

**STUDIES IN THE
USE OF SOLAR ENERGY IN
PREPARATION OF COTTON AND SILK FABRICS**

by
SANJAY GUPTA

A thesis submitted to the
Indian Institute of Technology, Delhi
for the award of the degree of

DOCTOR OF PHILOSOPHY

**Department of Textile Technology
INDIAN INSTITUTE OF TECHNOLOGY, DELHI**

November, 1989

To Kamlesh Gupta

My inspiration

My strength

My weakness

My mother

Certificate

This is to certify that the thesis entitled "*Studies in the Use of Solar Energy in Preparation of Cotton and Silk Fabrics*" being submitted by Mr. Sanjay Gupta to the Indian Institute of Technology, Delhi for the award of the degree of Doctor of Philosophy is a record of bonafide research work carried out by him under my guidance and supervision.

To the best of my knowledge this thesis has reached the required standard. The material presented in this thesis, in part or full has not been submitted to any other University or any other Institute for the award of degree or diploma.



M.L. Gulrajani

Professor

Department of Textile Technology
Indian Institute of Technology, Delhi
New Delhi-110016.

Acknowledgements

I wish to thank a number of people for their support and contribution to the effort involved in completion of this onerous task.

I owe the reality of this dissertation to my research adviser Prof. M.L. Gulrajani, whose personal attention and encouragement have helped me put in this final form, all the work done in the past four years under his fraternal guidance. My association with him has been a profoundly rewarding experience, something that was creative, fulfilling and free of fear. I, sincerely, express my thanks to Mohan Gulrajani.

To Mr. Arun Garodia, Executive Director, M/s East India Cotton Mfg. Co. Ltd. for his generous, enthusiastic cooperation in carrying out experimental studies at the mill; and to his managers Mr. Bhatia, Mr. Maheshwari, Mr. Bhandari and Mr. Mishra.

To Mr. S.K. Gupta, PSO, Solar Energy Centre, DNES, Govt. of India, for his contagious enthusiasm and technical support; to Dr. Raman, and Dr. Tripathi, DNES for financial assistance; to Munish Mathur of SEDCO (Solar Energy Devices Co. Ltd.) for his help in system design.

To the Technical and Administrative staff of Textile Department who were by my side, whenever called upon; to staff of Weaving Lab., Textile Testing Lab and SEM Lab; to Mr. V.A. Passi, Mr. Rajindra Prasad, Mr. ShivCharan, Mr. Prakash Chand, Jagdish and Suresh of Textile Chemistry Lab; to Mr. Rajesh Arora, Mr. K.G. Padam and Mr. Didar Mal.

To my friend, my colleagues and my fellow workers for their whole hearted support.

And finally to my family, who were always beside me, despite my eccentricities and idiosyncracies.

I thank all these fine people.



(Sanjay Gupta)

ABSTRACT

Textile processing involves a highly energy intensive set of processes consuming 60-80% of the total energy consumed by the textile industry. The preparatory processes i.e., desizing, scouring and bleaching account for nearly 20-25% of this share. The low grade heat required for these processes is produced using high grade fuels like coal and oil leading to high wastages, as conversion efficiencies are only 2-4%. Search is on for an alternate source of energy to provide this low grade heat, which will not only result in more efficient utilization of energy but will also save the precious high grade fuels.

Such a source is available in the form of solar thermal energy. Flat plate collectors, solar hot boxes and simple concentrators available today, commercially, have the potential to provide the low grade heat needed for textile wet processing. During the last decade few attempts have been made to tap this perennial source of energy for use in textile industry.

In the field of preparatory processes also, recent advances have made possible the combining of two or more processes. These single stage or two stage preparatory processes are flexible in terms of chemical concentrations, treatment time and temperatures. This means the fabric is not damaged even under adverse treatment conditions. The preparatory treatment for silk is called degumming whereby sericin is removed from the fibroin. A large number of degumming agents are being used all over the world, and the treatment conditions are almost similar. 1-2 hours at 95°C, depending on the grade of silk.

This thesis is an attempt to integrate the two technologies, to device solar thermal systems suitable for single and/or two stage preparatory processes for cotton and for degumming of silk; to study the performance of solar systems and the properties of the fabrics processed in them with respect to conventionally prepared fabrics; and to optimise the treatment conditions.

A solar *hot-box* type collector with double glazing and a booster mirror, termed *solar oven* was used for the experiments. The hot-box of the oven has been used for storing the samples padded in a chemical formulation meant to give combined Desizing and Scouring. Fabrics padded in the liquor were sealed inside a transparent, Polypropylene

bag and stored in the oven for 3 hours.

Two sets of fabric were tested. One during the winter period when the oven temperature was less than 100°C and second during the summers when the temperature was higher. Fabrics were tested for absorbency, strength loss and whiteness. All properties were comparable to that of the conventionally prepared one when the temperatures were less than 100°C. Temperatures above 100°C affected the whiteness adversely.

A pad-batch process was used for single stage desizing, scouring and bleaching of cotton fabrics in the solar oven. A self emulsifiable solvent based scouring agent was used along with H₂O₂ for this purpose. An attempt was made to analyse the solar oven for heat transfer coefficients which were used along with other variables to develop the performance equation of the oven. Performance equation was used to predict fabric temperature.

A regression analysis was carried out to determine the relationship between the process variables i.e., time, temperature of treatment and bleaching agent concentration. The results were used to optimise the treatment conditions.

Temperature of the solar oven varies with the incoming solar radiation. Hence it is not possible to measure the kinetics of peroxide consumption. However, it is instructive to determine the average rate on days when the temperature in the oven varies the least. Therefore, average rate of decomposition of peroxide has also been calculated.

A conventional kier was modified and integrated with a *solar hot water system*. The resultant machine was called as *solar kier*. Elements of fluid mechanics and heat transfer were used to design the storage tank and heat exchanger for the solar system. Number of collectors required to supply the desired energy were calculated for all the months in a year and the maximum number were taken. The system passed through several developmental stages during which the heat exchanger and kier vessel were modified.

Some 28 batches were processed in the kier using the self emulsifiable solvent based scouring agent and hydrogen peroxide. Samples were tested for strength loss, absorbency and whiteness; and optimum treatment conditions worked out. Eleven batches were then processed under the optimised treatment conditions.

Cost of the process as compared to conventional 3-stage process and low temperature single stage process have been worked out. The fabric processed in the solar kier shows lower processing cost.

The 20 kg solar kier was scaled up to a capacity of 100-125 kg. Heat exchanger length and number of solar collectors required were calculated as before.

The system was set up in a local processing unit (East India Cotton Mills, Faridabad, India) and semi-commercial trials were taken on various qualities of fabric and thread. The kier was found to be suitable for processing of yarns, threads and fabrics as well.

In the solar kier, although conventional thermal energy was completely replaced by solar thermal energy, electrical energy was still used to drive two pumps. For silk degumming a *thermosiphon* system was envisaged that works independent of any form of conventional energy.

A recipe based on carbonate - bicarbonate buffer was used to degum Mushirdabad silk. To estimate weight loss a calibration curve was prepared by making standard samples and staining them with a direct dye. K/S values were plotted against the weight loss to give the calibration curve. Also estimated were the strength (in warp and weft direction) whiteness and yellowness indices. The properties of these samples were compared with the samples prepared using commercial degumming agents like Marsaille soap, Japanese soap and an Italian product called Sapojet seta.

It was found that when solar insolation is weak (like in winters) a booster mirror is required to provide the necessary temperatures in the degumming vessel. Degumming is inadequate below 90°C. Treatment time of 2-3 h is sufficient to achieve satisfactory results.

CONTENTS

ABSTRACT

1.	INTRODUCTION AND REVIEW OF LITERATURE	1
1A.	Introduction to Preparatory Processes	2
1A.1	Cotton:its impurities and their removal	3
1A.2	Combined preparatory processes	5
	Two stage preparation	
	Single stage preparation of cotton fabrics	
1A.3	Low temperature preparation	9
1B.	Introduction to Solar Energy and Solar Energy Systems	11
1B.1	Solar energy availability	12
1B.2	Components of radiation	13
1B.3	Earth-Sun relationship	14
1B.4	Direction of beam radiation	14
1B.5	Solar radiation on a tilted surface	18
1B.6	Measurement of Solar radiation	19
1B.7	Terminology of solar energy and collector classification	21
	Collector classification	
1B.8	Selected topics in fluid flow, heat transfer and optics	23
	Heat transfer	
	Properties of transparent materials	
1B.9	Solar energy applications	36
	Solar water heating	
	Space heating and cooling	
	Electricity from solar energy-photovoltaics	
	Solar thermal power	
	Solar ovens or hot boxes	
1B.10	Solar Energy Applications in Textiles	38
	Case studies	
	Solar energy in India	

	OBJECTIVES OF THE PRESENT STUDY	46
2.	SOLAR OVEN	47
2A.	Combined desizing and scouring of cotton	49
2A.1	Experimental	49
	Fabric	
	Fabric treatment	
	Preparation of conventional samples	
	Fabrics testing	
2A.2	Results and Discussion	52
	Weight loss, strength and wettability	
	Whiteness index	
2A.3	Conclusions	55
2B	Combined Desizing, Scouring and Bleaching of Cotton	55
2B.1	Experimental	56
	Fabric	
	Fabric treatment	
	Conventional samples	
	Fabric testing	
2B.2	Heat transfer coefficients and efficiency of solar oven	57
2B.3	Development of performance equation for the solar oven	59
2B.4	Results and Discussion	61
	Whiteness index	
	Wetting time	
	Kinetics of H ₂ O ₂ consumption	
2B.5	Optimisation	67
2B.6	Conclusions	67
3.	SOLAR KIER	69
3A.	Design, Development and Performance of 20 kg Solar Kier	69
3A.1	Design of solar kier	70
	SHWS design	
	Storage tank and heat exchanger	

	Kier vessel	
3A.2	Experimental -----	75
	Fabric and its treatment	
	Fabric testing	
	Preparation of conventional samples	
3A.3	Results and Discussion -----	76
	Strength and wettability	
	Whiteness index	
	Optimised process conditions	
3A.4	Process Economics -----	78
3A.5	Conclusions -----	79
3B.	Design and Performance of Scaled Up (100 kg) Solar Kier -----	81
3B.1	Design -----	81
3B.2	Experimental -----	81
	Fabric	
	Threads	
3B.3	Results and Discussion -----	86
	Fabric	
	Threads	
3B.4	Conclusions -----	89
4.	INTRODUCTION AND REVIEW OF LITERATURE ON SILK DEGUMMING -----	90
4.1	Sericin -----	90
4.2	Methods of Degumming -----	92
	Extraction with water	
	Treatment with alkali	
	Digestion with enzyme	
4.3	Degumming of Silk Cocoons -----	99
4.4	Degumming of Raw Silk -----	100
	Degumming with soap solution	
	Degumming machines and processes	
4.5	Degumming of Waste Silk -----	103
4.6	Degumming of Silk Fabrics -----	104

4.7	Assessing the Effectiveness of Degumming	108
5.	DESIGN AND PERFORMANCE OF SOLAR DEGUMMING MACHINE	110
5.1	Thermosiphon Systems	110
	Design of thermosiphon based machine	
5.2	Experimental	112
	Fabrics	
	Fabric treatment	
	Fabric testing	
5.3	Results and Discussion	116
	Extent of degumming	
	Damage to the fabric	
5.4	Conclusions	121
6.	CONCLUSIONS	122
	REFERENCES	125
	ANNEXURES	131
	LIST OF PUBLICATIONS	142