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FEASIBILITY EVALUATION: SOLAR HEATED TEXTILE PROCESS WATER

Semiannual Progress Report, July 1975—February 1976

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College of Engineering
Clemson University
Clemson, South Carolina

MASTER

U.S. Department of Energy

Solar Energy

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FEASIBILITY EVALUATION

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Semi-Annual

Progress Report for the
Period July 1975-February 1976

College of Engineering
Clemson University
Clemson, South Carolina 29631

Approved: _____

J. Charles Hester
Project Director

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SUMMARY

Major progress has been made this period in terms of collaboration with textile firms, user needs, and dissemination of results. Software for facilitating the design of potential systems has reached an intermediate stage of development. The cost environment has been probed and is being systematically documented. Long-term economic impact programs are in the advanced stage of development. Areas of future effort have been prescribed.

PURPOSE AND SCOPE

The purpose of this report is to describe the activities of this project for its first semi-annual period. Future efforts will also be discussed.

INTRODUCTION

Background

The industrial community consumes almost half of the total energy used in the United States, and process heat accounts for well over half of this amount. It appears that solar energy would be a potentially profitable substitute for fossil fuels in some industries. In South Carolina much of the industrial use of energy is in the textile industry.

Objectives

The general objectives of this study are to determine the technical and economic feasibility of the use of solar energy for heating waters in

the textile industry and to develop a plan for efforts beyond this feasibility study phase. Specific objectives include (1) determine the industry requirements for heated process water, (2) assess particular schemes and their economic impact, (3) study the total cost environment for solar water heating in this industry, (4) and recommend future experiments. These objectives are guiding all efforts on this project to date.

Semi-Annual Progress

The efforts in the first phase of this project were directed toward the establishment of communications with the industry and the initiation of soft-ware design packages. On September 22-26, 1975 Clemson University project personnel met with the officers of local textile firms. As the result of these meetings Deering Milliken and Dan River agreed to provide plant data and personnel to assist in gathering information required to design appropriate solar heating systems for textile facilities. The attending parties felt that low temperature applications (approximately 140-160°) seems to be the area to pursue. Cold water make-up to boilers, topping of recovered hot water, and all open atmosphere dyeing machines are particular areas favored because they have large water usage at suitable temperatures which are appropriate to solar systems and because they represent large segments of the industry. In late October two plants, located in Pendleton, SC (a large, modern piece dyeing and finishing plant) and in Greenville, SC (a medium-sized carpet dyeing and finishing plant) were selected for detailed examination. Simultaneously, as these detailed examinations were taking place, other project members began construction of the collector simulator, piping simulator, and weather routines which would be used to assist in defining potential solar

water heating systems. Similarly, an economic impact program was being prepared which would help to determine long-range cost for the systems designed.

Progress in the last quarter, December through February inclusive, is measured by the (1) systematic execution of field research, (2) software development, and (3) a parallel study of hardware, installation, and maintenance costs of solar systems. Detailed study of the Pendleton plant is continuing. Of great importance have been discussions on ways energy management might be affected within the plant. Similar investigations have been initiated at the Greenville plant. Progress in the software systems is manifested by the creation of a general system simulator. This system takes as inputs the energy requirements of the plant and the desired output of a given collector and exposes these constrictions to a weather routine. After iterating around this loop, which also includes some engineering judgment, the specific number of collectors required to meet the energy demands is printed out along with a recommended piping configuration and associated parts list. The economic impact simulator has reached a level of maturity also. Upon imputing a given solar system cost profile, the simulator determines the tax, depreciation, and discount effects on cash flow for each year of operation. The parallel cost study involves a rigorous survey of current suppliers of solar equipment and initial investigations into installation and maintenance cost for such systems. Future effort will be directed toward progress in each of the three areas described above.

UTILIZATION OF PROJECT RESULTS

Collaboration with Potential Users

There has been extensive collaboration between potential industrial users and project personnel this reporting period. In a meeting at Deering Milliken Research Corporation on September 22, project personnel and industry officers discussed temperatures of solar systems, particular process applications, and selection of a plant for basic data collection. Initial industrial reaction preferred high temperatures (300-400°F) as opposed to the low temperature (160°F) application being recommended by Clemson University. We believed, and they concurred, that this lower temperature range utilized equipment believed to be most economically feasible. There would not be the added expense and cost of handling steam. Lower skill level personnel for installation, operation and maintenance could be utilized. It was agreed that dyeing, printing and finishing processes were good candidate processes at these temperatures. Large amounts of hot water are used for these purposes. Application to dyeing operations appeared especially attractive. Several plants employing these processes were suggested for data collection, including the polyester finishing plant at Pendleton which was subsequently selected by Clemson University for detailed study.

A similar meeting was held at Clemson University on September 26. Present at this gathering were officers of the Deering Milliken Research Corporation and Springs Mills Research and Development. It was the objective of this meeting to investigate other areas in the textile industry that would be appropriate for solar energy heating systems. The industry people evidenced a questioning attitude toward the economics associated with this technology.

They were assured that our objective was not to "sell" solar heating but to evaluate it. This subtle point made a significant difference to the industrial community. After further discussions of possibilities it was concluded that open dyers, boiler make-up, and selected process (e.g. washers) would also be potential applications. Candidate plants for basic data collection were discussed and a list developed, including Wunda Weve Carpets which was subsequently selected as a second plant for data collection.

There have been follow-up communications throughout the report period relating to the collaborations described above. Meetings with American Textile Manufacturers' Institute personnel and South Carolina Textile Manufacturers Association people have been held. Specific information on quantities of water used for certain plants was obtained. Boiler make-up involves from 6000 gallons to 150,000 gallons of water per week, depending on plant size. This application, with its significant heat load, promises to be a good starting point for solar analysis because it would be applicable to most, if not all, plants. Here heating would be limited by the economics of solar energy and not by specific process requirements.

Future collaboration with potential users of solar heating of process water will be required. Joint evaluation of candidate systems proposed by Clemson University will be necessary. Also, coordinated efforts for defining interface components between proposed and existing systems must be accomplished.

Investigation of User Needs

In order to ascertain user needs the Pendleton and Greenville plants have been visited frequently. A detailed study of the energy, water and fuel usage in these plants is being made.

A computer model of energy and water flow in the Pendleton plant is developing. This program uses temperature and mass data collected from the site. It is intended to provide the opportunity for optimizing energy management within the plant.

For the plant in Pendleton the ambient water supply is surface water. The cold water system receives water in the temperature range from 37°F to 60°F, depending upon the season. It is distributed to areas of the plant as follows:

- (1) to the chlorimeter
- (2) make-up to the hot water system
- (3) cold water to dyehouses to be heated in the process
- (4) to the boiler house
- (5) to washers
- (6) miscellaneous uses.

The hot water system accepts reclaimed hot water from processes in the plant. It is mixed with cold make-up water. A steam heat exchanger maintains the hot water storage system at 110-120°F. Higher temperature water is distributed from the boiler to various processes.

After supplying the processes with heated water from the boiler, the hot system reclaims water from certain of the processes. This water, reduced in temperature, returns to the hot water storage where it is reheated and used again. Thus, both boiler make-up water and topping of the 110-120°F hot water system can be considered for solar heating.

Energy routing in the plant follows a general path from boiler to HWS to processes and finally to the stacks and sewer. As indicated, there is recycling of some heated water and there is energy supplied at locations

other than the boiler. This additional heat is from gas fired sources in certain processes. The simplified drawing below shows the energy routing.

Figure 1. Energy routing in the piece dyeing and finishing plant in Pendleton.

Both the quantity of fuel consumed by this plant and the cost of relevant sources have been investigated. This plant uses both natural gas (for processes) and oil (for boiler).

The plant in Greenville is undergoing initial inspections similar to the Pendleton plant described above. Conferences with plant engineers have been conducted, and preliminary data have been gathered. An energy balance will be developed for the entire plant shortly. See the simplified drawing on the following page for energy routing in this installation.

Figure 2. Energy routing in the carpet finishing and dyeing plant in Greenville.

Energy and water mass losses occur in several places typical to this industry. Energy loss is in the form of heat vented from boiler and process stacks. Heat is lost to the processes themselves, to the plant environment and to the sewer. There is also associated water losses in the form of vapor and wastewater.

Dissemination of Project Results

A continuing investigation of the physical plant and the associated interaction with company personnel has fostered a closer understanding of the energy problems and needs of these firms. Prompt dissemination of data to plant personnel has been a continuous policy. On occasion faulty meters or

other control devices have been discovered and reported to maintenance personnel. Correction of these problems improves data collection; this in turn allows better plant management and ultimately a more accurate total energy and mass balance for the entire system results. Reclamation of heat from certain areas of the total thermal systems (e.g. hot wastewater) of the plants are being addressed. However, the most important contribution of Clemson University's interaction with these firms to date is the improved, computerized daily energy and mass balance now achievable. Communication with plant personnel investigation of needs, and dissemination of the results of the project will continue on a real-time basis for the duration of this study. Dissemination of this information to the entire industry will be an important facet of this study.

Effects on Future Course of Action

Collaboration with plant personnel, investigation of user needs, and dissemination of useful information to the plant has affected the course of this project by helping to focus more clearly on the unique energy requirements of the textile industry. Future efforts will include the logical continuation of these activities at the Pendleton plant and development of efforts at the plant in Greenville. Also, Clemson University will pursue the evaluation of the daily balance programs to a higher degree of accuracy.

DESIGN OF POTENTIAL SYSTEMS

General

To design an appropriate solar water heating system several considerations must be made. The (1) user requirements must be determined, a (2) variety

of mechanical and environmental constraints must be identified, and (3) a collector system meeting these specifications must be selected from a population of candidates. The economic impact of the system chosen may suggest recycling around the loop again. After several iterations a potential system may emerge. A computer program is being developed that will assist in performing step (2) described in the preceding paragraph.

When fully developed, the program will compare user needs and a specified collector. It will subject this comparison to a desired climatic environment. Finally, it will evolve a piping system and parts list. A schematic of this routine is shown in Appendix A.

Piping Simulator

This program describes a flow distribution to supply the collectors. It provides a parts list of fittings and specifies the hydraulic horsepower needed for the complete system. Parallel-series is the basic plumbing configuration assumed for this simulator. The number of parallel legs in the flow circuit is a function of the total mass flow rate and the maximum mass flow rate allowable for the particular collector being plumbed. Head loss for fittings, pipes and other items of the piping system are computed using the Darcy-Weisbach relation:

$$h_L = f \frac{L}{D} \frac{V^2}{2g}$$

where: h_L = head loss

L = length of pipe sections or the equivalent length in the case of fittings

D = diameter of pipe or fitting

V = velocity of fluid

g = gravitational constant.

To begin the piping program, default values for the head loss in each parallel leg are entered by the program. The simulator converges upon the proper head loss for each leg. The number of components and the geometry of the piping system are manipulated to obtain the proper head loss.

A feature of this program is the energy balance equation:

$$\frac{Q}{A} = C_p \frac{\dot{m} Tr}{A}$$

where:

Q = heat (but/hr)

A = area of collector

C_p = heat capacity

$\dot{m}$ = mass flow rate

Tr = temperature rise.

This allows the user to read in any two of the factors, $\dot{m}$, Tr or A, and the program will compute the third. This aspect allows flexibility in the application of the simulator. For example, a firm may be concerned with total area (cost) and flow rate (to be compatible with a process) but not so concerned with temperature rise because the solar water heating system is intended to complement his conventional heating system. Further development of the mechanical simulators will continue. See Appendix B for simplified flow diagram.

Collector Simulator

Presently this program has three modes of operation. It will simulate flat plate performance, it will simulate concentrator performance, and it will simulate "efficiency" performance. Efficiency mode is based on performance curves of any commercially available collector. Three data points from each of three efficiency curves are required. The efficiency curve comes from a

percent efficiency vs $\Delta T(T_{\text{air}} - T_{\text{inlet}})$ graph. There is a unique curve for each value of the flux parameter. Typically, manufacturers provide curves for 100, 200 300 btu/ft² per hour. This collector simulator requires as inputs a flow rate, required temperature rise, and system inlet temperature. It provides as output the required collector absorbing area to accomplish the temperature rise. This program simulates collector performance while under the influence of a weather program described below. Further development of the collector simulator will continue into the next quarter. See Appendix C.

Weather Routine

Solar flux, temperature, and wind speed are required inputs for the collector simulator. Flux data can be obtained from (1) solar tapes from a limited number of locations, (2) weather tapes from several locations, and (3) simulators using those weather tapes obtainable from many locations (e.g. airports, military bases).

The weather routine presently being used by this group is a combination of the easily available weather tapes and a routine "Sun and Cloud Cover Modified" from NBSLD. The temperature and wind outputs are actual recorded weather data from Charleston and the flux output is calculated data. As a check on this calculated flux, comparisons can be made with actual recorded flux information from the Charleston solar tape and other "standard" sources.

COST ANALYSIS

Cost and System Survey

Evaluation of solar system cost is proceeding on two fronts: initial capital expense and long-term cost are being studied.

A comprehensive survey of solar equipment producers is underway. Vendors are being contacted continuously. A library of pamphlets, specifications, and designs is being assembled. Also, the relevant data on each collector is being catalogued. This listing of specifications can be used to select the most appropriate product for a given industrial need. For example, one can narrow the choices by first scanning for low-cost units. This population of contenders is filtered further by progressively eliminating collectors of unacceptable material, tube size, etc. until the catalogue defines the most appropriate models on the market. Subsequently, the library of brochures could be consulted for further information. In addition to a market survey information on existing systems is being assembled.

Cost Models

An economic analysis of solar energy systems is underway. Concepts applying solar energy to the textile industry are the focus of this study. A search for existing cost models proved unfruitful. After identifying relevant cost elements, two cost models were formulated. Computer programs COSM01 and COSM02 were prepared to implement the models.

COSM01 reads in the specification of a given solar water heating system and related costs as inputs. Following is a list of these inputs:

- (1) use life of collector
- (2) number of different parts
- (3) quantity of collectors
- (4) maintenance skill levels required
- (5) anticipated failure rate
- (6) operating time

- (7) cost of collector components
- (8) cost of storing materials
- (9) cost of installation
- (10) repair time, labor costs
- (11) average annual quantity of fuel saved
- (12) salvage value

The program operates on this information and computes the following description parameters for both a before-tax and after-tax analysis:

- (1) Venture worth (undiscounted)
- (2) Venture worth (discounted)
- (3) Rate of return
- (4) Payback period (undiscounted)
- (5) Payback period (discounted)

This model is based on best available cost data and educated guesses. The major difficulty with this system is obtaining reliable cost data. See Appendix D.

COSMOS2 is a program which parameterizes on installed collector cost per unit area and attempts to avoid the uncertainties in cost prediction. It determines at what cost an appropriate solar design is economically viable. Specifically, this program determines the collector cost at which a minimum attractive after-tax rate of return is provided. COSMOS2 allows an "after-tax rate-of-return" versus "collector cost" graphical display. See Appendix D.

Future Efforts

The solar energy cost environment is being probed and future activity will broaden this effort. Information on current vendors and products will continue to accumulate. The programs to model long term cost will evolve further

and functioning systems will be investigated. The process of gathering vendor data will continue, the economic simulators will be applied to candidate solar energy systems. Further, inspections of existing systems and evaluation of their actual performance will be conducted in an effort to validate manufacturers' claims of performance. For the cost models, equipment component reliabilities will be investigated. Analysis and documentation of methods for modeling will continue. Finally, for COSMOS2 a number of textile firms will be polled to determine the minimum attractive after-tax rate-of-return that is acceptable.

CONCLUSION

Progress

Progress in this reporting period has been significant. There has been a continuing dialogue between members of this project and the textile firms selected for detailed study. The needs of these firms have been studied in the field. On many occasions there has been dissemination of useful information to the plants.

Designing of simulator systems has reached an intermediate level of development. The cost environment has been probed and a system for managing this information has been initiated.

Future Efforts

In the immediate future, effort will continue in the "user needs" area, simulator, and cost analysis. More specifically, collaboration on candidate systems and interface must be accomplished with the textile firms. The

energy balance program must be completed at a number of candidate locations. The simulators need completion and more efficient interfacing between programs. The cost study must proceed into such areas as installation, maintenance, reliability, and repair costs.

APPENDIX A

Piping and Collector Simulator Interaction Diagram

APPENDIX B

Piping Simulator -- Simplified Block Diagram

FLOW MODE

Controlled Flow

Equal Flow

APPENDIX C

Collector Simulator -- Simplified Block Diagram

DESIGN PARAMETERS

(Abridged List)

- (1) Radiative, heat transfers, and thermal properties⁽¹¹⁾ of materials of construction and working fluid
- (2) Pertinent dimensions (8 variables)
- (3) Assumed temperature for beginning iterations (arbitrary)⁽⁵⁾
- (4) Performance data T_{inlet} , T_{rise} , flow rate, area, mode of operation flux, specific heat at constant pressure of working fluids, number of collectors in the given leg ⁽²⁴⁾
- (5) If temp ramp--read ramp
- (6) Whether or not there is a temp ramp
- (7) Decision variables: efficiency collector flat plate, concentrator
- (8) Hour of analysis

APPENDIX D

COSMOS1--Simplified Block Diagram

COSMOS2--Simplified Block Diagram

COSM01 Subroutines

<u>Subroutine</u>	<u>Function</u>
EST	Computer elements of initial cost (collector material, distribution, storage, installation) and annual costs (repair parts, maintenance labor, operating cost).
DEPREC	Schedules annual depreciation amounts using Double-Declining-Balance and Sum-of-Years-Digits Methods and selects best schedule.
ITC	Schedules Investment Tax Credit in accordance with current tax law.
CASHFL	Constructs Before and After Tax Cash Flows and computes their undiscounted venture worths.
DISCNT	Computes discounted Venture Worth from a specified cash flow (before or after tax).
ROR	Computes (iteratively) Rate-of-Return implicit in a specified cash flow.
PBACK1	Computes undiscounted Payback Period for a specified cash flow.
PBACK2	Computes discounted Payback Period for a specified cash flow.
PUTOUT	Writes analysis results (undiscounted and discounted Venture Worth, Rate of Return, and undiscounted and discounted Payback Period) for a specified set (before or after tax).

Subroutines Peculiar to COSM02

<u>Subroutine</u>	<u>Function</u>
ATCFL	Constructs after-tax cash flow and its undiscounted venture worth.
PROUT	Writes elements of annual costs and the before and after tax cash flows.