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FEASIBILITY EVALUATION: SOLAR HEATED TEXTILE PROCESS WATER

Volume 1, Program Results. Final Report

By
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February 1977

MASTER

Work Performed Under Contract No. EY-76-S-09-0885

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U.S. Department of Energy

Solar Energy

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Final Report

VOLUME I -- PROGRAM RESULTS

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February 1977

Prepared for the United States
Energy Research and Development Administration
Division of Solar Energy
Agricultural and Industrial Process Heat Branch
Under Contract No. E(38-1)-885

Approved:

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ACKNOWLEDGEMENTS

This study was performed under ERDA Contract No. E(38-1)-885. The authors are grateful to Mr. William Auer and Mr. William Cherry of ERDA for providing stable technical guidance during the study when conditions were changing rapidly in both a technical and administrative sense in ERDA and in the solar energy field.

The authors are also grateful to the South Carolina Textile Manufacturers Association and to many individual textile firms for allowing us to determine realistic industry requirements by actual in-plant efforts in order to insure against the study's becoming an academic exercise.

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I. ABSTRACT

A feasibility study was conducted to evaluate the technical and economic constraints associated with the use of solar heating to produce process water for the textile industry. The study developed energy use data based upon actual plant processes to determine both the current water needs for the industry by temperature level and to assess the probable future impact of conservation schemes upon possible solar concepts. A realistic weather and solar flux environment definition was made based upon analysis of actual weather data for the southeast Piedmont region where most of the textile finishing plants are located. Collector area requirements to meet textile water demands of varying amounts and temperatures were generated using assembled test data for six collector types ranging from simple flat plate areas to tracking concentrator configurations. Energy collection densities for various types of collectors operating in a representative Southeast environment and producing process water of varying temperatures were generated. Using the assembled test data and performance predictions for various collector types and for various textile process water temperature levels, an after-taxes, rate-of-return economic analysis was performed, envisioning possible future energy price scenerios, to determine allowable installed collector costs per square foot. These ROR calculations indicate the cost levels at which collector configurations would provide incentive to industry to heat by solar processes as opposed to fossil fuels. Additionally, studies were conducted to determine the effects of possible federal inducements to solar conversion in the form of investment tax credit changes. Lastly, the effect upon economic viability of solar concepts due to the establishment of a leasing industry was evaluated.

II. PROGRAM OBJECTIVES

On a national basis the textile industry uses approximately 3% of the energy used by all industries each year.¹ However, since 75% of the textile industry is located in North Carolina, South Carolina, and Georgia, this 3% figure has no real significance when compared to the regional impact of textile energy use upon the Southeastern United States. (For example, in South Carolina textile energy use accounts for 32% of all industrial end uses and 8% of all energy used in the state.²) Nationally, finishing plants use approximately 60% ($\approx 1.5 \times 10^{14}$ Btu/yr) of the industry energy with weaving and knitting greige mills consuming the other 40% ($\approx 1.0 \times 10^{14}$ Btu/yr). The 40% goes for electrical output and environmental control in the greige mills while the 60% is essentially all finishing process related.

With this target application assuming such potential importance to the Southeast and recognizing the Southeast's growth importance to the nation's economic health, Clemson University's College of Engineering was tasked to perform a feasibility study to ascertain the viability of solar heating of textile process water. The study involved significant input from the textile industrial sector and involved technical, weather, labor and cost considerations.

The detailed objectives of the program were as follows:

- o To determine the hot water use patterns in finishing processes in the textile industry.
- o To analyze these use patterns to determine required temperature performance levels and required water delivery rates in processes for which solar augmentation might have potential benefits.
- o To determine the effect of conservation and heat recovery plans that might be developed in the textile industry upon water use rates

so that most realistic performance levels, against which solar concepts would be judged, could be developed.

- o To conceptualize solar heating systems which would meet these process water demands. Collector areas, temperature levels, water production rates, etc. would be developed.

- o To determine the costs of such systems and their economic viability in the textile industry.

- o To identify any special problems associated with the textile industry which might overly restrict the acceptance of solar technology by that group.

III. ENERGY USE ANALYSIS

The purpose of this section is to provide an estimate of the energy used in textile water processes. Energy used for fiber production, plant environmental control, from natural gas in the dryers and tenter frames, and in electrical components is not included.

Estimates are prepared for both industry-wide consumption and for "typical" processing plants. The data and estimates are based upon trade publications,³ inputs from industry personnel, and studies conducted in actual processing plants. These data are approximations which have been developed to define the water needs to be addressed by solar technology.

The approach taken in the energy use survey is as follows:

- (1) From annual fiber production figures the significant textile elements are identified.
- (2) For the significant textile elements processing schematics are formed.
- (3) Energy consumption levels for each of the processing subsets are bounded or bracketed by survey data.
- (4) Each of the individual processes then has a current energy use rate associated with it. This rate is based upon "typical" plant data analysis.

The initial step in the energy analysis is the definition of textile production levels. Table 1 shows the annual consumption of fibers in the U.S. in 1973 by fiber type. Since wool accounts for less than 2 percent of the fibers consumed, it will not be included in the discussion which follows. The 1973 data are the latest detailed data available. However, a gross evaluation of the current production rates

shows no marked deviation from this trend, and therefore the detailed data will be used. However, cottons and cotton blends are making a strong surge currently, and if this situation holds, the data should be biased toward that market. In any event, the latest detailed yearly data on fiber use is as follows:

Cotton	--	3.7×10^9 lbs
Wool	--	0.2×10^9 lbs
Synthetics	--	7.4×10^9 lbs
(a)		38% Polyester
(b)		15% Acrylic/Modacrylic
(c)		29% Nylon
(d)		6% Acetate
(e)		12% Rayon

Table 1: Fiber Production Rates

Appendix A is a summary of the end-uses of cotton plus synthetic fibers in the U.S. in 1973. An examination of Appendix A shows that about 30.4% of the total fiber consumption is in 100% cotton and cotton/synthetic blend goods. Another 15.6% of the fiber is in carpets (synthetics), and 17.8% is in synthetic knits and broadwovens. Table 2 reflects these common groupings.

	% of <u>Total Fibers</u>	
I. Cotton as an Ingredient		
100% cotton woven	18.2	} 3.4 x 10 ⁹ lbs/yr (combined fibers)
Cotton/synthetic blends	12.2	
II. 100% Synthetics		
Carpets	15.6	1.7 x 10 ⁹ lbs/yr
Polyester knits	9.3	} 2.0 x 10 ⁹ lbs/yr
Polyester broadwoven	1.5	
Other synthetic broadwoven	<u>7.0</u>	
	63.8% = 7.1 x 10 ⁹ lbs/yr	

Table 2: Significant Textile Groupings

These groupings account for approximately 64% of the textiles used yearly. Fabrics made of 100% cotton or cotton/synthetic blends are given essentially the same processing. Light weight apparel fabrics made of 100% synthetics are processed by different techniques, and the heavier weight carpet type goods are treated by yet another approach.

Simplified flowplans for fabric containing cotton and for 100% synthetic products (either light weight or carpet weight) are shown in Figures 1 and 2 respectively. The essential difference in these two routings is that fabric containing cotton is usually bleached with hydrogen peroxide and mercerized with caustic to improve its dyeing characteristics prior to dyeing.

The 36.2% of the fiber production unaccounted for in these three groupings (and two routing schemes), often involves end uses which require little or no finishing or dyeing and therefore has little impact on the question of hot water usage in the textile industry. Examples here are synthetics produced for use as tire cord, industrially used cotton, etc. Thus, the Table 2 groupings appear to include most of the energy consuming elements of the textile hot water market.

In order to keep this study as simple as possible, only those processing steps involving the use of significant quantities of process water will be discussed, thus operations such as singeing, infrared drying, heatsetting, etc. will not be included. Obviously, solar production of hot water will not address these high temperature textile applications in the near term and as such they do not impact the current study except as these high temperature uses provide waste heat opportunities which affect solar parameters. This aspect will be subsequently addressed.

Figure 1. Simplified Flowplan for Fabric Containing Cotton.

Figure 2. Simplified Flowplan for 100% Synthetic Products.

Having defined the fiber use rates in the various categories, the question of energy used in various processes within each category can be addressed. However, some introductory material with respect to the processes involved is appropriate before energy levels are discussed.

Most fabric is either knitted or woven (i.e. very little is matted pressed). It may be dyed before knitting or weaving (yarn or package dyed) or dyed after knitting or weaving (fabric dyed). Yarn dyeing permits the use of different colored yarns to produce plaids, checks, stripes, etc. Fabric dyeing is used for most solid color fabrics because it is less expensive and gives a more uniform color. Nonsolids may be fabric dyed also by selective dye take-up. The yarn dyeing routings are shown on the left sides of Figures 1 and 2 and the fabric dyeing is on the right.

Most carpeting is made by tufting; however, some is woven like cloth. The processing of carpet is in a general sense similar to the processing of cloth, therefore it is included in the synthetic processing flowplans. However, in the detailed processes described later, a carpeting facility analysis is included.

Knitting oils, which are usually applied to yarns to reduce static electricity during knitting, are removed by scouring. In a similar manner sizing (starch, polyvinyl alcohol, etc.) which is added in a slashing operation to protect the warp (lengthwise) yarn during weaving must be removed by scouring. Scouring and slashing apply to both cottons and synthetics.

Mercerizing is a process restricted to cottons and cotton blends which alters the cotton fiber prior to application of the dye.

Dyeing involves the addition of the pigment to the fabric, and its fixation in the fiber by combined chemical and thermal mechanisms. The actual dyeing temperature used for yarn or fabric may vary from 80°F for certain fabric and dye combinations; to 210°F for others when atmospheric dye baths (becks) are used; and up to 270°F when dyeing in pressurized becks. For the purposes of this study a temperature of 200°F is assumed for batch processes dyeing cottons, blends, and most synthetics, and 250°F is assumed for 100% polyesters. Scouring is usually carried out at temperatures ranging from 100°F to 212°F with 200°F being our assumed number for general use.

As an alternative to the batch dyeing processes discussed above, large quantities of fabric are dyed or printed on continuous ranges. Many of the continuous range processes take place at 190 - 200°F. Although the application of the dye itself on these continuous ranges does not require as much water as do the batch becks, there are several hot chemical stages involved; each followed by washers which do consume large quantities of hot water.

In many cases the specific process temperature does not indicate the total energy use profile. For example, the beck dyeing temperature indicated above may be specified as 200°F, but the plant personnel may insist on filling the beck with water which is supplied at 100°F to 120°F and subsequently using steam to heat it at a controlled rate to the 200°F value. The reason for this is that the dye takeup by the fabric may be too rapid at the higher temperatures and the dyeing may not be even. By letting the fabric dye relatively slowly initially, it is

easier to get an even dyeing and maintain a low fabric rejection rate. This means that if solar energy or waste heat recovery systems provide a source of 200°F water, the dyer may still prefer to fill with 120°F water and heat it with steam or heat exchange to the 200°F final temperature.

This point illustrates the degree of personal preference and variability that is involved in specifying many process variables. As energy costs become more significant, perhaps these personal constraints will ease. However, currently they are real constraints to hot water use regardless of their basis in either experience or technology.

The temperatures and water flow rates for the operations shown in Figures 1 and 2 vary widely depending on the particular plant, fiber type, dye type, type of dyeing machinery, the degree of success of conservation measures, personnel preferences and other factors. Analyses of reported plant data indicate a wide range in use rates and temperatures. For planning purposes the process water use rates and water temperature levels are bracketed by the data presented in Tables 3 and 4.

<u>Operation</u>	<u>Water Flow Rate</u> <u>gal/lb cloth</u>	<u>Typical</u> <u>Water Use</u> <u>Temperature, °F</u>
Slashing	.05 - 1.	80-120°F
Scouring and/or desizing	6. - 35.	140-200°F
Bleaching	.3 - 15.	140-200°F
Mercerizing	1. - 10.	150-200°F
Dyeing and rinsing		
Basic dyes	<div> <div>Very light colors</div> <div> <div>{</div> <div>20. - 40.</div> <div>}</div> </div> </div>	<div> <div>Very dark colors</div> <div> <div>{</div> <div>*</div> <div>}</div> </div> </div>
Developed colors		
Direct dyes		
Naphthol dyes		
Sulfur dyes		
Vat dyes		
Dispersed dyes		

* If kettle (beck) dyed: 100-120°F fill & controlled heating to use temp.
 If continuous dyeing: ~ 200°F

Table 3: Estimates of Process Water Flow Rates and Temperatures for Fabric Containing Cotton.

<u>Operation</u>	<u>Fiber</u>	<u>Water Flow Rate gal/lb cloth</u>	<u>Typical Water Use Temperature, °F</u>
Slashing	All	.05 - 1.	80. - 140°F
Scour	Nylon or Acrylic	6. - 8.	120. - 160.
	Polyester	3. - 5.	140. - 200.
Dye	Nylon, Acrylic, or Polyester	2. - 4.	100. - 200.*
			100. - 250.*
Scour & Dye	Rayon	2. - 4.	100. - 200.*
	Acetate	4. - 6.	100. - 200.*

* If beck dyed, filled @ 100° and heated at controlled rate to 200°F or 250°F

Table 4: Estimates of Process Water Flow Rates and Temperatures for 100% Synthetic Products.

Since the individual processes vary so widely from plant to plant in water used and process specifics, an attempt was made to define specific requirements for three "typical" installations running a range of colors and fabrics. Detailed data were obtained for a synthetic fabric finishing plant, a carpet finishing plant, and a finishing plant for fabric containing cotton. These three examples reflect the end use cases singled out in Table 2. They represent actual industry data. Much of it was obtained for the first time during the conduct of this energy use pattern study and was previously unknown to the particular plants themselves. Figure 3 is the flow plan for the synthetic plant using pressurized becks, Figure 4 is for the carpet plant which uses atmospheric becks, and Figure 5 is for the continuous cotton-contained finishing plant. These results define the energy and water requirements of "typical" finishing and preparation operations.

Figure 3. Energy Schematic for a Typical 100% Synthetic Pressurized Beck Finishing Plant.

Figure 4. Energy Schematic for a Typical Carpet Finishing Plant.

Figure 5. Energy Schematic for a Typical Cotton/Cotton Blend Finishing Plant.

However, the data are not exact and therefore rigorous energy balances may show minor omissions. The data are intended to define the application which solar hardware would be required to address in response to current use patterns. These data will be used in subsequent sections in sizing solar systems, etc. The computer routine used to develop the energy and mass balances for the textile processes is described in Appendix B.

The energy use analysis based upon the detailed processes of these three types of plants obviously does not address yarn dyeing processes or all the possible finishing steps that exist within the industry. However, it does contain those most frequently used. For purposes of industry wide energy use projections it was assumed that these other possible processes would exhibit energy characteristics similar to these most commonly used processes. By combining these process energy uses with the fiber production rates and end uses of Table 2 it is projected that most of the textile process energy uses exclusive of electricity and that associated with knitting and weaving are covered by the processes summarized in Table 5.

Of the approximately 1.5×10^{14} BTU/yr used in textile finishing processes some 72% of this energy is associated with cotton/cotton blends, 18% with apparel weight synthetics and 10% with heavy weight synthetics such as carpets, etc. The data indicate that approximately 30% of the energy used in all textile finishing processes goes into drying processes that use 325-350°F steam. These drying processes were not a part of the remainder of this study. However, temperatures of water in the

Table 5. CURRENT PROCESS WATER/ENERGY USE SUMMARY FOR FABRIC DYEING AND FINISHING

	Temp. (°F)	Use Rate Typical Mill (lbm H ₂ O/lbm product)	Use Rate Typical Mill (Gal/day)	Use Rate Industry Wide (Gal/year) (Btu/yr)	
<u>Continuous--Cotton Containing</u>					
Boiler Output	370°	25.	---	---	---
Scouring and Bleaching	¹ 200°	58.4	1,332,000	196.8 x 10 ⁸	2.3 x 10 ¹³
Mercerizing	210°	25.6	585,000	20.5 x 10 ⁸	2.5 x 10 ¹²
Dyeing	210° 160° ³	51.3 } Dyeing 38.3 } Rinsing	1,170,000 873,000	41.0 x 10 ⁸ 30.6 x 10 ⁸	5.1 x 10 ¹² 2.6 x 10 ¹²
Finishing	185°	2.7	60,000	2.2 x 10 ⁸	.2 x 10 ¹²
Sub-total		30,000 Btu/lbm	4,020,000	---	1.1 x 10 ¹⁴
<u>Pressurized Batch--Synthetics</u>					
Boiler Output	375°	7.3	---	---	---
Scouring	¹ 200°	16.7	225,000	24.8 x 10 ⁸	2.9 x 10 ¹²
Beck Dyeing	² 250° 140° ³	45.5 } Dyeing 39.9 } Rinsing	615,000 525,000	68.3 x 10 ⁸ 58.3 x 10 ⁸	10.6 x 10 ¹² 4.1 x 10 ¹²
Finishing	110°	2.2	30,000	3.3 x 10 ⁸	.2 x 10 ¹²
Sub-total		12,000 Btu/lbm	1,495,000	---	2.4 x 10 ¹³
<u>Atmospheric Batch--Carpets</u>					
Boiler Output	350°	5.7	75,000	---	---
Beck Dyeing	³ 212° 120° ³	24.1 } Dyeing 24.1 } Rinsing	324,000 324,000	39.0 x 10 ⁸ 39.0 x 10 ⁸	4.9 x 10 ¹² 2.1 x 10 ¹²
Finishing	N/A	0.0	0.0		
Sub-total		8,000 Btu/lbm	723,000	---	1.4 x 10 ¹³
¹ Supplied at lower temperature and heated with steam to use temperature.					
² Used at 250°F; Ramp from 110°F					
³ Used at 212°F; Ramp from 120°F					

250-270°F range were considered because pressurized systems do use the liquid phase at these temperatures for dyeing, etc.

In textile process water end uses, the industry-wide data of Table 5 can be generalized as follows:

120-160°F	{ Synthetic Fabric Rinsing After Dyeing	6x10 ⁹ gallons/yr
	{ Carpet Rinsing After Dyeing	4x10 ⁹ gallons/yr
	{ Cotton Rinsing After Dyeing	3x10 ⁹ gallons/yr
200-210°F	{ Cotton Scouring and Bleaching	2x10 ¹⁰ gallons/yr
	{ Cotton Dyeing	4x10 ⁹ gallons/yr
	{ Atm Carpet Dyeing	4x10 ⁹ gallons/yr
	{ Synthetic Fabric Scouring	2.5x10 ⁹ gallons/yr
	{ Cotton Mercerizing	2x10 ⁹ gallons/yr
250-270°F	{ Synthetic Fabric Dyeing	7x10 ⁹ gallons/yr

Thus, the largest single use of textile process water/energy is in cotton scouring and bleaching.

It is emphasized that these data are based upon generalizations of current processes and temperatures. Conservation efforts are expected to reduce consumption levels perhaps 30% below these values and to eventually lower the process temperatures and water rates significantly. For now, however, these data are descriptive of the water demands to be met by solar hardware systems.

IV. SOLAR ENVIRONMENT DEFINITION

System performance for solar process water heating is dependent upon the actual local climate and weather conditions. Factors such as cloud cover, latitude, orientation, etc. affect the local solar potential. Since 70% of the finishing activity nationally is located in North Carolina, South Carolina and Georgia, it was decided to use Greenville, South Carolina weather data to determine the solar potential available to textile applications.

A ten year analysis (1965-1974) of Greenville weather data was conducted. The analysis involved a statistical examination of the actual weather tapes to select the "most typical solar conditions" for spring, summer, fall and winter days. Most-typical seasons were also selected; as was the most-typical year. "Most typical" was defined as those conditions existing during the day (or season or year) which exhibited the minimum variation from the mean of the ten year data base. The variables examined, in order of priority, were flux level, ambient temperature and wind velocity. The results indicate the following:

Most typical seasonal days:

Winter	-	January 8, 1974
Spring	-	April 4, 1973
Summer	-	July 3, 1966
Fall	-	October 19, 1969

Most typical seasons:

Winter	-	(December '65 - February '66)
Spring	-	(March - May, 1969)
Summer	-	(June - August, 1965)
Fall	-	(September - November, 1972)

Most typical year: 1969

Using these conditions the "most probable" solar potential can be defined and used for system synthesis. Obviously, system analysis (as opposed to synthesis) demands the actual local variations with time.

This solar potential variation with time, the effects of orientation, etc., are defined by the output of a weather model developed and described in Appendix C. Output of the computer routine is flux level (both direct and diffuse) incident upon a defined surface orientation, ambient temperature, and wind speed. This is the time variant, local solar potential. Input is Weather Bureau data.⁴ Computer routine verification was obtained by comparing output of the routine (DRIVR 3/WMODEL) to the published values of Yellott⁵ for the same input conditions. Maximum deviations between calculated and reported values of 2% were found. The results of such an approach are presented in Figures 6, 7 and 8 for the most typical solar conditions that textile systems would experience.

Using this program, solar conditions are generated from weather data to provide inputs for the collector analysis (as opposed to synthesis) methods. Additionally, it was used to calculate average solar conditions during the sunlight periods of the design days and to define optimum collector orientations when variable tilt conditions were considered. Table 6 presents the average sunlight design conditions and the collector tilt angles for maximum solar potential.

Figure 6. Solar Radiation Potential for a Fixed Horizontal Surface at Greenville, S.C.

Figure 7. Solar Radiation Potential for a 45° South Facing Surface at Greenville, SC.

Figure 8. Solar Radiation Potential for a "Sun Normal" Tracking Surface at Greenville, S.C.

<u>Collector Orientation</u>	<u>Design Season</u>	<u>Daylight Mean Flux (BTU/hr ft²)</u>	<u>Mean Temp (°F)</u>	<u>Mean Velocity (fps)</u>
45°	Winter	161	46°	9
45°	Spring	157	65°	19
45°	Summer	109	79°	8
45°	Fall	150	64°	10
65.5° (Optimum)	Winter	171	46°	9
28.0° (Optimum)	Spring	158	65°	19
9.0° (Optimum)	Summer	125	79°	8
52.5° (Optimum)	Fall	151	64°	10

Table 6 Solar Potential Design Conditions

The introduction of mean flux levels rather than instantaneous time dependent values produced a tremendous reduction in the amount of computer time required to describe system performance for analysis considerations. Figure 9 shows the error introduced by this simplification. The analysis shows that flux level variation between average values and instantaneous values is significant for inefficient collector types at high use temperatures but is within 10% at other conditions. This high use temperature usually dictates more efficient systems, and therefore this simplification should be considered for first level design to minimize computer time used. For detailed system analysis the time variable flux levels obtainable from the weather routine should be used.

These weather data and analysis method produce incident flux levels as input variables to the collector computer model described in the next section. This incident flux, or local solar potential, contains both diffuse and direct components. It reflects actual weather data, etc. where the flux potential is decreased by clouds, dust and water vapor (note the summer day involves cloud cover over most of the day). The model predicts

EVACUATED TUBE COLLECTOR

		DATE			
		1-8-74	4-4-73	7-3-66	10-19-69
OUTLET TEMP. °F	135	⊙	⊠	△	◇
	225	⊕	⊞	△	◇
	295	○	□	△	◇

Figure 9a. Error Bands for Average Flux Level Calculations vs. Hourly Transient Flux.

DOUBLE-GLAZED FLAT PLATE COLLECTOR

		DATE			
		1-8-74	4-4-73	7-3-66	10-19-69
OUTLET TEMP. °F	135	○	◻	△	◇
	225	⊕	⊞	△	◇
	295	○	◻	△	◇

Figure 9b. Error Bands for Average Flux Level Calculations vs. Hourly Transient Flux.

the transient solar potential for South Carolina environs as varying between 365 Btu/hrft² maximum for the "typical" spring level to 265 Btu/hrft² maximum for the "typical" winter day. All other times (i.e. days, seasons, etc.) in system analysis would have flux levels generated from weather bureau data input. However, these "typical" day values will allow one to design systems as they represent the "most probable" conditions that the collector will experience.

V. HOT WATER SYSTEM DEFINITION

With the water use and temperature levels in textile processes defined (Section III) and the local solar potential defined (Section IV), candidate systems were conceptualized.

An evaluation of interface and operational constraints that solar hardware would be subject to, based upon actual plant conditions, was made. The outcome of this analysis is as follows:

1. Designs of water heating systems for textile processes should assume full fossil fuel baseline capability with solar assuming an "as available" status.

2. Interfacing on either a series basis with existing hot water facilities, or in parallel with this equipment appears to involve state-of-the-art controls, etc. and no problems were identified other than those discussed in Section VII.

Integration of solar into the central hot water facility does appear superior to affixing systems to individual machines, etc. in order to maximize the duty cycle match-up between solar availability and machine cycles.

3. Based upon this interfacing flexibility the solar hardware appears as applicable to existing facilities as to new construction. In new construction however, some solar costs may be defrayable as a part of roofing costs if integral roof panels/collectors become available. This general study does not defray these costs, which apparently run at the \$2.50 to \$3.00 per square foot level.

However, future collector developments and detailed specific designs should seriously consider such a combination.

4. An analysis of the energy use in textile processes indicated that solar collectors might see two interface conditions that significantly affect their performance and subsequent system design. This interface condition involves plants with or without heat recovery equipment. In the near- to mid-term, most textile plants will use high temperature energy in many processes. Heat recovery from these high temperature waste streams produces large quantities of 110 - 120°F process water. Plants which do not currently reclaim this energy should, and obviously will, install heat recovery conservation equipment prior to solar installations since heat recovery is a more cost competitive low temperature energy source. Therefore, until textile processes exclude these high temperature activities, systems interfacing with either 120°F heat recovery systems; or with 45-60°F feedwater should be assumed. Further, this current availability of low temperature process water from heat recovery equipment greatly negates the applicability of low temperature solar process water systems. Low temperature performance was analyzed, but higher temperatures should receive greater attention in the short term due to this heat recovery interface.

Having established water needs, local solar potential, and general design constraints, collector system synthesis and analysis was performed. Two approaches were used. Initially, efforts were expended to develop completely general analysis tools to allow variation of all the variables

such as coatings, cover optical properties, insulation effects, etc. for both flat plate and concentrating parabolic collectors. Computer routines were written to allow complete specification of all variables. However, based upon the results of the ERDA Process Heat Workshop in June, 1976 it appeared that design details of this level were superfluous at this time due to the rapidly changing, and emerging, state of the art in solar collector manufacture. Further, many of these design variables the manufacturers did not choose to release, even if they knew them. Accordingly, this approach was modified to base system synthesis and analysis upon test data actually generated from collector tests. This approach also allows the inclusion of much more complex, and more numerous, systems in the study. With this method the collector types shown in Table 7 could be included in the study, whereas only the first two, and perhaps three, systems could have been included in the first principles approach.

<u>Type</u>	<u>Acronym</u>
Single-glazed flat plate	SGFP
Double glazed flat plate	DCFP
Compound parabolic concentrator - Stationary	CPC
Evacuated tube collector - flat plate configuration	ETC
Tracking fresnel lens concentrator	TFC
Tracking fresnel lens concentrator with evacuated receiver	TF CER

Table 7. Collector Types Analyzed

All the systems analyzed assumed coolant in a 50-50 mixture of ethylene glycol and H₂O. Three modes of system analysis were available

in the collector analysis computer routine CMDL 1 (Appendix D). This routine takes weather model output data as input to any one of three analyses modes. These modes generate: required area for given mass flows and temperatures (the synthesis mode); water generation rates for specified areas and temperatures (energy collection mode); or delivery temperatures for specified areas and mass flow rates (availability mode).

As an aid in evaluating systems, a piping model was also generated to determine pumping power and plumbing requirements for solar hardware systems as variables in the subsequent cost modeling. However, when the cost procedure was changed as discussed in Section VI, the plumbing inventory aspect was no longer used, but is available (Appendix E).

Additionally, the piping model indicated such small ideal pumping powers that this element in operating costs (compared to initial costs) was omitted.

The solar collector system definition from computer routine CMDL 1 depends upon the collector test data supplied. It is based upon the collector efficiency versus a function of average fluid temperature, ambient temperature and incident flux method described by Hill and Kusuda⁶. The data collected from manufacturers and testing reports was averaged in the cases where multiple systems were available to generate the input data shown in Figure 10.7

This approach to system analysis is valid when applied to cases where the flow rate is sufficiently high to assure that the maximum attainable fluid temperature is reached at the collector exit, not before. Thus, extremely low mass flow rates produce inaccurate results. However, in real

Figure 10. Collector Efficiency Curves.

systems extremely low mass flow rates are of mathematical interest only. For purposes of establishing a limit on this variable, the method was evaluated and found to be accurate for values of $\dot{m}/A \approx 1.0 \frac{\text{lbm}}{\text{hrft}^2}$ for flux levels germane to textile systems.

For South Carolina's solar potential, achievable temperatures vary from approximately 210°F with single glazed systems; to approximately 300°F with double glazed configurations; to several hundred degrees with complex systems, for the trivial case of extremely low flow. Obviously as flow rate increases, efficiency also increases; but the attainable outlet temperature decreases. At the extreme point where the collector is most efficient, the attainable temperature is essentially equal to the entering temperature. This trade-off is shown in Figure 11. For readers familiar with heat exchanger analysis, this result is obvious. For the prospective user most interested in textile production, the trade-off between amount of energy collected and the attainable water temperature (i.e. availability) may not be as familiar.

For cases of textile interest the computer routine and test data were used to generate collector areas for various types of collectors as functions of the collector coolant flow rate at specified outlet temperatures. The prospective user may determine approximate area requirements to meet his specific plant needs by relating process water needs to the given coolant flow rates by the equations,

$$\dot{m}_1 C_{P1} (\Delta T)_1 = \dot{m}_2 C_{P2} (\Delta T)_2$$

and

$$\dot{m}_1 = \frac{m_1}{t} ,$$

Figure 11. Outlet Temperature/Flow Rate Relationship for Collectors.

where

- $\dot{m}_1$ = instantaneous mass-flow rate of collector coolant, mass/time;
- m_1 = total mass of collector coolant which must be heated by solar energy in one day;
- t = number of hours available for heating collector coolant in one day;
- m_2 = total mass of process water which must be heated in one day;
- C_{P1}, C_{P2} = specific heats, respectively, of collector coolant and process water;
- $(\Delta T)_1$ = temperature drop of collector coolant through heat exchanger;
- $(\Delta T)_2$ = temperature rise of process water through heat exchanger.

Required collector areas, by type of collector, were generated for process water use rates and temperatures covering the full range of textile processes from greige mills (10^3 lbm/hr); to full hot water production for continuous cotton dyeing and finishing (5×10^6 lbm/hr). These flow rates are for the collector system. Process water mass flow rates are considerably lower because system synthesis was based upon the assumption that the collector farm would produce during one sunlight period the process water for a full 24-hour, three shift, specified use rate. Since the sunlight period varies with season, the collector mass flow rate for a given required process flow rate also varies with season. However, this is reflected in the equations given previously. The user must specify the desired water use rate for the particular textile process of interest, the season (which gives the sunlit period) and then determine the collector flow rate that matches the desired process rate. If multiple days use (ie, for cloudy days) is proposed, the data still apply; one merely increments the process requirements by the specified cloudy period.

Similarly, temperatures indicated are collector outlet values. Temperatures out of the collectors should be approximately 15-20°F higher than

the desired process temperatures to provide sufficient ΔT to maintain reasonable heat exchanger sizes for one exchange to the process water. Again, these factors are internal assumptions in the synthesis mode. For multiple exchange concepts where heating ramps might be involved, the outlet temperature required might be considerably higher than the desired process temperature.

Since the required area for a specified water and temperature use condition is a function of collector inlet temperature, orientation of the collector, and the incident flux level (both time and season), these variables had to be included in the synthesis. Collector inlet temperatures of 60°F and 75°F, which correspond to fresh water supply temperature of 45°F (winter) and 60°F (summer), were considered. Also collector inlet temperatures of 120°F and 135°F, which correspond to $\sim 105^\circ\text{F}$ and $\sim 120^\circ\text{F}$ heat recovery supply temperatures, were considered. Orientations considered were the fixed position optimum of 45° (latitude + 10°) and the four-valued optimum seasonal tilt adjustment (OST) case (Table 6). Area requirements based upon the four seasonal flux levels were also included. Such a range of variables (i.e., collector type, use temps, use rates, orientation, interface with heat recovery, and seasonal flux levels) produces a tremendous array of data, as evidenced by Appendix F. However, to provide information of general applicability to the broad textile industry without restricting the design conditions to one or two collector types requires this coverage. The matrix at the beginning of Appendix F defines the synthesis cases.

Selected system configurations are shown in Figures 12 through 17 to illustrate the use of this data. Three collector types (DGFP, ETC and TFCER) for spring flux conditions, for optimum seasonal orientation, with and without interface with heat recovery equipment, are presented.

These example plots show required collector areas for various process water temperatures and use rates (all based upon one day generation and use). As an example of how to use the plots, the case of supplying 200°F water (220° collector outlet) for synthetic fabric scouring will be considered. For cases involving no heat recovery, Figure 12 indicates $\approx 2.5 \times 10^5 \text{ft}^2$ of DGFP would be required; compared to $\approx 1.7 \times 10^5$ of ETC (Figure 14); or $\approx 1.0 \times 10^5$ of the complex TFCER (Figure 16).

When heat recovery is integrated into the system significant effects may be produced. First, the collector areas (with heat recovery) do not decrease in proportion to the smaller ΔT across the collector because the efficiency of the collector has decreased due to the higher plate temperatures and the higher losses from the collector. In fact, in some cases where high outlet temperatures are involved and the collector shows a rather steep decrease in efficiency as the mean plate temperature increases, the higher inlet temperatures associated with heat recovery may cause the collector area to actually increase due to the increased collector losses i.e. the higher collector losses exceed the heat recovery effects (per ft^2) for some incident flux levels. Thus for these cases collector systems with flat efficiency curves (Figure 10) are generally superior to those with steep efficiency curves. The quantitative test of this impact is such that $(\eta_{w/o} \Delta T_w / \eta_w \Delta T_{w/o})$ must be less than 1.0 for the flux and temperature levels involved or the heat recovery system may actually increase the solar area required to produce a desired outlet temperature!

To illustrate the use of the plots involving heat recovery the same example of 200°F scouring water is considered. Figure 13 indicates $\approx 3.0 \times 10^5 \text{ft}^2$ of DGFP; $\approx 1 \times 10^5 \text{ft}^2$ of ETC (Figure 15); and $\approx 7 \times 10^4 \text{ft}^2$ of TFCER (Figure 17) required to do the scouring task. Appendix F contains the results of all the cases considered.

Figure 12. Area Required vs. Temperature and Water Use Rate DGFP/OST/60°/Spring.

Figure 13. Area Required vs. Temperature and Water Use Rate DGFP/OST/120°/ Spring.

Figure 14. Area Required vs. Temperature and Water Use Rate ETC/OST/60°/Spring.

Figure 15. Area Required vs. Temperature and Water Use Rate ETC/OST/120°/Spring.

Figure 16. Area Required vs. Temperature and Water Use Rate TFCER/OST/60°/Spring.

Figure 17. Area Required vs. Temperature and Water Use Rates TFCER/OST/120°/Spring.

These results indicate that differences between collector types tend to be emphasized at higher temperatures and unimportant at low temperatures. It also demonstrates very well the low availability levels associated with solar energy. In order to increase this availability requires a high collector efficiency. The examples also indicate to the potential user the necessity that specified water temperatures be as low as possible. For high temperature (combustion level) fossil fuel systems this effect is not so important due to the high initial fuel availability level.

The seasonal area requirements show the system dependence upon local solar potential. For example, a DGFP design for the previous 200°F with heat recovery scouring range case shows the following areas (Appendix F) to be required to supply the necessary process water: winter (C10B) $\approx 4 \times 10^5 \text{ft}^2$, spring (C12B) $\approx 3.0 \times 10^5 \text{ft}^2$, summer (C14B) $\approx 4 \times 10^5 \text{ft}^2$, fall (C16B) $\approx 4 \times 10^5 \text{ft}^2$. An ETC design, since efficiency (η) does not vary as greatly with flux or temperature as does DGFP, would require $\approx 1 \times 10^5 \text{ft}^2$ regardless of the season.

A thorough analytical analysis verified this approach. System synthesis should be based upon spring conditions to produce minimum area designs unless there exists some specific application constraint to dictate another season in which solar must meet the load demand. In general, the design approach would be to define minimum areas to meet the desired load in the spring and to only supply a portion of the load by the solar system during the other seasons. This requires augmentation of the solar production in summer, fall and winter but does not result in excess capacity at any time. For example, if textile designs were based upon winter conditions, when other fuels are least available, excess capacity would exist for the higher flux cases of other seasons.

The data presented may also be applied for the more realistic case of part load solar production. Again using the ETC scouring range example, a farm area of $\approx .5 \times 10^5 \text{ft}^2$ would be sufficient to supply 50% ($\approx 1.2 \times 10^5$ gallons/day) of the necessary process water for a "typical" synthetic scouring range of 200°F. Thus, desired temperature level, desired water flow rate, and collector type, is the only information necessary to use these plots to obtain required collector areas.

These data and examples demonstrate that many different types of systems are capable of meeting a specified textile process requirement. The use temperature, and heat recovery interface, dictates how much of each type is needed for a particular application. In some cases, i.e. at higher temperatures, some of the systems are not candidates regardless of the area involved because they cannot generate water of that temperature level, i.e., the collector efficiency approaches zero. This is true for SGFP in many textile applications. In general, however, for many, many textile applications most of the available collector configurations are capable of producing the desired process water. The question of interest is which of these systems produces hot water for a particular textile process most economically.

To address this question, the collector computer routine CMDL1 was run in mode 2 (energy collected) for the "typical" South Carolina weather data. The results are shown in Figures 18 through 23. These figures show energy collected per year (per unit area) for various collector types, for orientations of interest, with and without heat recovery interface, for the real environment (weather) the textile industry experiences. Outlet fluid temperatures (which are process temperatures + heat exchanger ΔT) vary from those corresponding to low rinse temperatures to those involved in dyeing synthetics under pressure beck conditions. Thus, for the same 200°F

Figure 18. Energy Collection Density for Various Collectors vs. Outlet Temperature/
45° Tilt/60° Inlet.

Figure 19. Energy Collection Density for Various Collectors vs. Outlet Temperature/45° Tilt/120° Inlet.

Figure 20. Energy Collection Density for Various Collectors vs. Outlet Temperature/OST/60° Inlet.

Figure 21. Energy Collection Density for Various Collectors vs. Outlet Temperature/OST/120° Inlet.

Figure 22. Energy Collection Density for Various Collectors
vs. Outlet Temperature/OST/75° Inlet.

Figure 23. Energy Collection Density for Various Collectors
vs. Outlet Temperature/OST/135° Inlet

scouring range case (with 105°F heat recovery equipment), the OST case shows that a DGFP system would collect 0.08×10^6 Btu/yr-ft² while an ETC system would collect 0.30×10^6 Btu/yr-ft². Since both systems will supply the desired process water, the system selected will depend upon whether real costs of the ETC compared to the DGFP (and compared ultimately to other available energy sources) are justified by the .30/.08 ratio in performance of the ETC compared to the DGFP. If real ETC costs are 5x the DGFP level, then DGFP is superior. If the factor is 4x, they are approximately equal; and at 2x the ETC is superior. If, however, the process application is to take fresh water and heat it to a rinsing temperature of 120-130°F (without interfacing with heat recovery equipment), the extra costs of a more complex ETC would be justified, compared to even the simple SGFP configuration, only to a .36/.32 ratio. The quantitative comparisons of the various collector types, and a comparison to fossil fuel alternatives, is the subject of the next section.

In summary, data have now been generated, based upon collector performance test data, to allow evaluation of a host of collector configurations, orientations, interfaces, etc. for real textile environments and varied textile process demands. The data are completely general and can be used for preliminary analysis of any solar augmented textile process water case of interest. Obviously, detailed transient analyses of the designs are required to get specific performance data.

VI. ECONOMIC EVALUATION

One of the primary objectives of this study was to define the economic viability of solar process water concepts. The data of Section V indicated the dependence of the system configuration upon the particular application selected. It also showed the extreme dependence upon the particular collector performance characteristics ($\eta = f(T_{\text{out}}, T_{\text{in}}, I, \dot{m}, \text{etc.})$). In order to make comparisons between systems, three applications and three types of collectors were considered. The applications involved collector outlet values at low temperatures (135°F); mid-level temperatures (225°F); and high temperatures (280°F). The data are generally applicable to any process but as examples one might theorize that after heat exchange the system might produce process water for pre-rinsing ($\approx 120^\circ\text{F}$); for scouring ($\approx 210^\circ\text{F}$); or for synthetic pressure beck dyeing ($\approx 240\text{--}250^\circ\text{F}$) respectively. For the mid- and high-temperature type applications the conditions of with and without heat recovery @ 120°F were considered (ie, collector inlet of 75° and 135°F). The optimum seasonal tilt (OST) case was analyzed since most textile industries have sufficient technician staff to accomplish this manually at low cost increment. No land costs were included in the analysis since many candidate textile plants already posses the available land.

The analysis assumes no reduction in the fossil fuel system in the plant. Thus the solar process water produced is viewed as a reduction in operating costs by not requiring the expenditure of the fossil energy it replaces.

Based upon these assumptions an after-taxes, rate-of-return (ROR) economic analysis was performed for the range of variables and constraints

shown in Table 8. Two approaches were attempted. First, an economic model was developed and implemented as computer code COSM01 to input component costs, pumping costs, storage costs, maintenance costs, etc. and to predict a ROR based upon various fuel replacement cost scenarios.

This approach was abandoned when it became clear that costs were changing quickly and could not be reliably obtained. COSM02 was then developed to solve the inverse problem; namely, to calculate allowable costs for various collector types, fuel costs, temperatures of application, etc. (based upon initial costs of all components normalized to unit area of collector) to achieve a prescribed after-taxes ROR (Appendix G). This approach avoids the uncertainties in costs such as installation labor, etc. and merely states that labor installation costs, collector costs, storage costs, etc. are all equally important to the textile user and allows maximum interplay between these variables so long as a specified total installed cost per square foot of collector surface is achieved. The collector performance (ie., η) then fixed the cost recovery rate.

The data output compares the three types of collector systems [simple (DGFP); mid-level (ETC); complex (TFCE)] to one another and to costs associated with using fossil fuel rather than solar. A positive ROR indicates the solar process water system will return all costs during its life by substituting for the fossil fuels. However, a positive ROR is not sufficient to justify the solar substitution. If equity funding is involved, the germane question becomes a choice between solar ROR and some alternative investment ROR. If debt funding is involved, obviously the solar ROR must exceed the borrowed capital costs. In practice a combination of debt and equity funding is normally used. Thus, the minimum attractive ROR for a

- o Collector Types: Double-glazed flat plate (DGFP); evacuated tube collector (ETC); and tracking fresnel concentrator with evacuated receiver (TFCER).
- o Collector Life: 12 and 20 year; no salvage value.
- o Process Water Temperatures: 120°F (135°F from collector); 210°F (225°F from collector); and 250°F (280°F from collector).
- o Heat Recovery Interfaces: None (75°F into collector corresponding to 60°F water supply temperature); and 120°F out of heat recovery system (135°F into collector).
- o Time Zero Fuel Costs: 36¢, 54¢ and 90¢/gal #2 fuel oil cases were considered. These values coupled with a boiler efficiency of approximately 0.9 produce process heat costs of \$2.65/10⁶Btu; \$4.00/10⁶Btu and \$6.67/10⁶Btu. This equates to net oil prices of 40¢, 60¢ and \$1.00/gal. Net prices (40¢, 60¢ and \$1.00) are always indicated.
- o Fuel Escalation Factor: 6, 8, 10 and 12% compounded annually; (e.g. 10% for 40¢ present oil price equates to \$1.38/gallon in 1990).
- o Annual Maintenance Costs:

Simple System (DGFP)	1.3¢/ft ²
Mid-level System (ETC)	1.97¢/ft ²
Complex System (TFCER)	2.89¢/ft ²
- o Storage, Installation, Framing, Plumbing, Pumps, Heat Exchangers etc. included in installed cost/ft².
- o Tax Rate: 52% Federal and 6% State; accelerated depreciation schedule (sum of years digits method)
- o Land Cost: not included.

Table 8: Range of Variables and Assumptions in Economic Modeling and Evaluation.

particular firm is also driven by the particular balance of debt and equity funding favored by its management. Knowledge of the ROR for a solar concept summarizes the essential aspects to allow the investment to be considered by the firm.

The full spectrum of variables reflected in Table 8 was considered for general applicability. The complete data set is included as Appendix H. Figures 24 through 28 are examples indicative of the results. Figure 24 shows that for one fuel cost projection, ie., 40¢ oil at 10% yearly increases, a twelve year life system, making 120°F water (135°F collector outlet) the after-tax ROR for the DGFP, ETC and TFCER configurations track consistently. Further, a \$7-10/ft² installed cost (DGFP-TFCER) would yield a ROR of 10%. However, as indicated previously the industry currently has large amounts of water at these levels available from heat recovery systems. Figure 25 reflects a more meaningful case. The same fuel cost projections, system life, etc. (but making 210°F water after heat recovery) shows quantitatively the impact of collector efficiency. Here a \$15.00/ft² installed cost would yield ROR of -6%, +2% and +5% for the DGFP, ETC and TFCER systems respectively. Alternately, to achieve a 10% ROR the textile industry should pay \$1.00, \$7.50 and \$9.00 respectively for a DGFP, ETC or TFCER system.* Obviously, then, the DGFP system appears non-competitive for such an application. Further, only an additional \$1.50 can be justified for the complex TFCER for this case compared to the ETC. If the lens, concentrator and tracking mechanism cost more than \$1.50/ft², the TFCER should not be considered for this application. Target values of ETC systems of \$5.00/ft² for the collector and \$2.50 for ancillaries would yield the

*Based upon the η values contained in Figure 10 data.

Figure 24. Rate-of-Return vs. Installed Collector Cost--
40¢ Oil/12 Yr. Life/10% FEF/120°F.

Figure 25. Rate-of-Return vs. Installed Collector Cost--
40¢ Oil/12 Yr. Life/10% FEF/210°F.

10% ROR. Current prices are in excess of this value and therefore a system built today at \$20.00/ft² installed would yield a 0% ROR and would be negative at all costs greater than \$20.00/ft².

Figure 26 indicates that in high temperature applications (250°F) the efficiency of collection is so low (ie., so little energy is being collected and substituted for fossil fuel) that in such a case a required ROR of 10% would dictate \$5.00 and \$7.50 allowable costs for ETC and TFCER systems. DGFP has dropped off and could not supply this temperature level at any cost. Thus, the acceptable \$7.50/ft² ETC system of the previous example is not acceptable only at the \$5.00/ft² level.

Figures 27 and 28 indicate other variable impacts. In Figure 27 the effect of system life is given. A 10% ROR for a twenty year life 210°F ETC allows an installed cost of \$9.00/ft² whereas the twelve year life system (Figure 25) indicates 10% for a \$7.50/ft² cost. Thus, the engineering and material and labor costs to extend system life from twelve to twenty years is worth \$1.50/ft² to the textile user who desires to make 210°F water interfacing with a 120°F heat recovery system; and who currently pays 40¢/gallon for fuel oil and expects it to increase in cost 10% per year. Figure 28 is for future zero time situations when oil prices are 60¢/gallon. At that time a ROR of 10% for 210°F water output, for a twelve year life, at 10% FEF, would allow ETC systems to cost up to \$10.00/ft² installed; and complex TFCER systems might cost an additional \$2.00/ft² (compared to \$7.50 and \$9.00 currently). Even at 60¢/gallon, the DGFP system could cost no more than approximately \$2.00/ft² to be competitive. These 40¢, 60¢, and \$1.00 oil prices correspond to time zero decision point costs, not energy costs in effect after system construction.

BASIS: 40¢/GAL, 12 YR LIFE, 10% FEF, 250 °F W/HEAT RECOVERY

Figure 26. Rate-of-Return vs. Installed Collector Cost--
40¢ Oil/12 Yr. Life/10% FEF/250 °F.

Figure 27. Rate-of-Return vs. Installed Collector Cost--
40¢ Oil/20 Yr. Life/10% FEF/210°F.

Figure 28. Rate-of-Return vs. Installed Collector Cost--
40¢ Oil/12 Yr. Life/10% FEF/210°F.

The way energy costs increase is reflected in the fuel escalation factor (FEF) of 6%, 8%, 10% or 12%. For example, a 40¢ 1977 figure (at 10% FEF) corresponds to a 1990 projected cost of \$1.38; a possible 1979 60¢ figure equates to a 1992 projected cost of \$2.07/gallon.

In summary, ROR data have been generated for general cases of interest to the textile industry for all reasonable (and unreasonable) fuel cost projections. The data indicate clearly the extent to which system costs must be reduced for solar process water heating to be economically viable in the textile industry.

In addition to addressing the economic viability of solar augmented textile process water heating, a study was conducted to evaluate the impact of concepts that might promote implementation of solar heating of process water. Two alternatives were considered. They were:

- 1) the impact of the investment tax credit rate at 7%, 10% or a 15% level. The time factors were assumed to be such that the full credit could be taken under essentially current scheduling practices.
- 2) the impact of the establishment of a lease option so textile industries could lease collector systems, heat exchangers, etc. rather than purchase them as previously analyzed. This allows higher collector cost systems to be more nearly competitive since to the textile firm the previously analyzed capital expense associated with purchase now becomes a fully deductible operating expense distributed over the system life.

Figure 29. Effect of Changes in Investment-Tax-Credit Upon Solar Viability--
210° ETC System.

Figure 30. Effect of Changes in Investment-Tax-Credit Upon Solar Viability--
210° TFCER System.

Figures 29 and 30 exhibit the impact of the investment tax credit change on the allowable costs for typical textile applications. The 210°F water case for current 40¢ oil prices increasing at 10% shows that at a 10% ROR change by the government from a 7% rate to a 15% rate would only allow slight changes in ETC or TFCER costs. It would not make a \$20.00/ft² ETC system competitive in this application; it would change the ROR from 0 to +10%. To get the ROR from 0 to +10% will require a \$7.50/ft² cost rather than a \$20.00/ft² cost. This may come by better manufacturing methods or by production level changes, but it does not appear that tax credit changes to the 15% level (5% greater than any previous level) would have much impact on solar acceptance and economic viability.

Figure 31 indicates the impact of a leasing option. For the 210°F case we have seen that a 10% ROR could be achieved for an ETC system purchased at \$7.50/ft². By the treatment of operating costs as opposed to capital costs (ie. leasing) the textile industry could still realize its 10% ROR from solar heating textile water, and the lessor would also realize 10% if this lessor had to pay \$10.00/ft² installed cost for the ETC system. The DGFP would be competitive only at \$2.00/ft² and the TFCER would be competitive (ie. ROR = 10%) at \$13.00/ft² rather than the \$9.00 level in the purchase option. Thus, the lease option does affect the economic viability of solar process water heating concepts.

These examples indicate the economic variables considered in the study. Other approaches such as low interest government loans, etc. merely affect the industry acceptance level of ROR in the general analysis previously discussed and do not pose a new situation.

Figure 31. Effect of Lease vs. Purchase Options Upon Solar Economic Viability.

VII. SPECIAL CONSTRAINTS/CONDITIONS

In addition to the technical and economic evaluation of the solar heated textile process water systems, an objective of the study was to determine any special constraints or conditions associated with this application. Among these already developed in previous sections are the following:

- 1) Textile applications will in the short term likely require interfacing of the solar hardware with approximately 120°F waste heat recovery systems.
- 2) Either parallel or in series solar capability appears feasible. However, it appears that series installations will result in better general utilization and less negative impact risk.
- 3) The transient behavior of the solar supply causes no significant problems in a technical sense. It manifests itself only in required storage costs.
- 4) The system for such a textile operation may be evaluated on a variable orientation basis (UST) as opposed to a fixed orientation without excessive penalty.
- 5) The specification of one particular candidate collector configuration for the textile industry cannot be made because water use temperatures vary greatly. However, for most applications the bias is toward higher temperatures (200°F⁺).

Additional factors relevant to solar hardware acceptance by the textile industry, exclusive of the bottom line cost considerations, are as follows:

1) The maintenance, reliability and replacement aspects of solar hardware appear compatible with industry expectancies and industry practices for its existing heat exchangers, etc. The pending ERDA demonstration projects will be valuable in developing data in these areas and will determine the degree to which optical characteristics must be monitored by the textile industry in candidate applications and the amount of washing, cleaning, etc. that must be done on the systems. This area of optical awareness is the only area identified as being unique to solar hardware as compared to existing industry procedures. Energy balances; temperature, pressure, and mass flow measurement; chemical analysis; etc. are all current industry activities and therefore should not effect the solar hardware acceptance by the textile industry.

2) The impact of solar hardware on labor and manpower in the textile industry does not appear to be significant. Technician capability is at a satisfactory level to handle solar hardware, and appears to be a factor in the number of technicians required, but does not require a change in skill level. Obviously training sessions, etc. would be required to orient service personnel, but this is normal procedure in the industry for all new equipment and no uniqueness associated with solar servicing is apparent.

3) The problems of freezing and overtemping in stagnant collectors appear no more significant in the textile industry than in any other application except that required areas appear to negate placement of extensive systems on roof areas. Previous discussions indicated that available area was not a concern to many textile plants in that they already possess surrounding land areas to accomodate the solar farm. However, the draining of stagnant systems at ground level, as opposed to roof-top installations, must be considered in the textile applications, just as in all other large area applications.

4) The impact on energy suppliers, labor and the environment were other factors addressed in the program statement of work. Obviously no negative impacts are projected on energy suppliers in today's crisis. The labor increases are not significant and therefore, represent no discernable problem. The environment issue similarly does not appear significant either from a degradation or "sun-rights" question due to the typical availability of land surrounding textile plants as was previously discussed.

In summary, no significant constraints were identified which would restrict the acceptability of solar hardware by the textile industry if the energy from these systems becomes cost competitive with alternate sources.

VIII. RESULTS AND CONCLUSIONS

The significant findings of the study have been introduced and developed in the previous sections of this report. The most important result is the development of the data itself which will serve as source information for textile firms considering solar installations and as target information for solar hardware manufacturers desiring to interface with the textile industry. However, several specific conclusions can be drawn from the data. The conclusions considered significant are:

1) In the short term, (3-8 years), solar hardware in the 200°F to 280°F capability level will have maximum applicability since process temperatures may not yet be changed by new technology. Waste heat from high temperature drying operations will likely cover the low temperature water demands and will also influence collector inlet temperatures and efficiencies.

2) No technical constraints appear to exist relative to supplying textile process water from solar farms. The technical improvements that might be made in efficiency, coatings, etc. appear minor in impact compared to the raw cost reductions required.

3) The textile industry appears receptive to process water generation from solar means if cost factors become favorable. It appears that textile industry economic trade-offs will require that solar water systems capable of $\approx 200^{\circ}\text{F}$ process water delivery temperatures at rates of ≈ 1 gallon/ft²/day be obtainable at \$7.50-\$8.00/ft² installed cost to compete with coal or oil sources for any foreseeable energy price increase scenario. These costs are based upon the general efficiency levels implied in the collector test data used as a basis for all further developments (Figure 10).

4) Flat plate systems interfacing with the aforementioned heat recovery capability (120°F) and 200°F process temperature requirements, do not look promising for textile operations unless efficiency factors could be increased by a factor of 3x. Ten-to-fifteen percent efficiency improvements do not appear to produce competitiveness.

5) As required process temperature levels change due to technology developments, it is anticipated that three temperature level systems will evolve, ie. 140°F, 200°F and 260°F. Since cost optimum systems for these three levels are probably not of one collector type, it is recommended that ERDA begin a design effort to develop the optimum collector type for these three levels of process water temperature. It is strongly recommended that an objective function of usable Btu/yr ft² PROBABLE INSTALLED COST be the overriding variable in funding decisions for the three levels. Life cycle costing is required in the probable cost figure. If ERDA does not specify the temperature target level for which the collector will be optimized, no optimum will necessarily result at any level and cost competitiveness may not be achieved for any textile application. Technical improvements in η , life, etc. should be measured against this criteria, just as cost reductions are viewed.

6) Target values for solar hardware manufacturers should be established at approximately 70% of the current energy use rates presented in Chapter III. Industry conservation programs should achieve this level within two to five years. Process temperature changes will require more detailed study and experience to demonstrate acceptable quality control levels to the industry prior to adoption and will be somewhat slower to result than water quantity changes. However, it is imperative that wherever possible the textile process temperatures be lowered to interface with

the maximum number of energy sources, whether solar or otherwise. A strong technology program in this area does not exist but is needed.

7) The capital, labor and environment issues all appear to promote the quick acceptance of solar process water heating by the textile industry if the cost effectiveness of the candidate systems can be established.

8) Analysis indicates that an investment tax credit modification to stimulate solar hardware acceptability in textile applications would have very slight effects upon its acceptance since levels up to 15% changed the economics only slightly. However, a companion analysis did indicate that the establishment of a leasing mechanism in lieu of system purchase could have an approximate \$2.00/ft² impact in improving the cost competitiveness of solar water heating systems.

9) The demonstration efforts planned by ERDA to include textile process water are needed to determine realistic maintenance costs, system degradation with time, unnecessary system components, etc. Care must be taken in the textile applications to insure the distinction between demonstration and implied economic viability so as not to jeopardize future prospects for large scale acceptability of solar process water heating when cost factors are reduced to competitive levels.

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