in aqueous baths containing sodium hydroxide.
sodium hydroxide 2.0% (w/w)
"mote removal chemical" 1.0% (w/w)

This was followed by a thorough rinse at 80°C.

None of these treatments were effective in altering the appearance of the motes in the fabric, even though there was some small degree of bleaching when sodium hydroxide was used, as would be expected.

The literature reveals that the problem of combining the processes of scouring and hydrogen peroxide bleaching is the high concentration of sodium hydroxide needed for scouring which, in turn, renders the cotton more easily oxidized (degraded). A combined scouring and bleaching process must be one in which the sodium hydroxide concentration is lower than that used in conventional scouring.

The following experiments representing combined processes were carried out:

Two levels of concentration for the following ingredients were used:

Sodium hydroxide 2.0 and 4.0 g/l
Sodium silicate 5.0 and 10.0 b/l
Prestogen PC Liquid 5.0 and 10.0 g/l
H₂O₂ (30-35%) 10.0 and 25.0 ml/l

All of the baths contained:

2.0 g/l Kieralon C
10.0 g/l Lufilrol KB Liquid

Thus, these were 2⁴ or 16 different scouring/bleaching processes. The fabrics were padded with the solutions (100% wet pickup) and then steamed in sealed glass tubes for one (1) hour. This treatment was followed by thorough rinsing at about 80°C. Inspection of the fabrics revealed that the most severe conditions, i.e. high alkali and high peroxide concentration, were required to obtain a reasonably good white with no apparent motes. None of the fabrics were as white as the standard, i.e., a fabric scoured and bleached in two separate steps.

The next phase of this work will be to establish the optimum concentrations of chemicals in the one-step scouring-bleaching process to produce a mote-free, bleached fabric which has satisfactory properties comparable to the material prepared by the conventional techniques.
THERMOMECHANICAL DRYING OF TEXTILES

During the past three months an effort has been made to determine the drying potential of a system of steam cans in a subatmospheric pressure environment. The cans were not charged with steam but instead were charged with hot water, a by-product of many textile finishing operations.

The experimental effort was conducted by electrically heating a cylindrical surface (similar to a steam can) followed by application of a fabric to the surface and then partial evacuation of the environment. The fabrics were predried with a mechanical wringer prior to thermal drying.

The experiments were conducted at three different temperatures: 140°F, 160°F and 180°F. The atmospheric pressure ranged from about 1/4 to 1 atmosphere. The results of these experiments are presented in Figures 1, 2, and 3.

Further work on the use of low temperature conductive cans for predrying (discussed in the last report) has been focused on building a housing around the cans and providing make up air ventilation of equal magnitude to that found in textile mills. When this is completed, processing parameters which affect sub-212°F drying can be investigated.

Lastly, the machnozzle described in earlier reports has arrived. The steam generator which will supply steam for machnozzle research has been shipped. Installation of the electrical service for the steam generator is expected to begin within a few days.

GEORGIA TECH CONTRIBUTION TO PROJECT

Two masters students have conducted research on the ERDA project, but were funded from school sources. Ms. Rachel Moore has completed her thesis work entitled "Dyebath Reuse in Pressure Package Dyeing of Textile Yarns" with a Georgia Tech stipend of $4,000. Mr. Tim Wallace has completed his research work on "Dyebath Reuse in Beck Dyeing of Cotton and Cotton/Polyester Knit Fabrics" with a school stipend of $5,000. Thus to date a total of $9,000 in student assistance has been supplied by Georgia Tech toward the project research.
Figure 1. Moisture Reduction of Fabric Passed Over Cans Containing 140°F Water
Figure 2. Moisture Reduction of Fabric Passed Over Cans Containing 160°F Water
Figure 3. Moisture Reduction of Fabric Passed Over Cans Containing 180 F Water
QUARTERLY PROGRESS REPORT

December 1, 1977 through February 28, 1978

Energy Conservation in the
Textile Industry

Contract No. EY-76-S- 05-5099
(Formerly E(40-1)-5099)
Research Project A-1853 & E-27-642

Prepared For
The Department of Energy
Buildings and Industry Conservation
Washington, D.C.

By

The Engineering Experiment Station
The School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

April 1978
INTRODUCTION

Research Projects A-1853 and E-27-642 are being conducted for the Department of Energy pursuant to contract EY-76-S-05-5099 by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. The purpose of these research projects are to identify and demonstrate process modifications which will reduce energy requirements in textile manufacturing wet processes without decreasing process efficiencies. This will include development of energy use profiles for textile processes, identification of energy intensive processes, development and demonstration of modifications to these processes to reduce energy requirements, and dissemination of the research results throughout the industry.

Phase I of the project had the specific objectives of:
1. Identifying major energy intensive processes which might be subject to energy conserving modifications and determining the energy conservation potential for these process modifications and
2. Defining the potential for energy conservation in manufacturing wet processes used in the textile industry.

Phase II of the project has the specific objectives of:
1. Developing and demonstrating, on a pilot or full-scale basis, energy conserving modifications for selected processes identified in Phase I,
2. Examining cost-benefit relationships of proposed process modifications, and
3. Disseminating the results of the research to industry.

Phase I of the project has been completed, and the Phase I report has been reviewed, modified, and transmitted to the DOE program manager. Phase II of this effort was initiated early in 1977, and this quarterly activity report describes these activities for the time period from December 1, 1977 through February 28, 1978.
CASE STUDIES

ENERGY BALANCE ON A CONTINUOUS DYEING KUSTER RANGE

A major carpet manufacturer has given Georgia Tech permission to make an energy balance on the manufacturer's continuous dyeing Kuster Range. A schematic diagram of energy inputs and outputs of the Kuster Range is shown in Figure 1.

The objectives of this work are to determine the energy consumption per pound of product dyed on this continuous machine, to compare the energy requirements per pound of product for the continuous Kuster Range with those of batch atmospheric dye becks, and to identify the energy conservation potentials of each step of the continuous dyeing process.

Orifice plates to be used to monitor steam flows to the Kuster Range are currently being sized. They are to be purchased and installed in the near future. As soon as the orifice plates are installed and operational, monitoring energy flows on the continuous dyeing machine will begin.

INCREASED ENERGY RECOVERY FROM WASTE WATER

A study of a heat recovery system used in a Georgia carpet mill is being made. The heat recovery system utilizes waste water from both continuous and batch processes to heat make-up water for the plant boiler. The objective of this work is to increase the energy recovered from the waste water.

The heat recovery system is shown schematically in Figure 2. Waste water from the dyeing processes flows into a holding pit and is then pumped through a heat exchanger. After flowing through the exchanger, the waste water flows to the waste water treatment plant. Cold fresh water flows counter-currently through the heat exchanger, where it is heated by the waste water. The heated fresh water is pumped to a tank storing make-up water for the plant boiler. The flow rate of the fresh water through the heat exchanger is determined by the plant boiler make-up water needs.

With the current set-up, both hot and cool waste water flow into the holding pit. The proposed gate, shown in Figure 2, would divert the cooler waste water away from the holding pit directly to the waste water treatment plant. Since mixing the cool waste water with the hot waste water causes some of the availability of the hot water to be lost, there are some conditions where
*Steams used in cleaning rolls between runs

**Figure 1. Schematic of Energy Inputs and Outputs of a Continuous Dyeing Kuster Range**
FIGURE 2. HEAT RECOVERY SYSTEM FOR WASTE WATER FROM DYEING PROCESSES
it is desirable to divert the cool waste water directly to the waste treatment plant. Whether or not the cool waste water should be diverted depends on both the temperatures and quantities of cool and hot waste water. For a given fresh water flow rate through the heat exchanger, the objective is to control the waste water flowing through the heat exchanger in such a manner as to maximize the temperature \((T_c)_{out}\) of the fresh water leaving the heat exchanger.

An expression for \((T_c)_{out}\), which has been derived for a simple counter-flow heat exchanger, reveals that \((T_c)_{out}\) is a function of five parameters. These are: 1) the input temperature of the waste water \((T_{h \,\text{in}})\), 2) the input temperature of the fresh water \((T_{c \,\text{in}})\), 3) the flow rate of the waste water \((Q_h)\), 4) the flow rate of the fresh water \((Q_c)\), and 5) heat exchanger parameters. All of these except \((T_{c \,\text{in}})\) change as the operations in the plant are varied. Currently, efforts are being made to determine the operational ranges of these parameters. Once this is done, the potential energy recovery that can be realized by installing the proposed gate will be calculated. The cost-benefit relationship for the proposed gate will then be examined.
Major effort in dyebath reuse for carpet dyeing has been directed this quarter toward completion of the work on polyester carpet dyeing. The 4-foot beck has been modified by installation of a pump and holding tank to permit 30 pound carpet samples to be dyed in exactly the same sequence planned for plant demonstrations. The following sequence was used:

1. Dye a beige carpet in conventional manner
2. Pump dyebath to holding tank
3. Rinse carpet 1 in beck
4. Remove carpet 1 from beck
5. Clean fiber from rinse water
6. Enter carpet 2 for pre-scour
7. Drop rinse-pre-scour water
8. Pump dyebath to beck
9. Dye carpet 2 beige
10. Repeat steps 2-9 for carpets 2 through 7

The color sequence run was beige, beige, beige, blue, blue, rust, rust.

Initial inspection of the dyed carpets suggested that good color reproducibility and uniformity has been achieved. Only one problem was uncorrected during the dyeings; the second blue carpet sample (#5) parted at the seam and fell from the winch into the beck. However, there did not seem to be any extreme adverse effects due to this problem.

The samples were cut from each of the dyed samples and the color measured on the Diano Automate Colorimeter. Each sample was measured three times to average out variation due to instrument changes and sample texture differences. Tristimulus values (x,y,z) were calculated from the average of the 3 measurements.

The base color of each dyed sample was determined by averaging the 10 values obtained from the 10 different samples cut from each carpet. Color uniformity was evaluated by calculation of the color difference of each of the 10 samples from the average value for the carpet. These results
for the 7 dyed carpets are shown in Table 1. The color difference values were calculated using the FMC color difference equation. Although probably not significant, the sample dyed in a fresh bath using the conventional dyeing procedure (Beige #1) shows the greatest variability in the series.

Color difference between the beaker dyed samples and standards prepared previously in beaker dyeings by conventional dyeing procedures have also been determined. In these calculations the average color for each carpet was determined from 10 measurements, and the difference of the average from the average of 10 measurements on the standard was determined. These calculations give a measure of the reproducibility of the dyeings in the recycled baths and are shown in Table 2. In addition to the usual FMC II color differences, the color differences in the new C.I.E. 1976 recommended color space are shown for comparison. With the exception of the two blue samples the reproducibility was excellent. Reproducibility in the blue samples was at the outer limit of what can be considered acceptable commercial carpet dyeing. A comparison of the two blue samples with each other showed that they were very close together in color (DE=1.44), but different from the standard. In both blue carpets the yellow was higher than the standard, and the samples were lighter than the standard. Addition of a small quantity of blue dye would have corrected this color difference between the samples and the standard. Since we had elected to do "no add" dyeing in this series, this dye add was not made. A slight modification of the dye formula would have corrected the small difference between the blue samples and the standard.

Measurements of the fastness properties of the dyeings to light, cracking, and water are now underway. These results and work on dyeing of nylon carpet with acid dyes will be reported next quarter.
### TABLE 1

Color Uniformity in Polyester Carpet Dyeings with Dyebath Reuse

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Beige #1</th>
<th>Beige #2</th>
<th>Beige #3</th>
<th>Blue #1</th>
<th>Blue #2</th>
<th>Rust #1</th>
<th>Rust #2</th>
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<tbody>
<tr>
<td>1</td>
<td>1.14</td>
<td>1.93</td>
<td>1.97</td>
<td>1.15</td>
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<td>2</td>
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<td>2.58</td>
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<td>1.00</td>
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<td>0.89</td>
<td>0.76</td>
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<td>5</td>
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<td>0.96</td>
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<tr>
<td>6</td>
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<td>2.82</td>
<td>2.92</td>
<td>1.44</td>
</tr>
</tbody>
</table>

### TABLE 2

Color Reproducibility in Polyester Carpet Dyeings With Dyebath Reuse

<table>
<thead>
<tr>
<th>Sample</th>
<th>FMC II</th>
<th>CIE 1 a b</th>
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<tbody>
<tr>
<td></td>
<td>Δ e</td>
<td>Δ E</td>
</tr>
<tr>
<td>Beige #1</td>
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<td>1.22</td>
</tr>
<tr>
<td>Beige #2</td>
<td>0.76</td>
<td>0.43</td>
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<td>Beige #3</td>
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<td>0.09</td>
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<tr>
<td>Blue #1</td>
<td>4.85</td>
<td>3.64</td>
</tr>
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<td>Blue #2</td>
<td>3.74</td>
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<td>Rust #1</td>
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<td>Rust #2</td>
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</table>
**HOSIERY**

**Pantyhose** - Following the successful 13 cycle pilot scale reuse sequence on pantyhose detailed in the previous report, Adams-Millis Corporation agreed to a submission of a joint proposal to DOE for an in-plant demonstration. The proposal was submitted to DOE (Mr. John Rossmeissl, Program Director) on January 31, and is currently being routed through the proper channels for assessment. The Georgia Tech researchers are working with Adams-Millis in selecting specific equipment, assembling ordering information, and setting up apparatus in preparation for the demonstration.

**Men's Nylon Socks** - The two high volume shades in men's nylon socks, navy and black, utilize a blended black acid dye (Altcotast Black ACB) that contains orange and blue components. Since these components exhaust at different rates, they must be analyzed for and readded as two individual dyes. The dye manufacturers, Crompton and Knowles, were contacted to determine the nature of the two components. To date, no progress has been made with the dye manufacturer in obtaining the necessary information, and work has been halted on the men's nylon socks until the matter is resolved. If an agreement cannot be reached with Crompton & Knowles, a recommendation will be made to Adams-Millis to negotiate with dye manufacturers to match the black and navy shades with a commercially-available dye of known composition.

**Men's Acrylic Socks** - A procedure has been developed for dyeing the nylon, spandex, and acrylic portions of the men's acrylic socks. The brown and navy shades will be the systems investigated. The acid dyes and auxiliaries will be applied initially to the bath, the temperature raised to 170°F, and the nylon and spandex components (15% by weight) will be colored. The basic dyes and auxiliaries for coloration of the acrylic portion of the sock (85% by weight) will be added at 170°F to the same bath, the temperature raised to the boil, and the temperature held for dyeing. A cooling cycle will then be necessary in order to bring the acrylic portion of the socks below the glass transition temperature and thus avoid "cracking" problems. The plant currently cools all the way to 120°F before drop; however, from an energy viewpoint, such a drop is excessive. The Georgia Tech research will thus be directed initially toward defining a maximum drop temperature that will provide the greatest energy savings without affecting the quality of the dyed product.
Analysis of the bath, which will contain a mixture of up to six acid and basic dyes, will be conducted using the 16 point computer program described in previous reports. Beaker scale experiments have shown that neutralization with a weak base such as ammonium hydroxide produces excessive buffer in solution. This necessitates using exponentially increasing amounts of acid in subsequent batches to regenerate the correct pH. To avoid this problem, a bath pH of 3.8 will be held. It is projected that by slow addition of the acid dyes on bath regeneration at approximately 150°F, the Class 2 acid dyes will not produce a hard strike (with subsequent unlevelness) on the nylon portion of the socks. The Adams-Millis dyer has concurred with this projection on the dark shades.

Beaker scale experiments are now underway on the men's acrylic socks. Scale up to the rotary drum hosiery machine and completion of acrylic sock research are expected by the May 31 contract termination date.

YARN PACKAGES

Agreement has been reached with the participating package dyeing plant to ship 100 lbs. of cotton/polyester yarn and 100 lbs. of 100% cotton yarn to Georgia Tech. These materials, which constitute approximately 70% and 29%, respectively, of the plant's production, will be used to investigate transfer of reactive dyebath reuse technology from knit fabrics to packages.

High volume procedures for both types of yarn have been obtained from the company. The cotton/polyester procedure is a two-cycle procedure that includes a single disperse dye in the polyester dyeing cycle followed by a caustic/hydrosulfite reduction clearing and cotton coloration in a separate cycle with two low-temperature active dyes. The initial work on the polyester yarn will retain the two separate cycles, but will reuse all of the baths involved (disperse dyebath, reduction/clearing bath, reactive impregnation dyebath, and the caustic fixation bath for the reactive dye). This process will simulate closely the process at the plant, but with reuse included.

In addition, a combined process in which a base-stable disperse dye and a high-temperature stable reactive dye will be applied from the same impregnation bath in a single cycle will be run. Both the dyebath and the fixation bath will be recycled. A sample of the shade standard to be utilized in the shades has been sent to ICI, and a shade match with the proper disperse/reactive dye for the one-cycle system is being formulated.
The dyes for the 100% cotton yarn will be the same two reactive dyes as for the polyester/cotton 2-cycle procedure, but will include one additional reactive dye. The 100% cotton yarn experiments will be conducted prior to the polyester/cotton research to insure that the most difficult of the dye classes, reactive dyes, can be applied uniformly to packages with dyebath reuse. Both through package and lot-to-lot color differences will be examined.

In conjunction with continuing experiments on dyebath reuse of reactive dyes applied to cotton-containing knit underwear fabric (detailed later in this report), a system must be developed to pinpoint the added concentration of dye needed to reach the proper depth of shade. Traditional reactive dye systems in which base is added directly to the dyebath to effect fixations have a "step-up" in exhaustion on base additions (Figure 3). Using the split-bath system (detailed in earlier reports) to avoid hydrolysis and generation of colored impurities detrimental to spectrophotometric analysis, a single phase curve such as that shown by the upper line must be followed to get the same overall exhaustion from the impregnation bath. The ability to "hit" the highest point on the curve accurately determines the shade difference with a standard; this ability has not yet been developed. Good lot-to-lot color differences have been obtained with the reactive reuse on fabrics, but color differences with conventional dyed standards due to inaccurate estimates on the curves are excessive (see section on fabrics).

The research on the packages will be limited to a single package machine. This work will begin in late March and will continue up to the May 31, 1978, termination date at Georgia Tech. Follow-up research to complete the single-package research and to conduct runs at the plant's pilot laboratory, in which a 12-package machine will be available, will be proposed to DOE in the near future.
FIGURE 3
REACTIVE EXHAUST DYEING
IDEAL SITUATION

<table>
<thead>
<tr>
<th>Time</th>
<th>0.5 hr</th>
<th>1 hr</th>
<th>1.5 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaustion and Leveling with Salt</td>
<td> </td>
<td> </td>
<td> </td>
</tr>
<tr>
<td>Fixation with Alkali</td>
<td> </td>
<td> </td>
<td> </td>
</tr>
<tr>
<td>Leveling Ceases</td>
<td> </td>
<td> </td>
<td> </td>
</tr>
</tbody>
</table>

Desired for Reuse Reactive Dye System

Curve for Conventional Reactive Dye System
Cotton Containing Knit Fabrics - Tables 3-5 contain data detailing the final color difference calculations of the 100% cotton and 50/50 polyester/cotton knit underwear fabrics whose dyeings were reported in the previous quarterly report. Good lot-to-lot shade correlation was shown for the samples, both against the average of the reflectance values and the first dyeing as a standard. However, due to the as-yet unsolved problem of achieving the correct exhaust in the impregnation bath (see previous section), color differences between reuse-dyed samples and company standards (Table 4, Column 4) and conventionally dyed standards (Table 5, Column 4) were extreme.

In conjunction with reactive dye reuse transfer to packages described in the previous section, a method will be developed to predict the amount of excess dye needed in the impregnation bath to reach the desired level of exhaustion. A series of dyeings will be conducted at different concentrations of the reactive dyes, and the color of the fabric will be measured on the Diano color eye instrument. A computer program will then be devised that will allow accurate predictions of the excess dye required in the impregnation bath to reach the proper exhaust level. This program will use reflectance values from a standard and the data base generated in the sample dyeings.

Scale-up research to one foot and four foot beck stages on the knit underwear fabric will not be possible before May 31, due to manpower limitations in relation to the overall program. A proposal to complete the pilot scale-up of reactive dye reuse in coloration of knit underwear fabric in preparation for an in-plant demonstration will be submitted to DOE in the near future.

Nylon Upholstery Fabrics - Development of the 16-point program for complex dyebath analysis, followed by manpower limitations, has delayed research on upholstery reuse on beck-dyed nylon upholstery fabrics. A student has been hired for the next quarter to devote full effort to the initial studies on the nylon upholstery fabric with acid dyes.

Perusal of the fabric procedures revealed complicated dye mixtures (5-6 dyes per shade) with few common dyes in shades. As a result, switching from shade-to-shade will not be possible due to the lack of dye correlation.
### TABLE 3

**DYEBATH REUSE COLOR DIFFERENCE CALCULATIONS**

100% COTTON/ONE MX REACTIVE DYE

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<th>Sample</th>
<th>Color Difference (MacAdam Units)</th>
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### TABLE 4

**DYEBATH REUSE COLOR DIFFERENCE CALCULATIONS**

100% COTTON/THREE MX REACTIVE DYES

<table>
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<th>Sample</th>
<th>Color Difference vs. Average</th>
<th>Color Difference vs. #1</th>
<th>Color Difference vs. Co. Standard</th>
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<td>1.3</td>
<td>3.1</td>
<td>15.4</td>
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### TABLE 5

**DYEBAITH REUSE COLOR DIFFERENCE CALCULATIONS**

**ONE HE REACTIVE DYE/ONE DISPERSOL DISPERSE DYE**

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<th>Sample</th>
<th>Color Difference vs. Average</th>
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and the 10-20% of dye left in solution in the atmospheric system. Standards supplied to the company will thus be used to isolate three high volume shades, and the reuse research will be directed toward single-shade runs.

An additional problem with the fabric is caused by the adhesive used to bind the velvet nylon face to the backing. A stain is leached out of the adhesive into the dyebath. The colored stain will have to be treated as a dye, similar to the stain observed earlier in dyebath reuse experiments on jute-backed carpet, thus complicating the spectrophotometric analysis.
PREPARATION OF COTTON AND COTTON/POLYESTER BLEND FABRICS

Previously reported attempts to discover means for reducing the energy requirements in the preparation of cotton/polyester woven fabrics by a combined scouring and bleaching process point to the need for discovering a way in which the caustic (NaOH) requirements can be reduced. Current practice in the continuous scouring of cotton and cotton/polyester blend fabrics is to use an approximately (4) per cent solution of sodium hydroxide in order to achieve good mote removal. This high concentration is detrimental to cotton in a combined scouring-bleaching process. One approach is to mercerize the fabric and to follow with a combined scour-bleach treatment in which the caustic concentration is reduced. Fabrics treated in this manner were not acceptable, particularly from the standpoint of mote removal.

Other approaches to reducing the caustic requirements in combined scour-bleach process have been investigated. These include:

1. Use of thiocyanates of calcium and sodium
2. Use of Ca(OH)₂
3. Replacements of caustic with trisodium phosphate

In these studies, it was found that a cold acid (H₂SO₄) following the scour-bleach process gave an appreciable improvement in whiteness of the fabric. The use of thiocyanates was investigated because concentrated solutions of thiocyanates are known to be solvents for cellulose. To date the most promising combined scour-bleach process is as follows:

Pad onto fabric (100% wet pick-up) a solution consisting of

\[
\begin{align*}
\text{NaOH} & \quad 10 \text{ g/l} \\
\text{Na}_3\text{PO}_4 & \quad 10 \text{ g/l} \\
\text{Prestogen} & \quad 5 \text{ g/l} \\
\text{H}_2\text{O}_2 (35\% \text{ by weight}) & \quad 15 \text{ ml/l}
\end{align*}
\]

Steam for one (1) hour.
Rinse thoroughly.

A cotton/polyester fabric treated in this manner has an acceptable whiteness and is mote free.
In the past quarterly report, it was indicated that an effort had been made to determine the drying potential of a system of heat conducting cylinders charged with waste low quality hot water in a subatmospheric environment. These data have been carefully evaluated, and some conclusions can now be offered.

Industrial textile finishers indicate that fabrics usually have a residence time of about one minute on existing steam can set-ups. Accordingly it is not relevant to look at drying times which would require more than one minute residence time, since any modifications might require significant capital input. When one looks back at the data from the last report, one realizes that subatmospheric drying is not really useful unless one can implement at least a two minute residence time.

However, a summary of the data indicates that when a 50/50 polyester cotton sheeting fabric is subjected to heating cans charged with 180°F water for one minute, a moisture reduction from 52% to 39% is obtained. The significance of this result is that 180°F water can be obtained through waste water recovery. Moreover, this hot water can be obtained from the Machnozzle described in earlier reports subsequent to steam condensation.

During this quarter the heating cans have been housed and instrumented to determine the processing parameters which affect subatmospheric drying. These parameters are can water temperature, makeup air flow rate, incoming air temperature, housing humidity, and fabric residence time.
MACHNOZZLE SYSTEM

Construction has begun on a system for testing the effectiveness of the Machnozzle in fabric drying. A fabric transport system will be provided by modification of a piece of equipment utilized in previous research. A schematic of the transport system and machnozzle is presented in Figure 4. This transport system will be capable of drawing the wetted fabric under tension through the Machnozzle test apparatus. Variable fabric speeds of up to 100 yards per minute are planned.

The initial configuration will be for a single-pass batch process which will simulate a fabric history similar to that obtained in industry. Later the equipment will be altered to provide for continuous-loop processing of the fabric. This method will allow for longer runs in which both steady-state and controlled transient effects may be studied without the use of very large quantities of fabric.

The steam generator equipment has been received, and installation plans and specifications are being prepared. When these are finalized, bids for the work will be solicited. Work is underway on installation of the electrical supply lines for the generator.
FIGURE 4. MACHNOZZLE ASSEMBLY
EXECUTIVE SUMMARY

ENERGY CONSERVATION IN THE TEXTILE INDUSTRY

By
F. L. Cook, W. W. Carr, W. C. Tincher,
D. S. Brookstein, W. C. Carter, and J. L. Clark

Submitted by
School of Textile Engineering
and
Engineering Experiment Station
Georgia Institute of Technology

Prepared for
DEPARTMENT OF ENERGY
OFFICE OF CONSERVATION AND SOLAR APPLICATIONS
DIVISION OF INDUSTRIAL ENERGY CONSERVATION

UNDER Contract No. EY—76—S—05—5099
(Formerly E(40—1)—5099)


OCTOBER 1978

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332
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Investigators:
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EXECUTIVE SUMMARY

PHASE I

Phase I of the project had the following objectives:

1. To profile the energy consumption of major energy-intensive wet processes in the textile manufacturing industry.

2. To identify major energy intensive wet processes where energy conservation potential would be most productive.

The first step to meeting the objectives was to determine the volume of textiles wet processed by various techniques. Little information was found in the literature, and therefore a Process Production Matrix was compiled based on available data and the combined experience of the investigators (Table 1).

The energy consumption per weight of finished goods by wet process was also compiled. Again, little information was available concerning BTU/lb-process, either from the literature or from the plants themselves. Few companies had installed the necessary devices to monitor the energy consumption of individual processes, and low energy consumption had not previously been an engineering design criterion for equipment manufacturers. Using available data and measurements/calculations conducted by the investigators, a process consumption profile was derived (Table 2).

Combining the consumption data of Table 2 and the production data of Table 1, an estimate was made of the industry-wide energy conservation potential of wet processes (also shown in Table 2). The conservation potential included both engineering and process modifications, and included an application factor since some companies would not be able to implement the projected modifications due to economic and/or technical limitations.

PHASE II

Based on the data compiled in Phase I, several energy-intensive areas were identified for pilot-scale research in Phase II:

1. Investigation of engineering modifications of batch dyeing equipment.

2. Evaluation of dyebath reuse as an alternative dyeing process.

3. Optimization through process steamlining of batch dyeing operations.
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</tr>
<tr>
<td></td>
<td></td>
<td>KNITS</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CARPET RUGS</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NARROWWEVEN</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
</tr>
</tbody>
</table>

* F: FILAMENT
* ST: STABLING AND TOW
### TABLE 2 - PROCESS CONSUMPTION AND CONSERVATION POTENTIAL

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Consumption:</th>
<th>Per Cent</th>
<th>Estimated Savings</th>
<th>Conservation Potential</th>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal BTU/lb.</td>
<td>Electrical BTU/lb.</td>
<td>Fiber lbs x 10^6</td>
<td>of Total Consumption</td>
<td>Application, BOE</td>
</tr>
<tr>
<td>Batch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Beck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpet</td>
<td>13,300</td>
<td>330</td>
<td>605</td>
<td>1,400,000</td>
<td>3</td>
</tr>
<tr>
<td>Fabric</td>
<td>23,500</td>
<td>600</td>
<td>1,005</td>
<td>4,220,000</td>
<td>10</td>
</tr>
<tr>
<td>Hosiery</td>
<td>23,500</td>
<td>600</td>
<td>465</td>
<td>1,907,000</td>
<td>5</td>
</tr>
<tr>
<td>Jig</td>
<td>2,700</td>
<td>670</td>
<td>448</td>
<td>257,000</td>
<td>1</td>
</tr>
<tr>
<td>Pressure Beck</td>
<td>6,400</td>
<td>660</td>
<td>534</td>
<td>641,000</td>
<td>2</td>
</tr>
<tr>
<td>Jet</td>
<td>9,200</td>
<td>880</td>
<td>431</td>
<td>738,000</td>
<td>2</td>
</tr>
<tr>
<td>Package/beam</td>
<td>17,300</td>
<td>1,980</td>
<td>1,018</td>
<td>3,340,000</td>
<td>8</td>
</tr>
<tr>
<td>Stock</td>
<td>12,000</td>
<td>1,426</td>
<td>375</td>
<td>857,000</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slashing</td>
<td>2,900</td>
<td>-</td>
<td>3,905</td>
<td>1,900,000</td>
<td>6</td>
</tr>
<tr>
<td>Single</td>
<td>200</td>
<td>-</td>
<td>3,717</td>
<td>126,000</td>
<td>1</td>
</tr>
<tr>
<td>Preparation Range</td>
<td>2,100</td>
<td>150</td>
<td>3,863</td>
<td>1,478,000</td>
<td>5</td>
</tr>
<tr>
<td>Mercerize</td>
<td>5,100</td>
<td>250</td>
<td>1,728</td>
<td>1,572,000</td>
<td>5</td>
</tr>
<tr>
<td>Fabric Dye Range</td>
<td>4,400</td>
<td>150</td>
<td>2,493</td>
<td>1,929,000</td>
<td>6</td>
</tr>
<tr>
<td>Finishing Range</td>
<td>7,800</td>
<td>660</td>
<td>3,207</td>
<td>4,612,000</td>
<td>12</td>
</tr>
<tr>
<td>Carpet Dye Range</td>
<td>12,300</td>
<td>1,300</td>
<td>351</td>
<td>826,000</td>
<td>2</td>
</tr>
<tr>
<td>Printer</td>
<td>9,300</td>
<td>230</td>
<td>1,018</td>
<td>1,656,000</td>
<td>5</td>
</tr>
<tr>
<td>Predryer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infra-red</td>
<td>900</td>
<td>-</td>
<td>7,528</td>
<td>1,152,000</td>
<td>3</td>
</tr>
<tr>
<td>Mechanical</td>
<td>-</td>
<td>200</td>
<td>4,895</td>
<td>166,000</td>
<td>-</td>
</tr>
<tr>
<td>Steam Cans</td>
<td>1,600</td>
<td>-</td>
<td>4,124</td>
<td>1,122,000</td>
<td>3</td>
</tr>
<tr>
<td>Dryers</td>
<td>2,100</td>
<td>200</td>
<td>16,471</td>
<td>6,331,000</td>
<td>19</td>
</tr>
<tr>
<td>Sub Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous Idle time (.2 x 22,870,000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conservation Potential - 12,545,000/40,804,000 = 31%

5. Development of predryer and dryer modifications, including thermomechanical drying, hot water can drying and utilization of supersonic steam flows for water removal.

6. Derivation of an energy balance for a Kuster continuous carpet dyeing unit.

7. Derivation of cost/benefit analyses for the research modifications. Engineering modifications for a typical atmospheric dyeing machine, a carpet dye beck, were effected in a step-wise fashion and the energy reduction resulting from the modifications were quantified. The modifications concentrated on improving sparge control, insuring efficiency and reducing evaporation losses. Reduction in the control demand from 218°F (condition termed a "rolling boil") to 210°F (simmering condition) lowered the steam requirement by 1150 lb/hr during the hold period. Sparge covers were utilized to improve sparging efficiency. The cover reduced steam consumption during the boil hold period by 1800 lb/hr.

Exhaust was controlled by using a beck door and cutting off the stack exhaust fan. Steam consumption was reduced during heat-up by an additional 400 pounds compared to the sparge cover technique. Overall, the combined engineering modifications were calculated to reduce energy consumption of the carpet beck by 28%.

One glaring inefficiency observed during the beck studies was found in water-to-water heat exchanger practices. Many plants have installed pit-type heat exchangers into which all sources of waste water, flowing at different temperatures and mass flow rates, are commonly funneled. Intuitively, low-temperature flows (such as a cold overflow rinse) were suspected of reducing the heat recovery obtainable from the higher temperature streams.

A simple counterflow heat exchanger was analyzed to obtain equations describing the heat recovery from available waste water. Equations were derived to relate the rate of heat recovery to important system parameters, and a procedure for using the equation to optimize heat recovery was developed. A case study of a Georgia carpet mill was conducted to illustrate the usefulness of the equations in optimizing heat recovery from waste water streams flowing at different temperatures and mass flow rates. In the Georgia carpet mill, two waste streams commonly entered the pit-type heat exchanger: one at 170°F corresponding to dyebaths, and the other at 80°F composed of rinse water. The calculations revealed that the maximum heat recovery occured when all of the high temperature
stream was used, but none of the low-temperature stream was allowed to enter the heat exchanger.

The fresh water input temperature, which varies in most climates depending on the season, was also shown to be important. The increases in heat recovery obtainable by stream segregation were 39, 46, and 59% for fresh water input temperatures of 40, 50, and 65°F, respectively.

Two alternate procedures were recommended for segregating the waste stream flows: 1) separate drainage channels, and 2) a temperature-controlled swinging gate. Due to the beck arrangement in the participating plant, the latter option was preferred. In this system a gate operated by a temperature sensing device is mounted in the drainage ditch in such a manner that it can direct the waste water to either the exchanger or the sewer, dependent on the stream temperature. Estimated cost for implementing the modification was $15,000, with an estimated savings calculated as $107,082 per year.

In evaluating the atmospheric dyeing process, the energy was lost "out the stack (49%) and down the drain (49%)". For pressure dyeing systems, the major loss was to the drain (79%). Examination of the hot residual dyebaths revealed that most of the dye had exhausted, and the majority of auxiliary chemicals were present in unaltered condition. Rather than drop the hot bath to the drain, a system was developed to analyze the remaining dye, reconstitute the hot dyebath, and reuse it for subsequent dyeings. Analysis of the colorless auxiliary chemicals was not necessary after each batch, as the majority of these chemicals were present in large excess and were unexhausted. The technology, termed dyebath reuse, incorporated a simple but accurate dye analytical system that was compatible with existing dyehouse personnel, space, time and equipment constraints. Engineering modifications required a pumping system and a holding tank for routing the hot bath from the dye machine.

Dyebath reuse was demonstrated on a pilot scale to be applicable to a wide variety of batch dyeing operations, including both atmospheric and pressure systems. In some cases, auxiliary cleaning and/or fixation baths were reused in addition to the dyebath. Table 3 details the processes determined ready for in-plant demonstrations while Table 4 details additional processes which appeared
Table 3

Processes Determined Ready for In-Plant Demonstration of Dyebath Reuse

<table>
<thead>
<tr>
<th>Textile Material</th>
<th>Fiber Type</th>
<th>Dye Class</th>
<th>Mode</th>
<th>Baths Reused</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladies' Pantyhose</td>
<td>Nylon 6</td>
<td>Disperse</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Nylon 66</td>
<td>Disperse</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Carpet</td>
<td>Nylon 6</td>
<td>Acid</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Nylon 6</td>
<td>Disperse</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Carpet</td>
<td>Polyester</td>
<td>Disperse</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 4.
Processes Requiring Additional Research Before In-Plant Reuse Implementation

<table>
<thead>
<tr>
<th>TEXTILE MATERIAL</th>
<th>FIBER TYPE</th>
<th>DYE CLASS</th>
<th>PROGRESS SCALE</th>
<th>MODE</th>
<th>BATHS REUSED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men's Socks</td>
<td>Acrylic/Nylon</td>
<td>Basic/Acid</td>
<td>X (^1)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Auto Upholstery</td>
<td>Nylon/Cotton</td>
<td>Acid/Direct</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Knit Underwear</td>
<td>Cotton</td>
<td>Reactive</td>
<td>X (^2)</td>
<td></td>
<td>X X</td>
</tr>
<tr>
<td></td>
<td>Cotton/Polyester</td>
<td>Reactive/Disperse</td>
<td>X (^2)</td>
<td></td>
<td>X X</td>
</tr>
<tr>
<td>Package Yarn</td>
<td>Cotton</td>
<td>Reactive</td>
<td>X (^3)</td>
<td></td>
<td>X X</td>
</tr>
<tr>
<td></td>
<td>Cotton/Polyester</td>
<td>Reactive/Disperse</td>
<td>X (^3)</td>
<td></td>
<td>X X</td>
</tr>
<tr>
<td></td>
<td>Polyester (staple,</td>
<td>Disperse</td>
<td>X (^3)</td>
<td></td>
<td>X X</td>
</tr>
</tbody>
</table>

\(^1\) Eight-pound rotary drum machine.

\(^2\) One-foot atmospheric beck.

\(^3\) One-package pressure machine.
promising on a bench-scale, but which were not developed fully in Phase II due to project and manpower limitations. The goods colored by reuse techniques were comparable in color uniformity, color repeatability, and fastness properties to materials dyed by the conventional processes. Direct savings in energy, water/sewer, and chemical requirements were substantial in each case. Projected return on capital investment from implementation of dyebath reuse in the participating plants varied according to the particular process. In all cases, however, the projected recovery of raw capital investment (excluding tax benefits) was less than the usual two-year period required by the majority of plants.

In discussing dyebath reuse with plant personnel, two questions were common: 1) How many batches of material can be dyed before buildup of chemical impurities (spin finishes and oligomer from the fiber, dye fillers, etc.) interferes with the dyeing behavior, and 2) Is it necessary to dye long sequences (20 cycles per bath) in order to realize the bulk of the economic savings? To answer the first question, a theoretical analysis was conducted assuming that the goods retain 25% of the dyebath volume each cycle, necessitating a 25% add-back of fresh water on the subsequent cycle. The results are summarized in Figure 1, where:

- \( C \) = impurity concentration for any given run
- \( C_1 \) = impurity concentration in the first run
- \( N \) = number of dye cycles
- \( X \) = fraction of impurity added to the spent bath each run
- \( Y \) = fraction of total dyebath volume retained

Figure 1 reveals that the concentration of the impurities approaches a steady-state condition after 7-10 cycles, and therefore is unaffected by continued reuse of the bath. The theoretical analysis thus indicated that if a significant fraction of fresh water is added to the depleted bath each cycle, the number of batches that can be colored by dyebath reuse is not limited by chemical impurity accumulation.

To answer the economic question, a theoretical analysis was conducted to predict the variation of cost savings with the number of cycles in a reuse
FIGURE 1. THE VARIATION OF $C/C_1$ WITH $N$ ($X = 1.0$ AND $Y = 0.25$)
sequence. The results are displayed in Figure 2, where:

\[ \begin{align*}
N & = \text{Number of dye cycles} \\
S & = \text{Savings per pound for any given run} \\
S_{\text{max}} & = \text{Maximum achievable earnings per pound} \\
X & = \text{Cost per pound for a conventional dyeing cycle}
\end{align*} \]

The overall cost per pound drops rapidly during the first few cycles. However, a limiting value is reached after 7-10 cycles that essentially levels the curve for additional cycles. Therefore the savings on runs past Cycle 10 are approximately the difference in cost between the \( n \)th cycle and the initial conventional run, regardless of sequence position of the \( n \)th cycle.

The analysis thus demonstrated that long reuse sequences are not necessary to economically justify dyebath reuse. An appreciable percentage of the maximum achievable savings with dyebath reuse can be achieved with only a short sequence of runs, e.g., 83% savings after only five runs (Figure 2).

During evaluation of the dyeing processes, it was discovered that many of the conventional routes were highly inefficient and wasteful. Most of the processes were developed during the period when energy prices/supply and pollution control were not major production factors. The majority of the processes had been recommended by dye manufacturers and/or fiber producers whose main concern was optimum performance of their products in the dyeing process. As a result, the procedures obtained from the plants were generally "over-engineered". The dyebath reuse research was therefore coupled with an effort to optimize the processes wherever possible by eliminating unnecessary rinses, lowering hold temperatures, speeding up rate-of-rise cycles, etc. Significant improvement was thus made in the conventional processes before dyebath reuse was adapted.

The dyebath reuse research with accompanying process optimization was extremely successful on the pilot scale systems. Convincing the conservative textile industry that the technology is technically and economically feasible, however, may require in-plant demonstrations of the various processes on commercial scale equipment. DOE has subsequently committed funding for in-plant demonstrations of dyebath reuse in two of the areas detailed in Table 3: disperse dyeing of nylon hosiery and acid dyeing of nylon carpet. Results of the demonstrations will be contained in future Phase III reports under the present contract number.
FIGURE 2. VARIATION OF AVERAGE COST PER POUND WITH NUMBER OF DYE CYCLES
Reduction in the energy requirements for continuous preparation of cotton-containing textiles was approached from the viewpoint of shortening the overall process, i.e., the concept of conservation via elimination. As currently practiced by the industry, the fabric is prepared in three distinct steps: desizing, scouring, and bleaching. Each step requires a steaming and a washing of the fabric. The research was therefore directed toward developing a combination of chemicals which would allow complete preparation of the fabric for dyeing in a single pad-steam-wash sequence.

A process was developed which allowed combined scour-bleach processing of a previously desized fabric on a bench scale. The desized fabric was first treated with a 0.5% by weight solution of sulfuric acid at room temperature. After neutralization, the fabric was padded with a solution of sodium hydroxide (1.0%), concentration of 15 ml/l. The fabrics gave acceptable whiteness values and were free of motes and other impurities.

The combined scour-bleach process eliminated one steaming and one hot wash. The combined process was shown to give substantial savings in energy, water/sewer and chemical requirements over the conventional processes, as well as releasing floor space for other production equipment. Due to the high volume of cotton-containing fabrics (3.9 x 10^9 lbs/year) that is continuously prepared, approximately 1% of the energy consumed in textile wet processing was projected as potential savings in combining the scour-bleach process industry wide. Calculating return of capital investment was irrelevant, as the new procedure simply eliminated a portion of the existing process machinery without additions. Savings for a model plant with two open-width preparation ranges was calculated to be $103,000/year. Further pilot-scale research is needed, however, before plant implementation is attempted.

The drying research was first directed toward combined thermomechanical methods. Particular emphasis was placed on the use of vacuum techniques. The investigation showed, however, that subatmospheric pressure drying is only effective at a pressure of 350 mm, and even at this pressure the benefits were marginal.

Since the subatmospheric drying research was not fruitful, utilizing hot water instead of steam in predrying can systems was next investigated as a route to lower energy consumption. The highest moisture reductions occurred at an average water temperature of 169°F and an exhaust rate of 41.8 CFM, with an
average moisture reduction of 23.5% for polyester/cotton fabric. The results thus showed substantial moisture reduction can be obtained by using hot water (usually in generous supply in a finishing plant) in lieu of steam in can dryers.

The final research route to alternate drying procedures involved the utilization of a new device by Brugman, Inc., termed a Machnozzle. A 16-inch model of the device was purchased. The Machnozzle is designed to accelerate high pressure steam to sonic speed by passing it through a narrow slot (0.001 inches, Figure 3). The fabric is passed across the slot exit where the high velocity steam flow creates a large pressure differential across the fabric. The water is then literally blown out of the fabric. The steam passing through the fabric loses little of its thermal energy, and can therefore be mixed with cold water to yield a hot water source for the plant.

The major role of the Georgia Tech research on the Machnozzle was to evaluate and optimize the system while comparing the drying efficiency to the manufacturer's data. A test system was thus built which simulated projected plant conditions of fabric speed and steam pressures. Due to project limitations, no runs were possible on the unit before Phase II termination; however, additional funding has been granted to Georgia Tech to continue both the hot water can drying research as well as the Machnozzle investigation (Part 2, Phase III extension of the reported contract).

Phase I revealed that almost no information existed on the energy consumption of continuous dyeing ranges. The lack of data was mainly due to the large number of energy input points on the ranges, increasing the difficulty in obtaining the overall energy requirements. One of the objectives of Phase II was thus to determine the energy consumption per pound of product dyed on a continuous unit (a Kuster Carpet Dyeing Range), and to obtain an energy balance for each section of the range. Collection of the data was necessary in order to recommend engineering modifications to conserve energy.

Figure 4 shows the energy inputs and outputs of the continuous Kuster range for which energy measurements were made. The seven positions of steam input were monitored, and the electrical input into each major section was measured. To complete the energy balances, various measurements were made to obtain the rates of energy lost from the range, to include stack gas, condensate, overflow temperature and flow rates, and component surface temperatures.
FIGURE 3. MACHNOZZLE CROSS-SECTION
FIGURE 4. SCHEMATIC OF ENERGY INPUTS AND OUTPUTS OF A CONTINUOUS DYEING KUSTER RANGE
The thermal energy distribution to the Kuster Range is shown in Figure 5. The electrical power consumption for the range, which was considerably lower than the thermal consumption, is detailed in Table 5. The section considered most wasteful and the area with the highest potential for energy recovery at low capital investment was the steamer section. The energy balance on the steamers, shown in Figure 6, revealed that 65.4% of the energy input was lost out of the stacks.

Summary

The researched process and engineering modifications have a strict national energy conservation potential of $3.3 \times 10^6$ BOE/year, or 8% of the total wet processing energy based on the pilot scale and plant investigations. Many of the modifications were easily adaptable to other related processes, e.g., engineering and process modifications on an atmospheric dye beck would apply equally well to atmospheric paddle machines, dye jigs, slashers, etc. The actual energy conservation potential is thus considerably higher than the strict estimate. Based on the Georgia Tech research as well as that reported in the literature during the period of performance, the Phase I estimate of the energy conservation potential for the wet processing sector of $12.5 \times 10^6$ BOE (31% of the total consumption, Table 2) is concluded to be accurate when all technically-feasible engineering and process modifications are included. Some of the developed technologies such as dyebath reuse and combination of preparation processes also involve indirect energy savings of undetermined magnitude due to reduced chemical and water/sewer requirements.
**FIGURE 5, THERMAL ENERGY DISTRIBUTION TO KUSTER RANGE COMPONENTS FOR PRODUCTION RUN CONDITIONS**
Table 5
Electrical Power Requirement Of The Kuster Range
For Production Run Contributions

<table>
<thead>
<tr>
<th>Kuster Range Zone</th>
<th>Electrical Power Requirements (kw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dye*</td>
<td>198</td>
</tr>
<tr>
<td>Finisher (Vacuum Extractors)</td>
<td>154</td>
</tr>
<tr>
<td>Dryer</td>
<td>64</td>
</tr>
<tr>
<td>Total</td>
<td>416</td>
</tr>
</tbody>
</table>

*Dye Zone includes all electrical power (drive motors, fans, etc.) to components from the feed through the wash boxes and the entire drive system.
FIGURE 6. THERMAL ENERGY BALANCE ON HORIZONTAL AND VERTICAL STEAMERS