**PROJECT ADMINISTRATION DATA SHEET**

**Project No.** E-25-A04 (R6059-0A1)

**Project Director:** Dr. William Z. Black

**Sponsor:** Georgia Power Company

**Type Agreement:** Letter of Acceptance Task M1 under BOA 95

**Award Period:** From 9/18/85 To 12/31/85

**Sponsor Amount:**
- Estimated: $5,253
- Funded: $5,253

**Cost Sharing Amount:** None

**Title:** Member of Advisory Committee Establishing a Test Facility for Process Heating, Drying and Cutting

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### ADMINISTRATIVE DATA

1) **Sponsor Technical Contact:**
   - Gary L. Birdwell
   - Georgia Power Company
   - 333 Piemont Ave., NE (20th Floor)
   - Atlanta, Georgia 30308
   - 526-7359

2) **Sponsor Admin/Contractual Matters:**
   - Same as 1)

**Defense Priority Rating:** N/A

**Military Security Classification:** N/A

**OR (or) Company/Industrial Proprietary:** See Below

---

### RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

**Travel:** Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

**Equipment:** Title vests with Sponsor

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### COMMENTS:

A Non-Disclosure Agreement has been negotiated.

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**SPONSOR’S I. D. NO.** 02.256.000.86.004

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Project No. E-25-A04

School/Ext: ME

Includes Subproject No.(s) A-4437 and E-27-A01/Carr

Project Director(s) Dr. William Z. Black

GTRC / 384

Sponsor Georgia Power Company

Title Member of Advisory Committee. Establishing a Test Facility for Process Heating, Drying, and Curing

Effective Completion Date: 7/30/87 (Performance) 7/30/87 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [ ] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [x] Final Report of Inventions - Questionnaire to P.I.
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. 

Continued by Project No. 

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Russ Embry

FORM OCA 69.285
FINAL REPORT
Georgia Power Contract

ESTABLISHING A TEST FACILITY FOR PROCESS
HEATING, DRYING AND CURING

May 1987
FINAL REPORT

Georgia Power Contract

Technology Development Center Task Statement
BOA-95 Task A01

ESTABLISHING A TEST FACILITY FOR PROCESS HEATING, DRYING AND CURING

Submitted by

W. Z. Black - ME
W. W. Carr - TE
P. V. Desai - ME
J. G. Hartley - ME
W. A. Hendrix - GTRI

May 1987
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OBJECTIVES

The major objectives of this project were to establish a test facility on the campus of Georgia Tech where problems involving process heating drying and curing can be studied. The facility will be equipped with efficient heating, drying and curing equipment so that potential customers can have access to new and innovative heating and drying equipment. This facility will also allow potential customers to evaluate new equipment and determine if it is economically feasible to utilize innovative heating and drying processes on their own products.

A second objective of this project was to formulate a general mathematical model to study the problem of simultaneous heat and mass transfer in a porous media in the presence of an electromagnetic field. The model will form the framework for a basic study of drying of a porous material matrix and in the process it will identify those material properties and equipment parameters which contribute to an efficient heating and drying process.

TEST FACILITY

To achieve the first objective, space in the Georgia Tech Advanced Technology Development Center was obtained for use as a test facility. Also a number of manufacturers of heating and drying equipment were visited and potential equipment was evaluated for use in the test facility. The manufacturers visited were:
1. Cober Electronics, Stamford, CT, 23 January 1986 -- Discussed line of industrial microwave heating equipment was well as experience with industrial applications.

2. Raytheon, Waltham, MA, 24 January 1986 -- Discussed line of industrial microwave equipment and their experience with drying of bulk fibers and carpet.


6. Strayfield/Lawson-Hemphill, Spartanburg, SC, 29 April 1986 -- Attended a meeting on the Georgia Tech campus with a representative from Strayfield, a British manufacturer of industrial radio frequency heating equipment, and a representative from Lawson-Hemphill, Strayfield's U.S. sales outlet, to discuss their line of equipment and its applications, particularly those related to the textile industry.

7. Several firms that manufacture traditional industrial infrared heating equipment have been contacted. They include: Fostoria Industries Inc., Glenro Inc., and Heraeus Americil.
In addition, a number of Georgia industries that have potential heating and drying problems were contacted or visited. These industries include:

1. Columbus Mills, Columbus, GA, December 1985 -- Discussed the application of electric-based heating for processing of carpet.

2. Briggs Plumbingware, Atlanta, GA, 17 February 1986 -- Discussed application of microwaves to slip casting of vitreous china sanitary ware.

3. Coats and Clark, Albany, GA, 16 July 1986 -- Evaluated condition of used Strayfield 20 kW RF dryer which was in storage at a Coats and Clark hand knitting yarn plant. Discussed application and problems associated with use of RF drying in the production of knitting yarns.

4. Standard Coosa Thatcher, Washington, CA, 18 April 1986 -- Contacted Mr. Don Durden concerning more efficient ways to dry up to 35,000 lbs. of bulk polyester/cotton yarn packages per day.

5. Kimberly Clark, Norcross GA, 28 February 1986 -- Discussed a more practical manner in which to dry a composite fabric used for surgical gowns.

6. Johnson & Johnson Products, Inc. -- Discussed possibility of drying and curing prints on nonwoven fabrics by microwave or radio frequency energy.
IDENTIFICATION OF FUTURE PROJECTS

As part of the effort to identify projects which the test facility may wish to consider in the future, three potentially beneficial projects have been identified. These three research areas were selected for their potential impact on the productivity of the carpet industry. Other research activities will certainly be identified as more equipment becomes available at the test facility.

1. **Hybrid Drying of Carpets.** Successful drying of carpet at any step in the manufacturing process using dielectric heating is expected to be economic only by coupling of conventional and dielectric heating equipment. This requires identification of the point in the tenter frame where convective heating becomes inefficient such that the high efficiency delivery of thermal energy by dielectric heating can be economically competitive. Very little data exists for carpet drying rates as a function of drying time for conventional drying equipment and none exists for dielectrics drying equipment. Experimental work is being performed in the Textile Engineering School at Georgia Tech to develop data on conventional drying rates as a function drying time for various styles of carpet. Similar experimental work for dielectric heating equipment must also be performed. Another impetus of this drying research is that the better control of heating afforded by dielectric technologies could limit surface temperatures experienced by the carpet yarn and possibly lead to improved quality; e.g. better hand.
2. **Carpet Dye-Setting.** As indicated above, dye-setting using dielectric heating has been investigated in a preliminary way by some researchers. Application of this technology could lead to the replacement of the conventional steamer resulting in both energy savings and improved dyeing performance. Research is needed to show that carpet dyes can be set using dielectric heating and to correlate dyeing quality parameters with the characteristics of this dye-setting method.

3. **Carpet Yarn Heat-Setting.** It is well known that the temperature history experienced by carpet yarn during heat-setting is extremely important to the final quality of the carpet produced from it. This factor is particularly important to dyeing performance and is also felt to have an impact on quality parameters such as hand. If a method for heat-setting of carpet yarn based on dielectric heating could be devised, then better carpet quality might result due to the better heating control afforded by the dielectric technology. Research is needed to investigate development of such a heat-setting method and to correlate carpet quality parameters with the characteristics of the method.

**ASSESSMENT OF HYBRID DRYING OF TEXTILES AND CARPETS**

Initial tests on drying of carpets and textiles have been carried out in the School of Textile Engineering. These tests have been directed toward the problem of determining the critical regain for various styles.
Table 1. Carpet Description

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Wt (in oz/yd²)</th>
<th>Pile Ht. (mm)</th>
<th>Pile Density (tufts/in²)</th>
<th>Tuft Fiber</th>
<th>Cut Pile</th>
<th>Loop Pile</th>
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<tr>
<td>1</td>
<td>50</td>
<td>13</td>
<td>220</td>
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<td>X</td>
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<td>2</td>
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<tr>
<td>5</td>
<td>28</td>
<td>4.5</td>
<td>100</td>
<td>Nylon 6.6</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

-Carpet samples 2, 4, 5 had straight line (Plain) tuft patterns.
-Carpet samples 1, 3 had herringbone tuft patterns.
[OVEN-TEST]

- CARPET SAMPLE WT. = 50 oz/yd²
- CARPET SAMPLE WT. = 30 oz/yd²
- CARPET SAMPLE WT. = 28 oz/yd²
- CARPET SAMPLE WT. = 35 oz/yd²
- CARPET SAMPLE WT. = 33 oz/yd²

Figure 1. Carpet Convection Drying Results
regains. However, carpet drying curves for dielectric ovens are not available to ascertain the extent to which dielectric dryers are more effective at low regain. Thus, the next step in the project is to generate carpet drying data using microwave and/or radio frequency dryers.

LITERATURE REVIEW

A computer search of the literature in the area of heating, drying and curing was completed as part of this project. The search has uncovered over 100 pertinent references and each has been cataloged including a brief summary. These references are listed in alphabetical order in Appendix A. Many of these references have been collected and they are attached to the final report.

MATHEMATICAL DRYING MODEL

A clearer understanding of the role of dielectric heating and subsequent moisture removal from textile materials has now been established. Initial removal of surface wetness by highly efficient conventional drying methods (conduction, convection, radiation heat transfer coupled with air flow) ensures a uniform moisture distribution along and across the material, thus preparing it in an optimum state for subsequent radio frequency drying cycle in the 10 to 100 mHz band. Since conventional drying has been modeled adequately elsewhere, the mathematical model of the process has been limited to the r.f. dryer with a staggered throughfield and ventilated by airflow along the length of the material. The model necessitates a prior knowledge of a number of parameters, such as
the electric field strength, the heat transfer coefficient and the
dependence of the material loss-factor (the ability of the material to
produce heat in a high-frequency field) on temperature/moisture content.

The mathematical model is based on a one-dimensional, transient,
simultaneous heat/mass transfer under radio frequency heating conditions
and employs the Lewis number analogy for the air/water vapor mixtures. In
particular, it encompasses (a) the heat balance on an infinitesimal slab of
uniform moisture, taking into account sensible heat, latent heat of
vaporization, convection from the air and dielectric heating, (b) the mass
balance on the air in the well-mixed dryer and (c) the heat balance on the
gas phase.

The model may be applied to a real situation with a variable moisture
across the direction of motion by subdividing the material into a finite
number of small parallel webs, each with its own uniform moisture content.

In the development of a mathematical model for the carpet-drying
process, the carpet is assumed either (1) stationary and being dried
uniformly along the length and width or (2) moving at a constant speed that
is fast enough to preclude the development of large temperature and
moisture gradients in the carpet in the direction of motion. Under these
conditions, heat transfer and moisture transfer are assumed to occur only
through the thickness of the carpet.

The traditional models used to describe the heat and moisture transfer
in porous media such as soils or slurries can be adapted for modeling
conventional drying of textile products such as carpets. Furthermore,
microwave or radio-frequency (RF) drying can be modeled by including in the
energy equation a heat generation term that accounts for the energy absorbed by the water in the carpet from an electromagnetic field. Thus the mathematical model of the drying process can be expressed by the following equations [1,7]:

Conservation of Energy

\[
C \frac{\partial T}{\partial t} = \frac{\partial}{\partial y} \left( k e \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial y} \left( \rho_l \lambda v \frac{\partial \theta}{\partial y} \right) + q'''' \tag{1}
\]

Conservation of Mass (Water)

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial y} \left( D_\theta \frac{\partial \theta}{\partial y} \right) + \frac{\partial}{\partial y} \left( D_T \frac{\partial T}{\partial y} \right) \tag{2}
\]

This model can be simplified if it is expressed in terms of the average temperature \( \bar{T} \) and average moisture content \( \bar{\theta} \), the averages being taken across the thickness (or effective thickness), \( \bar{\theta} \), of the carpet. The resulting averaged equations, corresponding to Equations (1) and (2), are
The model expressed in Equations (3) and (4) can be applied to conventional drying, RF drying and hybrid drying processes.

Conventional Drying

In conventional drying, or in that portion of a hybrid drying process employing conventional drying, energy absorption by the water from the electromagnetic field is absent. Thus, the heat generation term in Equation (3) is zero. If the ambient temperature and moisture content do not change during the drying process, and if the heat and moisture transfer coefficients are assumed independent of carpet moisture content, we can integrate Equations (3) and (4) to obtain a description of the transient temperature and moisture content at a fixed location on the carpet.

\[
\frac{T - T_\infty}{\bar{T}_0 - T_\infty} = e^{-\frac{h_T}{c8} \frac{t}{\bar{T}_0}}
\]  

(5)
and

\[
\frac{\bar{\theta} - \theta_\infty}{\bar{\theta}_0 - \theta_\infty} = e^{-h_m t/\bar{\theta}}
\]  \hspace{1cm} (6)

Equation (6) predicts that the natural logarithm of the moisture content should vary linearly with time when the assumptions described above are valid. Kaviany and Mittal [10] have shown that the surface saturation is nearly constant over a wide range of average saturations (see Figure 2). Thus, if the initial regain of the carpet is not too high, the surface saturation, and therefore the surface moisture transfer coefficient, should remain approximately constant until the pendular (or bound-water) state is reached. This state coincides approximately to the critical regain of the carpet. Once the critical regain has been reached, Equation (6) is no longer valid and Equation (4) must be solved numerically because the moisture transfer coefficient at the surface changes owing to the change in the surface saturation coefficient.

The behavior predicted by Equation (6) is evident in the results of the drying experiment performed under this contract as can be seen in Figure 3 which was developed from the data in Figure 1. Drying experiments such as those described in the previous Section can be used to develop a means of determining the parameter \( h_m/\bar{\theta} \) in Equation (6) for various carpet types or to determine the surface saturation coefficient as a function of average saturation. With such data, Equation (4) can be used to model and to predict the moisture content (or carpet regain) during carpet drying by either conventional or hybrid drying processes.
Figure 2. Surface Saturation Coefficient As a Function of Average Saturation for a Porous Slab (After [10])
Figure 3. Carpet Convection Drying Results
Future experiments should, however, include measurements of the carpet temperature so that data for the heat transfer coefficient in Equation (3) can be developed.

**Radio-Frequency Drying**

In RF drying, the water in the carpet absorbs energy from an electromagnetic field. The amount of energy absorbed per unit volume of the carpet can be expressed as

\[ q'''' = \pi \varepsilon'' fE^2 \bar{\theta} \] (7)

where \( \varepsilon'' \) is the loss factor, \( f \) and \( E \) are the frequency and rms voltage gradient of the applied field, and \( \bar{\theta} \) is the average volumetric moisture content. For a fixed frequency and field strength, the magnitude of the energy absorption is directly proportional to the average volumetric moisture content, and Equation (3) can be expressed as

\[ C \frac{dT}{dt} = -\frac{h}{\bar{\theta}} (T - T_\infty) + d\bar{\theta} \] (8)

where \( d = \pi \varepsilon'' fE^2 \).
The model described by Equations (3) and (4) or (8), together with model parameters derived from carpet drying experiments, can be used to examine the drying of carpets using conventional or hybrid processes. With this model, one can determine when the conventional process should be discontinued in favor of an RF drying process. In addition, the model results can be used to evaluate the cost and cost savings for hybrid drying processes.

Selected References:


TECHNICAL BRIEF

A technical brief entitled RF Textile Drying has been proposed jointly by Georgia Tech and Georgia Power Company. This brief describes the process of RF drying and it discusses the advantages and disadvantages of RF drying when applied to textile materials. A draft copy of the technical brief is included in Appendix B.
APPENDIX A

HEAT, DRYING, CURING REFERENCES.
ANALYTICAL SOLUTIONS TO THE DRYING OF TEXTILE MATERIALS WITH MICROWAVE HEATING
HATCHER, J.D.; HIGGINS, K.B.; LYONS, D.W.
TEXTILE RESEARCH JOURNAL
1975, 45, No. 3, 223 - 229
NEW WORK

APPARATUS FOR DEVELOPMENT AND FIXATION OF DYES WITH A PRINTED TEXTILE SHEET BY APPLICATION OF MICROWAVE HEATING APPARATUS FOR DYE FIXING
ICHIKIN USP 4425718
17 JANUARY 1984, APPLICATION 258889

APPARATUS FOR IMPROVED AFTER TREATMENT OF TEXTILE MATERIAL BY APPLICATION OF MICROWAVES
KAWAGUCHI, B.
PATENT: USP 4,274,209

PATENT

APPARATUS FOR IMPROVED AFTER TREATMENT OF TEXTILE MATERIAL BY APPLICATION OF MICROWAVES
KAWAGUCHI, B.
PATENT: USP 4,274,209

PATENT
APPLICATION OF HIGH-FREQUENCY ELECTROMAGNETIC FIELD IN THE THERMAL PROCESSES OF THE TEXTILE
JONAS, P.; BLANKA, R.
TEXTIL, 1985
40, No. 2, 53-55
SHORT SURVEY OF DIELECTRIC HEATING AND EQUIPMENT

APPLICATION OF INFRA-RED, HIGH FREQUENCY AND MICROWAVE HEATING TO THE DRYING AND TREATMENT OF
CHABERT, J.
COMPTRENDU DE TRAVAUX LECARIM
1974, 39 - 62
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APPLICATION OF MICROWAVE TO TEXTILE DYEING
MORIZANE, H.
(THROUGH CHEMICAL ABSTRACTS 1984 100
1983, 35, No.7, 325- 333
REVIEW OF TECHNICAL INFORMATION
APPLICATION OF RADIO-FREQUENCY DRYERS IN THE TEXTILE INDUSTRY

HOLLAND, J.M.

TEXTIL PRAXIS INTERNATIONAL

1985, 40, No. 6, 648-650 + XIII-XV

APPLICATIONS OF RF DRYING OF TEXTILES. STRAYFIELD INT. SUPPLIED 209 RF DRYERS TO THE WORLD

APPLICATIONS OF INFRARED, HIGH FREQUENCY AND MICROWAVE HEATING TECHNIQUES IN TEXTILE

CHABERT, J.

CONTRIBUTIONS OF SCIENCE TO THE DEVELOPMENT OF THE TEXTILE INDUSTRY (INSTITUTE TEXTILE DE FRANCE

1975, 153 - 166

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APPLICATIONS OF RADIO-FREQUENCY HEATING TECHNOLOGY OF TEXTILES

HENDERSON, K.; McAULAY, T.; YOUNG, R.; SMITH, G.

JOURNAL OF THE SOCIETY OF DYERS AND COLOURISTS

1982, 98, No. 9, 303 - 305

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APPLICATIONS OF INFRARED, HIGH FREQUENCY AND MICROWAVE HEATING TECHNIQUES IN TEXTILE

CHABERT, J.

CONTRIBUTIONS OF SCIENCE TO THE DEVELOPMENT OF THE TEXTILE INDUSTRY (INSTITUTE TEXTILE DE FRANCE

1975, 153 - 166

REVIEWS AND SURVEYS; TECHNICAL INFORMATION
APPLICATIONS TO TEXTILES
HENDERSON K. McAULAY T. YOUNG R. SMITH G.
JOURNAL SOC. DYERS AND COLOURISTS
98: 303-305 (SEPT 1982)
APPLICATIONS

AT THE SIGN OF 'ITMA 1983'. PART 1. FINISHING
GUZZINATI M.G.
NUOVA SELEZIONE TESSILE
SUPP. TO No. 12: 2-4 (DEC 1983)
RF DRYING GAS DIRECT HEATING OF TENTERS AND USE OF STEAMERS FOR VARIOUS STEPS

ATME: DYEING AND FINISHING REPORT
GREAVES R.L. (CSIRO)
AUSTRALASIAN TEXTILES
1: 23-25 (MARCH/APRIL 1981)
THE TRIATEX MINIMUM-APPLICATION PROCESS REPORTED
ALSO RF DRYING

RF DRYING GAS DIRECT HEATING OF TENTERS AND USE OF STEAMERS FOR VARIOUS STEPS

THE TRIATEX MINIMUM-APPLICATION PROCESS REPORTED
ALSO RF DRYING

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<td>BOOST YOUR SHIFT PRODUCTION WITH MICROWAVES. HOW A MICROWAVE DRYER COULD IMPROVE YOUR EFFICIENCY</td>
<td>METAXES, A.C.; MEREDITH, R.; HOLME, I.</td>
<td>CARPET REVIEW WEEKLY</td>
<td>1979, 19 JULY, 30, 42</td>
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<td>DAILY NEWS RECORD</td>
<td>10: 5 (DEC. 22, 1980)</td>
<td>AUSSIE RESEARCHERS W/ INTN. WOOL SECRETARIAT'S RAW WOOL SERVICES, ENG. EXAMINE THE WARMING OF BALES OF WOOL BY RF</td>
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<td>DETERMINATION OF THE DIELECTRIC PROPERTIES OF TEXTILES IN HIGH-FREQUENCY FIELDS AND POSSIBLE</td>
<td>IONESCU, D.; CHIRIAZI, V.; VISINESCU, M.N.</td>
<td>INDUSTRIA USOARA--TEXTILE, TRICOTAJE, CONFECTII TEXTILE</td>
<td>1979, 30, No. 12, 549-552</td>
<td>TECHNICAL INFORMATION</td>
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DIELECTRIC DRYER

SCHOLL MODEL HF DIELECTRIC DRYER. USES RF FOR THE DRYING OF CARPET AND OTHER TEXTILE YARNS AND FIBERS

DISTRIBUTION OF RESIN ON COTTON FABRICS. PART 3. A COMPARISON BETWEEN RADIO-FREQUENCY AND CONVENTIONAL WITH EMPHASIS ON EFFECT ON PHYSICAL PROPERTIES OF DIFFERENT RESIN TREATED COTTON FABRICS

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title  DRYING RAYON TEXTILE FILAMENTS WITH HIGH FREQUENCY CURRENT
journal  SINTET. I PRIROD. POLIM. MATER., THROUGH ABSTRACT BULLETIN OF THE INST. OF PAPER CHEMISTRY
pages  1975, 46, No. 5 ABSTRACT 4519
description  TECHNICAL INFORMATION; NEW WORK

page on dbase sheet 43/118
language  RUSSIAN

title  DRYING TEXTILES BY RADIO FREQUENCY
author  WALSAM, D.J.
journal  CANADIAN TEXTILE JOURNAL
pages  1979, 96, No. 6, JUNE, 55 - 58
description  TECHNICAL INFORMATION

page on dbase sheet 39/118
language  ENGLISH

title  ECONOMY AND EFFICIENCY ARE KEYNOTES OF COLORATION EQUIPMENT AT ITMA '79
author  HAZEL B.J.
journal  TEXTILE MONTH
pages  33-35 (JAN. 1980)
description  TRENDS IN RF DISCUSSED

page on dbase sheet 22,23/100
language  ENGLISH
EFFECTS OF MICROWAVE RADIATION ON THE WEBBING CLOTHES MOTH, TINEOLA BISSELLIELLA AND TEXTILES

REAGAN, B.M.; CHIAO-CHENG, J.H.; STREIT, N.J

J. FOOD PROT.

1980, 43, No.8, 658-663

NEW WORK, TECHNICAL INFORMATION

ELECTRICAL RESEARCH BREAKTHROUGH 'GIVES 500% BETTER DRYING PERFORMANCE'

TEXTILE MONTH

44 (DEC. 1983)

COMBINATION AIR FLOAT DRYING WITH RF

ELECTRICAL RESEARCH BREAKTHROUGH 'GIVES 500% BETTER DRYING PERFORMANCE'

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1983, DECEMBER, 44

DESCRIPTION OF ELECTRICAL DEVELOPMENT THAT COMBINES AIR FLOAT DRYING WITH RADIO FREQUENCY HEATING

ELECTRICAL RESEARCH BREAKTHROUGH 'GIVES 500% BETTER DRYING PERFORMANCE'

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DESCRIPTION OF ELECTRICAL DEVELOPMENT THAT COMBINES AIR FLOAT DRYING WITH RADIO FREQUENCY HEATING
VARIOUS TECHNICAL DEVELOPMENTS IN TEXTILE MACHINERY INCLUDES RF DRYING

DEScribed THE ELECTRODRY system of RF DRYING by SAM. PEGG & SON

INSTALLATION OF THREAD DRYING CO., DONISTHORPE AND COMPANY, IN TANDEM OPS OF STRAYFIELD RF DRYER WITH DETTIN BERTHA 24 TWIN HYDROEXTRACTOR OUTLINED. BENEFITS AND FEATURES DESCRIBED
**FUTURE OF ELECTRICAL TECHNIQUES IN THE PRODUCTION OF PRINTED TUFTED CARPETS**

**METAXES, A.C.**

**J. MICROWAVE PUR.**

1981, 16, No.1, MARCH, 43-55

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**GREENBANK DEVELOPS NEW TYPE OF CARPET BACKING OVEN**

**ICB INTERNATIONAL CARPET BULLETIN**

No. 152: 2-4 (SEPT 1983)

**NEW OVEN DRYING SYSTEM DEVELOPED BY THE UK ELECTRICITY COUNCIL RESEARCH CENTRE USED IN LATEX BACKING TRIALS BY GREENBANK-DARWEN ENGINEERING COMBINES RF DRYING AND AIR FLOATATION/AIR IMPINGEMENT DRYING**

**HIGH FREQUENCY DRYING**

**STEINER R.**

**TEXTILVEREDLUNG**

17: 70-72 (FEB 1982)

**PRINCIPLES AND ADVANTAGES OF DIELECTRIC DRYING**
HIGH FREQUENCY DRYING AND ITS APPLICATIONS IN THE TEXTILE INDUSTRY

SINHA D.K.; KAIMAL M.K.

BTRA SCAN

15, No. 4: 7 - 11 (Dec. 1984)

PRINCIPLES OF R. F. DRYING AND uWAVE HEATING ARE EXAMINED.

HIGH-FREQUENCY AND MICROWAVE HEATING METHODS FOR DRYING AND TREATMENT OF TEXTILES

CHABERT, J.

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HIGH-FREQUENCY DRYER IN THE TEXTILE MILL. PRINCIPLE OF ITS FUNCTIONING AND PRACT. APPLI.

NAEFE, P.

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1985, 40, No. 7, 757-762

PHYSICAL PRINCIPLES OF RF DRYING AND KRANTZ RF DRYING TUNNELS ARE DESCRIBED

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author CHABERT, J.

journal TEINTEX

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language GERMAN, ENGLISH
**HIGH-FREQUENCY DRYING AND ITS APPLICATION IN TEXTILE DYEING AND FINISHING**

**BERGER, K.**

**INTERNATIONAL TEXTILE BULLETIN. DYEING/PRINTING/FINISHING**

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**PRINCIPLES OF HIGH FREQUENCY DRYING ARE EXPLAINED. THE OPERATION, OUTPUT AND COST EFFICIENCY OF HF DRYERS IN DYEING AND FINISHING**

**HIGH-FREQUENCY HEATING IN TEXTILE FINISHING. I, II**

**BECHTER, D.; SEEGER, J.**

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**HOT AIR DRYING BY ELECTRIC HEATING**

**CHEVALIER J. P.**

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APPLICATIONS OF GREENBANK-DARWEN ARFA DISCUSSED

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IMPROVED DYE FIXATION OF CARPET YARNS USING A FUNDAMENTAL MODE RESONANT CAVITY AT 2.45 GHz
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HOLLAND, J.M.

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IS HYBRID DRYING THE ROUTE TO FASTER, MORE EFFICIENT PROCESSING?

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**Title**: ITMA 1983: NEW DEVELOPMENTS IN DYEING AND PRINTING  
**Author**: ERNST E.  
**Journal**: CHEMIEFASERN/TEXTIL-INDUSTRIE  
**Pages**: 34/86, No. 1: 63 - 70 (JAN 1984)  
**Description**: COMPUTER CONTROLLED PROCESSES FOR CONTINUOUS AND SEMI CONTINUOUS DYEING AND USE OF uWAVE DRYING PROCESSES

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**Title**: ITMA '79: PASSPORT TO THE '80'S - WET PROCESSING  
**Author**: SUCHECKI S.M.  
**Journal**: TEXTILE INDS.  
**Pages**: 144: 36-38, 40, 42-43 (FEB. 1980)  
**Description**: RF DRYING AND KNIT GOODS MERCERIZATION IS REVIEWED

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**Title**: MATHEMATICAL MODEL OF THE CONDITIONS FOR JOINING FIBROUS MATERIALS HAVING A NON-UNIFORM STRUCTURE  
**Author**: SKRIPNIK, V.N.; RADZIEVSKII, V.A.; TURZHITSKII, M.  
**Journal**: TECKNOLOGIYA LEGKOI PROMYSHLENNOSTI  
**Pages**: 1984, 27, No. 1/157 120- 123  
**Description**: DETAILS FOR THE MATHEMATICAL MODEL FOR BACKING NYLON 6/POLYPROPYLENE WOVEN CARPET ETC. WITH AID OF DIELECTRIC HEATING

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**Language**: GERMAN

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**Language**: ENGLISH

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**Language**: RUSSIAN
METHOD AND APPARATUS FOR CONTINUAL TREATMENT OF
TEXTILE SHEET MATERIAL BY APPLICATION OF

FABRIC WOUND AROUND GUIDE ROLLERS IN A CHAMBER,
STEAM IS INTRODUCED INTO THE CHAMBER AND THE
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METHOD FOR SELECTIVE HEATING IN TEXTILES WITH
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PEPPERMAN, A.B.; VAIL, S.L.; LYONS, D.W.
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<td>JAP. FIRM, ICHIKIN LTD. DEVELOPED APOLLOTEX DYEING MACHINE THAT USES uWAVES IN A STEAMING CHAMBER FOR APPLYING DYES AND CHEMICALS TO WET TEXTILES</td>
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<td>Author</td>
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<td>Description</td>
<td>DISCUSSES STATE OF THE ART OF uWAVE HEATING AND POTENTIAL TO IMPROVE PRODUCTIVITY OF TEXTILE INDUSTRY</td>
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MICROWAVE HEATING OF PRINTER FABRICS

KATO N.
GIFE-KEN KOGYO GIJUTSU SENTA KENKYU HOKOKU
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USED MICROWAVES AS A CARRIER

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PRINCIPLES AND APPLICATIONS OF RF HEATING INCLUDES HEAT TRANSFER, DRYING DIELECTRIC HEATING, MICROWAVES SYSTEMS RF SYSTEMS AND SAFETY

PROCESS FOR THE CONTINUOUS DYEING OF TEXTILE WEBS PRE-HEATED WITH INFRARED OR MICRO-WAVES

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PATENT: BP 1,567,111

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BARBER, F.W.

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SMITH, G.A.; MCAULEY, T.F.

PATENT: USP 4,304,048

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LATEST DEVELOPMENTS IN RF SYSTEMS NAMELY NEW SERIES OF 40KW DRYING UNITS FROM STRAYFIELD AND TATHAM FELTING UNITS

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SUCCESS STORY FOR SMITH ENG

DESCRIPTION OF THE SMITH-FASTRAN LINE CREATED BY SMITH ENGINEERING PROJECTS LTD.

TEXTILE DRYING PROJECT AT ENGINEERING STAGE

RESULTS ACHIEVED BY ELECTRICITY COUNCIL RESEARCH CENTER AT CAPENHURST WITH USE AIR FLOAT DRYER WITH RF ENERGY APPLIED

THE ARFA SYSTEM: COMBINING HOT AIR AND RADIO FREQUENCY DRYING

COATING AND DRYING SYSTEMS COMBINING HOT AIR AND RADIO FREQUENCY TECHNIQUES ARE DESCRIBED
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<tr>
<td>THE COMMERCIAL APPLICATION OF DIELECTRIC HEATING</td>
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<td>ELECTRICAL DRYING TECHNIQUES FOR EFFICIENT BULK WATER REMOVAL. FOCUS ON CONVEYORIZED RF, TRANSFER PRINTING AND RF WEB HEATING</td>
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<td>THE EFFICIENCY OF RADIOFREQUENCY APPLICATORS FOR TEXTILE DRYING</td>
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<td>SMITH-FASTRAN EQUIPMENT FOR DRYING OF LOOSE STOCK USING RF DRYING</td>
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JOURNAL MICROWAVE POWER (CANADA)

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JONES F.

PATENT NO.: BP 1 583 953

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NONWOVENS REPORT INTERNATIONAL

No. 152: 5-7 (DEC. 1983)

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UNIFORM REGAIN WITH PYE'S RF DRYER

PYE TEXTILE DRYER, A SELF-CONTAINED AND FREE STANDING UNIT DEVELOPED BY PYE RF SYSTEMS LTD.
<table>
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<tr>
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<th>Author</th>
<th>Journal</th>
<th>Pages</th>
<th>Description</th>
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<td>USE OF HIGH FREQUENCY ELECTRICITY IN THE TEXTILE INDUSTRY</td>
<td>KOVACS, J.</td>
<td>MAGYAR TEXTILTEHCNIKA</td>
<td>1975, 28, No. 11, 582 - 586</td>
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<td>USE OF MICROWAVE DRYING IN THE APPLICATION OF FLAME RETARDANTS FOR COTTON FABRICS</td>
<td>PEPPERMAN, A.B.; VAIL, S.L.; LYONS, D.W.</td>
<td>JOURNAL OF COATED FABRICS</td>
<td>1976, 6, No. 2, OCTOBER, 95 - 104</td>
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- HUNGARIAN
- ENGLISH
- ITALIAN


APPENDIX B

TECHNICAL BRIEF - RF TEXTILE DRYING
RF TEXTILE DRYING

PROCESS DESCRIPTION

Radio Frequency (RF) drying works by internally heating the textile. Energy losses associated with "indirect" heating where heat is generated externally and transferred to the textile are minimized. The heat developed within the product is proportional to the moisture to be removed; the more moisture the greater the heat generated. There is a self-leveling effect. Wet areas dry faster than the drier cooler area, and thus, the moisture in the product is leveled out to a predetermined regain value.

The basic design of a RF dryer is shown schematically in Figure 1. RF heating can operate only on electrically insulating products containing polar molecules such as water. When a voltage is applied to the condenser plates, the polar molecules (water) in the textile tend to align themselves with the electromagnetic field. Since the polarity of the plates varies at a high frequency (typically 13.56 or 27.12 MHz), the polar molecules vigorously oscillate attempting to follow the electromagnetic field. The work done on the polar molecules by the electromagnetic field is manifested as heat.

APPLICATIONS

RF drying is most useful in drying bulky textile products such as packages, top, loose stock, etc., although web drying applications do exist. Traditional thermal drying processes heat from the outside and thus dry outside layers first, forming an excellent thermal insulation barrier. As a result, drying of inner layers is slow and energy intensive. Since RF dryers selectively heat the moisture, even drying occurs, reducing drying times drastically. In the case of package drying, required times can be reduced from hours to minutes.

The most economic way of using RF drying is to couple it with conventional mechanical or thermal drying systems. Free or unbound water can be removed efficiently with conventional systems, but removal of bound water is much less efficient with these systems. RF dryers can remove the bound water rapidly and efficiently. Thus
overall process speed and energy efficiency can be greatly improved.

PROCESS ADVANTAGES/DISADVANTAGES

The "direct-heat" nature of RF drying results in several advantages. The elimination of thermal barriers allows drying time to be greatly reduced, increasing productivity. Inner layers of packages can be dried without over drying outer layers. Thus complete or bone drying is not necessary, resulting in energy saving and improved product quality. Moisture profiling throughout the product can be achieved. Dye migration problems associated with some conventional drying systems are avoided. RF dryers can be switched on with virtually no warm-up time being necessary. Thus RF units can be operated intermittently without greatly impacting energy efficiency.

One disadvantage sometimes associated with RF dryers is energy cost. A unit of heat produced from electricity is usually more expensive than a unit of heat produced directly from a gas or oil. However, since RF dryers are more efficient in the drying of bulky textile products, electric heat via RF systems can actually prove to be less expensive.

PRODUCTION RATE AND ENERGY EFFICIENCY

RF drying equipment offers great possibility for increasing productivity. Normally free water is removed mechanically, and RF drying is used for the more difficult task of removing bound water. Obviously production rate depends on the size of the RF unit and the material being processed. Typical equipment consists of 25 KW or 50 KW modules arranged in series.

Typical production rates for two size RF units and several materials are given in Table 1. The modules are rated at the RF power put into the product. For example, a 50 module is capable of delivering 50 KW to the product. System efficiency is usually 60% to 70%. A rule of thermal for calculating size of unit needed is that 50 KW unit can remove 132 pounds of water per hour.

<table>
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<th>Material</th>
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<td>Fiber</td>
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<tr>
<td>Moisture</td>
<td>25 KW</td>
</tr>
<tr>
<td>Wool</td>
<td>422-17%</td>
</tr>
<tr>
<td>Polyester</td>
<td>202-42</td>
</tr>
<tr>
<td>Acrylic</td>
<td>181-32</td>
</tr>
<tr>
<td>Cotton</td>
<td>482-82</td>
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</tbody>
</table>

(Data from Strayfield International)

Table 1. Typical Performance for RF Drying

COST/ECONOMIC CONSIDERATIONS

RF equipment is fairly expensive, costing approximately $2000 per KW of capacity. Thus RF drying must be utilized properly to ensure its use is cost effective. Normally RF drying is utilized to remove bound water, where RF units are much more efficient than conventional systems. Although a unit of electrical energy is more expensive than a unit of energy from fossil fuel, savings in energy cost of as much as 60% via RF drying have been reported. An economic evaluation of the viability of RF drying should consider that productivity can be increased significantly, and space requirements of RF units are usually 1/4 to 1/2 that of conventional equipment.
EQUIPMENT MANUFACTURES

Manufactures that offer radio frequency drying equipment include:

- Radio Frequency Co.
  Millis, Massachusetts

- Siemens AG
  Erlangen, West Germany

- Scholl AG
  Zofingen, Switzerland

- Strayfield International
  Reading, England

For more information, please contact Dr. Wallace W. Carr, Textile Engineering
Georgia Tech, Atlanta, GA (404)894-2538.

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