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UTILIZATION POTENTIAL OF SOLAR ENERGY IN THE INDIAN SILK INDUSTRY

SANJAY GUPTA†

Textile Technology Department, Indian Institute of Technology, Hauz Khas, New Delhi-110 016, India

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Abstract—A case is made for the use of solar energy in meeting the energy requirements of the silk production and processing industry of India. The paper briefly reviews the energy requirements of the silk industry and identifies the potential areas existing therein for the application of solar energy. Experiments carried out in this area at the Textile Department of the Indian Institute of Technology, Delhi, are described.

Silk reeling Silk dyeing Silk degumming Cocoon cooking Silk processing Print curing Utilization potential in silk industry Silkworm rearing Cocoon dryer Thermosyphon Circular trough concentrator Passive cooling

INTRODUCTION

The textile industry is among the most energy intensive industries in India, its share being ~9% of the total energy requirement of India. The potential of solar energy utilization in this industry, particularly the cotton processing sector, has been investigated earlier [1]. If cotton is the king, silk is the queen of textile fibres. It occupies a unique position in the world of textiles due to its optimum fibre properties. Production and processing of silk are high potential areas for use of solar energy.

The world demand for silk is increasing, and an estimated 26.3% shortfall in supply is expected against estimated global demand. World silk production in 1990 was about 72,879 tonnes, of which India's share was about 10,905 tonnes [2]. India now ranks second among the mulberry silk producing countries of the world, accounting for 16% of total world raw silk production. India has the unique distinction of producing all commercially known varieties of silk, namely mulberry, tasar, eri and muga. It is the second largest producer of tasar silk and holds the world monopoly in the production of muga.

The silk industry in India is a cottage industry with an agricultural base and a labour-intensive nature. Practised in about 60,000 villages and employing about 6 million people, the industry expects to increase its raw silk production to 15,200 tonnes by 1993–1994.

Sericulture is energy-intensive in all its stages, i.e. silkworm rearing, cocoon drying, cooking and reeling, and the post-cocoon stage processes like degumming, bleaching, dyeing, printing and finishing. Being a cottage industry, located mostly in small villages and towns, the industry depends on fire wood, cow-dung and other biomass for energy needs. Coal is used in a very small quantity. No data is available on the exact energy requirement and consumption pattern of this industry, however, an estimate by the Planning Commission, Government of India, of the quantum of energy supplied by non-commercial energy sources to the industrial sector is given in Table 1. This heavy dependence on fire wood and other agro-residues by the silk industry (and other such industries) has heavily taxed the forest cover and deprived the soil of valuable nutrients and organic conditioning material. This can have serious ecological implications. Shortages and unavailability of fuel wood and other agro-residues causes an increase in fuel costs. This increase, coupled with the limited purchasing power of this large and dispersed industry, compels processors to use lower processing temperatures and time, leading to inferior quality of the finished products. Poor quality

†Present address: Technological Institute of Textiles & Sciences, P.O. Birla Colony, Bhiwani-125 021, Haryana, India.

Table 1. Energy consumption matrix for India by sector and source (in Mtce)

Sector: Source	Domestic	Industry	Transport	Agriculture	Others	Total
Commercial energy	13.8	58.05	36.93	7.43	4.69	120.9
Non-commercial energy	200	50	—	—	—	250.0
Total	213.8	108.05	36.93	7.43	4.69	370.9

of dyed and printed silk goods has a direct bearing on their marketability and export potential. Another characteristic feature of the energy consumption pattern of this industry is the predominance of direct thermal application of low grade heat (as distinct from mechanized or other high grade uses).

Solar energy can prove to be a cheap, low grade, localized source of energy for the silk industry of India. India receives a daily average incidence of solar radiation of 5000 kcal/m^2/day for 8–10 h/day over most of the calendar year [3]. Figure 1 shows the annual mean solar insolation over the various silk producing regions and silk processing centres of India. In this paper, an effort has been made to identify those areas in production and processing of silk where solar energy can effectively substitute for, or supplement, the conventional energy sources used. Experiments carried out at the Textile Department of the Indian Institute of Technology, New Delhi, India, in this field are briefly discussed.

POTENTIAL AREAS FOR SOLAR ENERGY APPLICATION

The various energy consumption points in production and processing of silk material, with potential for solar energy application are given in Table 2 along with the operating temperatures.

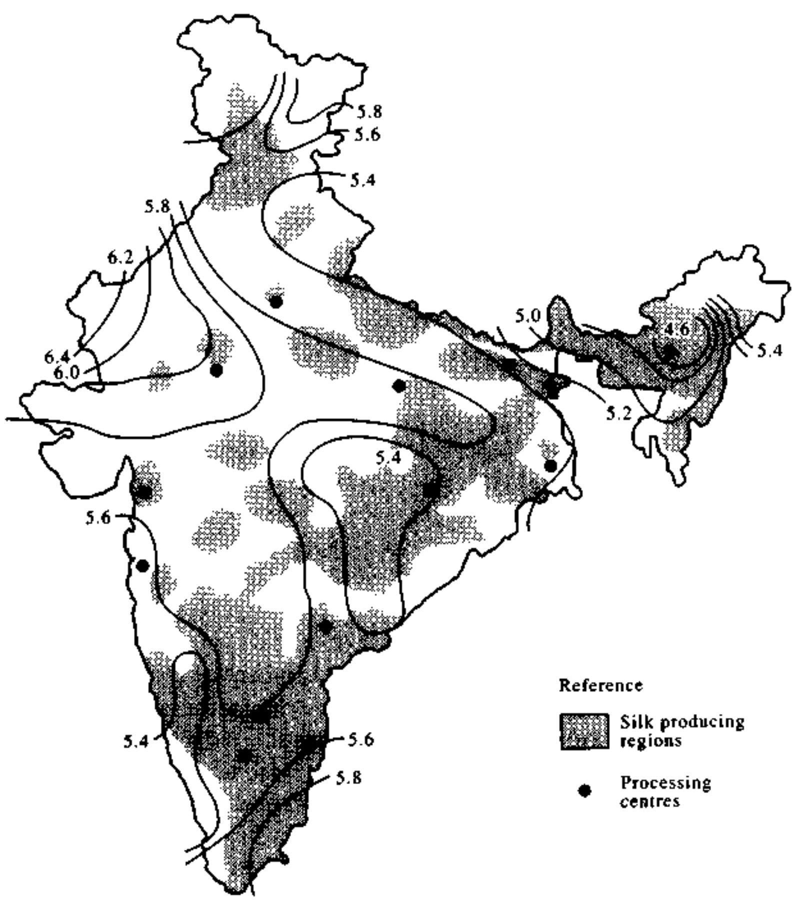

Fig. 1. Annual mean solar radiation over various silk producing regions and silk processing centres of India. Unit: kWh/m^2/day.

Table 2. Various energy consumption points in silk production and processing and the corresponding operational temperature

S. No.	Operation	Temperature (°C)
1	Silkworm rearing room	
	(a) Chawki	27–28
	(b) Old-age	23–25
2	Cocoon drying	
	(a) Sun drying	ambient
	(b) Steam stifling	95–100
	(c) Hot air drying (in stages)	60–95
3	Cooking of cocoons	
	(a) Open pan system	90–95
	(b) Three pan system	65–95
	(c) Pressurized system	75–100
4	Brushing/deflossing	85–90
5	Reeling and re-reeling	40–45
6	Degumming	
	(a) Soap/soap–soda	90–95
	(b) Enzyme (alkalase)	60–70
7	Bleaching	60–90
8	Dyeing	
	(a) Acid/metal complex dyes	85–90
	(b) Reactive dyes	60–70
9	Curing	140–150

The temperatures are within the range of 25–150°C. Such temperatures are easily attained with currently available solar technology in India. Potential solar energy applications for each consumption point are discussed below.

During rearing of silkworms, the temperature and humidity in the rearing room has to be controlled within specified limits. In most of the regions where silkworm rearing is practised, the ambient temperature is much higher than these limits. The economic status of the silk industry does not allow air conditioning or even air cooling to be used. Passive (or natural) cooling of buildings, using different shapes, locations and orientations with respect to the sun, can be of significant help in keeping the rearing rooms cool. Heat enters the building in three major ways: (a) penetration of direct beam sunlight, (b) conduction of heat through walls, roof, etc. and (c) infiltration of outside air [4]. Direct sunlight on the south wall can be controlled by a horizontal projection of appropriate depth (Fig. 2). This will exclude the summer sun while still permitting winter sunlight into the building. The east and west walls can also be protected by suitable shades. Conduction of heat through the walls and roof can be prevented by providing adequate shading and insulation.

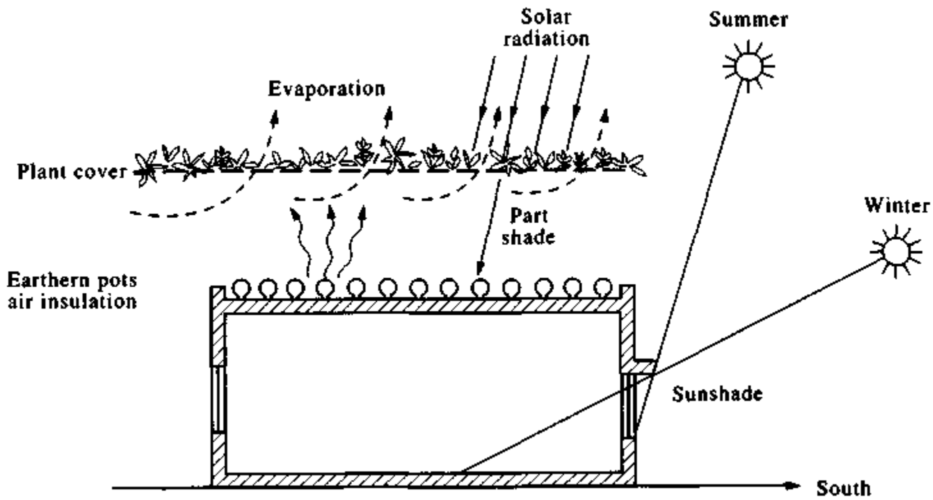

Fig. 2. Options for passive cooling of silkworm rearing building—horizontal projection over south facing windows; roof insulation with earthern pots; and overhanging tree cover.

For example, a cover of overhanging trees (deciduous type) or creepers (Fig. 2) can provide excellent shade during the summer. Such plants will shed their leaves in winter, hence allowing the sunshine to pass through. An excellent roof insulation is provided by covering the entire roof with small, closely packed, inverted, earthen pots (Fig. 2). Frequent whitewashing of the rearing room building from outside can be quite effective, as its reflectivity and emissivity are both quite high. Active systems can also be integrated with these measures for further cooling. One such alternative is to provide a Thermosyphonic Air Panel (TAP) heater on the south wall or roof to take away the hot air from inside [5]. A cool area, such as an alcove of dense trees and shrubs and a wet sand ground, can be provided on the north side to supply cooling air (Fig. 3). Many such options are available in the literature [6, 7]. In cooler regions, passive heating principles may be applied to raise the temperature.

Fresh cocoons contain live pupae. They are, therefore, dried immediately after formation to stifle and kill the pupae and to remove the moisture. Fresh cocoons contain, on average, 68–70% moisture which must be brought down to 10–12%. An extensively practised method is open sun drying, in which the cocoons are thinly spread on mats and exposed to the sun from dawn to dusk. This method gives a distinctly inferior quality silk, as the cocoons are exposed to direct sunlight, dirt, dust, etc. Simple solar dryers, like cabinet dryers and tent dryers (Fig. 4), can speed up this drying process several times and offer protection from dirt and dust. The cocoons, however, will still be exposed to sunlight. A more scientific method is hot air drying in which the cocoons are placed in a tray in a chamber and a hot air current is passed through it. The temperature is increased from 60 to 100°C over a period of 6 h. Natural convection or forced flow shelf-type dryers, shown in Fig. 5, can provide a similar type of service [8].

Silk reeling operations, involving the cooking, brushing, deflossing and reeling of cocoons, and post reeling operations, like degumming, bleaching, dyeing, etc. require water or process liquor to be heated to temperatures ranging between 40 and 95°C. These temperatures can easily be provided by commercially available water heating systems based on flat plate and evacuated tube solar collectors. Machines may be designed on forced flow or thermosyphon principles, or collectors may be retrofitted to existing machines to provide the necessary thermal energy. The modifications required are simple and inexpensive. Other higher efficiency collectors can be used to generate steam for heating purposes. One such system in a silk factory in Mysore, India, uses line focusing collectors to produce process steam at a rate of 100 kg/h and temperature of 150°C [9]. Such collectors are, however, not available in India at present.

Fixation of pigments and metallic powder prints and some resin based finishes on silk are carried out by curing at 140–150°C for a few minutes. With suitable catalysts, the curing temperature can be brought down to 110–125°C [10]. Dry heat, up to 125°C, can be easily made available using solar concentrators (ovens).

In most of the systems described above, no auxiliary conventional energy source is needed, and thus, they can be operated in the remote villages of India which house the silk industry.

EXPERIMENTS CARRIED OUT AT TEXTILE DEPARTMENT, IIT DELHI

A study at this department aims at developing suitable machines and technology for solarizing the production and processing of silk textiles. The research is sponsored by the Department of

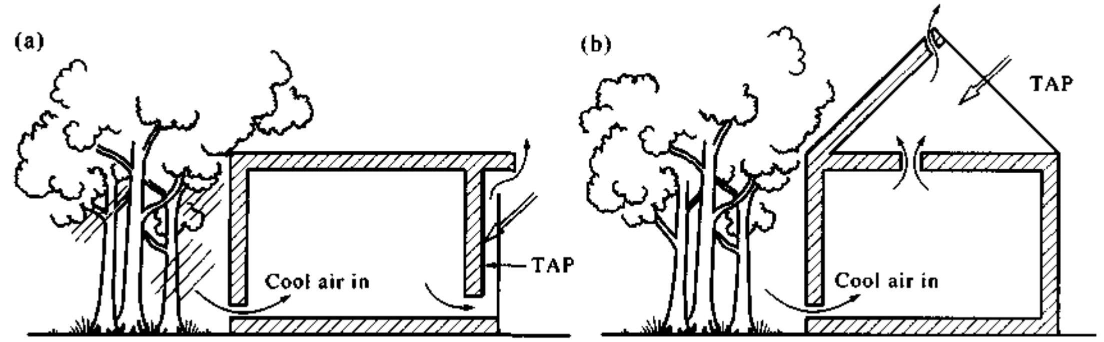

Fig. 3. Active cooling system using Thermosyphonic Air Panel (TAP).

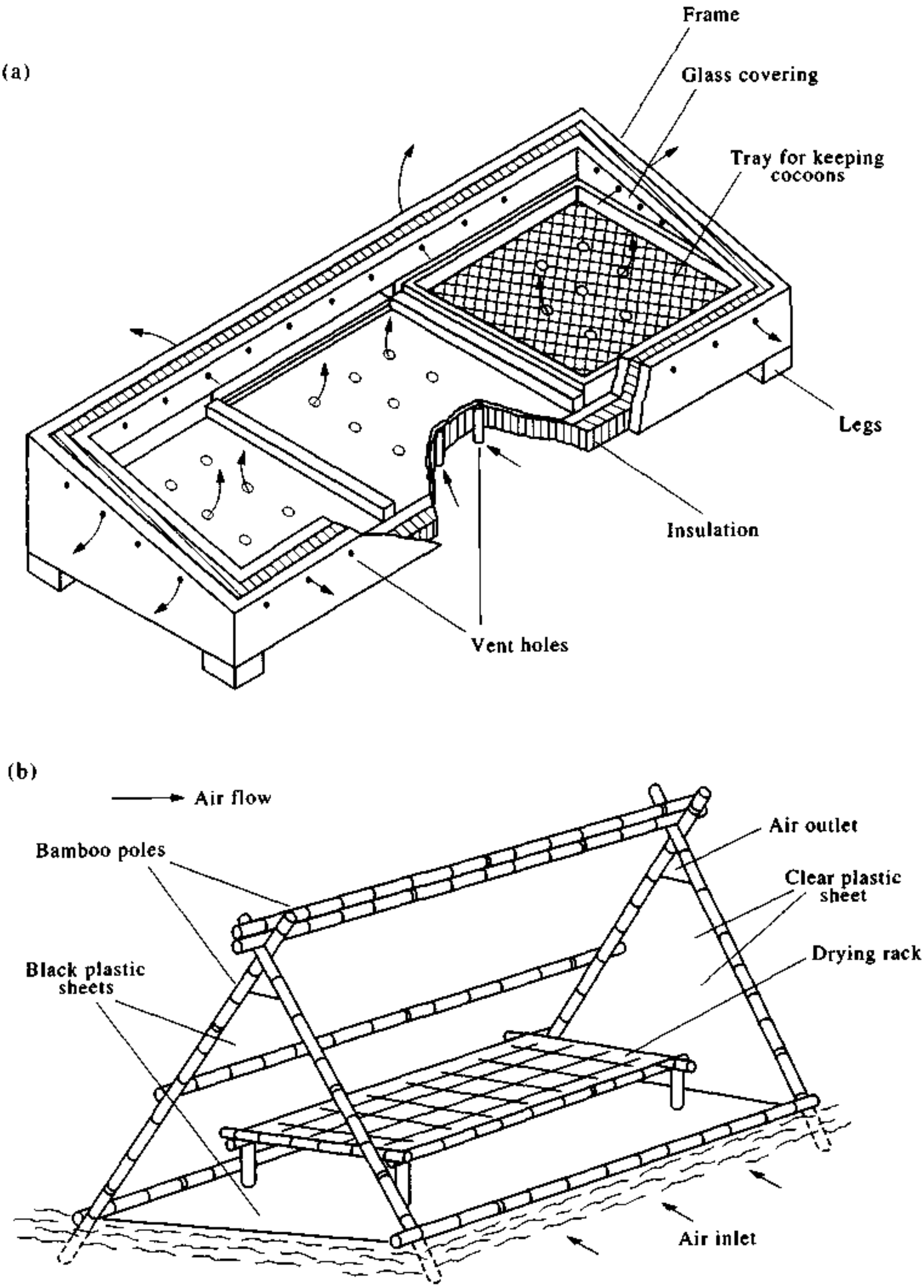

Fig. 4. Simple solar dryers: (a) cabinet dryer and (b) tent dryer.

Non-Conventional Energy Sources, Ministry of Energy and also by the Ministry of Textiles, Government of India. The machines that have been developed and the processes optimized on them are described below:

Solar silk processing machine

A thermosyphon system is the simplest of all system designs in which water circulates by itself in a convective self-flow brought about by the density differential of heated water in the solar collector. The silk processing machine is based on this principle. A 7.5 l. tank, acting as the processing vessel, was connected to a 1 m^2 solar collector as shown in the schematic diagram (Fig. 6). A reflector was connected to supplement the solar energy in winter by increasing the solar flux

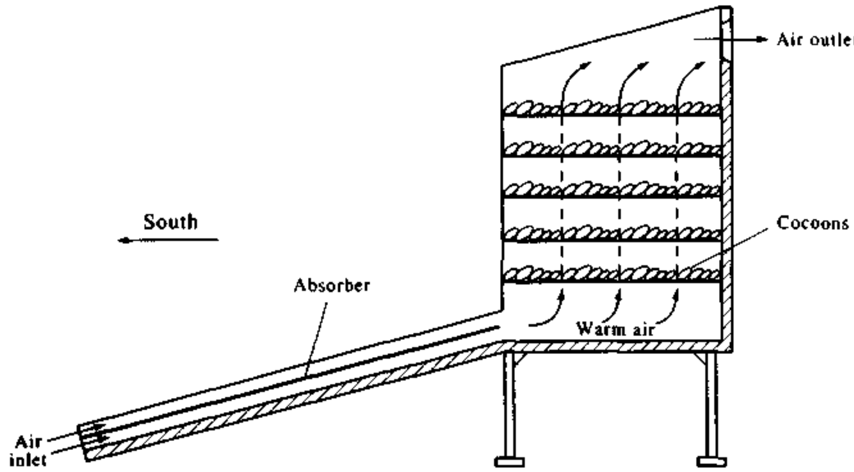

Fig. 5. Natural convection shelf-type cocoon dryer.

to provide the requisite 90–95°C temperature. The temperature obtained and solar radiation profiles are shown in Fig. 7. Hot water from the collector enters the vessel from the top and cold water exits from the bottom. The fabric can be hung on a star frame which can be manually rotated.

Degumming experiments were carried out on raw Murshidabad silk fabric (a locally cultivated variety of mulberry) containing about 25% gum. The fabric weighed 45 g/m^2 and had 49 ends and 86 picks/in. Fabrics were treated in the solar machine for 1.5–3 h in a solution containing:

10.6 gpl (0.1 mol/l)	Sodium carbonate
8.4 gpl (0.1 mol/l)	Sodium bicarbonate and
3 gpl NI wetting agent	(a nonyl phenol 10 EO condensate).

Different properties of these samples were measured and their values are listed in Table 3. Satisfactory degumming was obtained at 90°C with good whiteness and strength retention. Higher temperatures and times of treatment cause strength loss and degradation (viscosity increases). [11]. For higher capacity machines, temperatures of the order of 90°C and above are difficult to attain using flat plate collectors. Degumming of silk with the chemical formulation mentioned above can only be done at 90–95°C, however, one can degum using enzymes at lower temperatures. Alkalase, a protease, is activated at 60–70°C. These temperatures are easily achieved in solar thermosyphon systems. The process conditions optimized on the solar machine were as follows [12]:

5% owf	alkalase enzyme
7.5% owf	sodium bicarbonate and
1.5 gpl	NI wetting agent.

pH adjusted to 8.5; treatment at 60–70°C for 3 h.

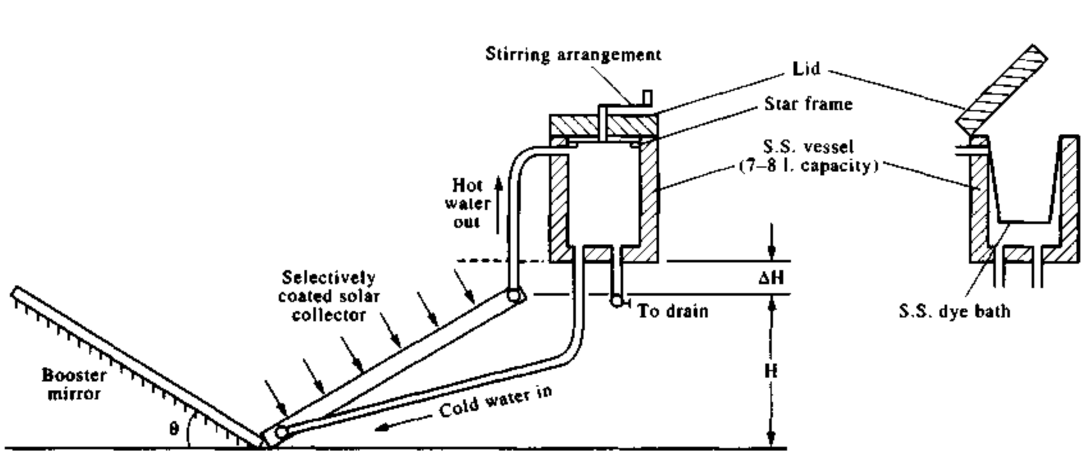

Fig. 6. Schematic diagram of the solar silk processing machine and its attachments.

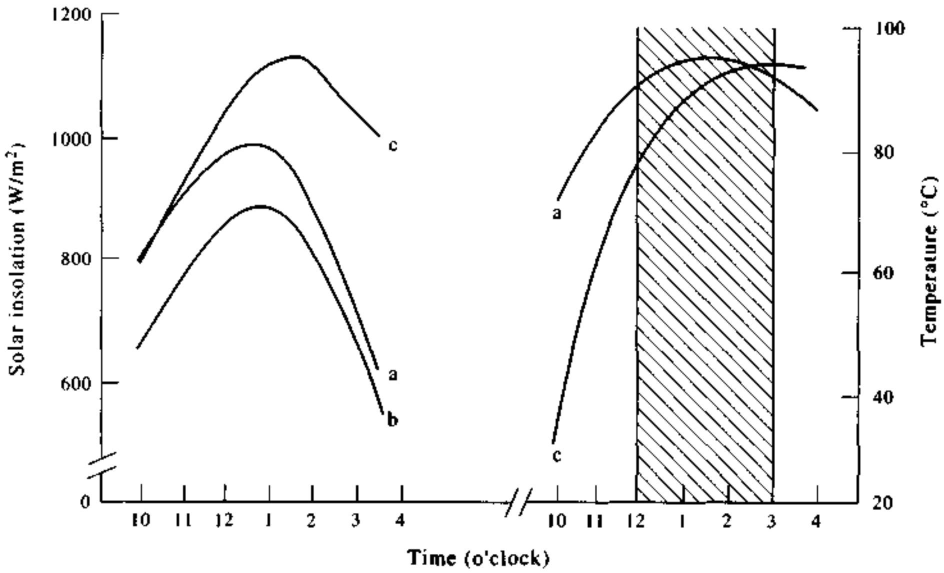

Fig. 7. Solar radiation profile and the temperatures attained in the solar silk processing machine.

Table 3. Treatment conditions and values of properties of degummed samples

S. No.	Treatment conditions: Treatment	Temp. (°C)	Time (h)	Strength (W + F)/2 (kg/g)	Viscosity	Hunter's Whiteness	Wt loss (%)
1	Marseilles soap I	90	3	67.65	0.92	40.81	22.63
2	Marseilles soap II	94	3	63.10	0.98	36.74	21.95
3	Carbonate-bicarbonate buffer	95	3	57.8	0.71	39.72	21.95
4	Carbonate-bicarbonate buffer	90	3	70.05	0.62	34.19	21.66
5	Carbonate-bicarbonate buffer	90	1.5	71.35	0.75	40.28	19.6

This machine was also used for dyeing silk hanks and for boiling cocoons. The treatment liquor for these cannot be allowed to pass through the collector. In the case of dyeing, there is potential danger of the dye remaining in the collector tubes and contaminating the fresh dye or degumming solution. Cocoon boiling leaves behind significant residues, including small entangled fibres which can choke the system. This problem was overcome by introducing a smaller stainless steel vessel into the original one (see Fig. 6). The space between the two acted as a hot water jacket for the smaller vessel, heating the dye solution in it to 70–80°C.

In an experiment, degummed hanks were dyed using acid and metal complex dyes in the solar machine and in a laboratory dyeing machine by a conventional method. K/S values (a measure of depth of colour) of the dyed samples were measured and a comparison is given in Table 4. The solar machine dyed samples showed all round good dye uptake [13].

This machine has been installed as a demonstration model at the Indian Institute of Handloom Technology, Varanasi (a major silk processing centre in India). In a higher capacity machine, two modifications were made. The outlet of hot water was shifted near the bottom of the vessel (Fig. 8).

Table 4. Colour value of the samples dyed in the solar dyeing machine and in laboratory dyeing machine

		K/S			
		Solar machine dyed		Lab machine dyed	
S. No.	Dye	1% shade	2% shade	1% shade	2% shade
1	Sandosilk brill red 3B	12.37	23.46	9.20	24.26
2	Sandosilk yellow P	5.46	7.45	4.27	5.50
3	Sandosilk turquoise AS	28.72	24.59	27.78	22.61
4	Polar red brown V	13.19	8.42	16.98	9.84
5	Neolan brown 2G	4.71	2.13	6.19	4.00
6	Neolan yellow GR	11.03	4.77	12.94	9.43

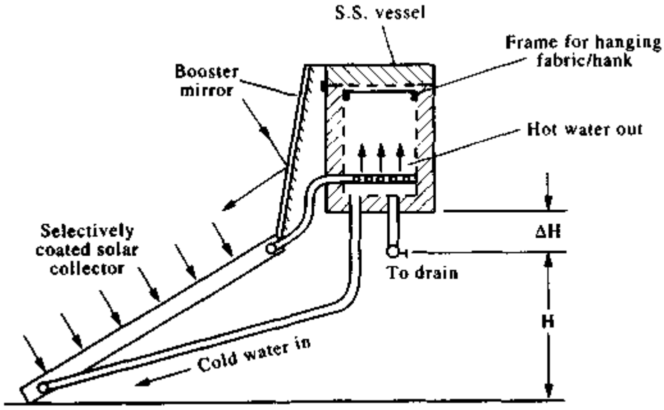

Fig. 8. Modified solar silk processing machine.

Hot water currents rising from the outlet holes cause the turbulence needed during degumming and dyeing. The circulation starts early and is faster. The reflector has been shifted to a hinge on top of the collector for space conservation and easier handling. This model is installed at the Karnataka State Sericulture Development Institute, Bangalore (another major silk producing and processing centre) for demonstration purposes.

Solar oven

The solar oven is a circular trough solar concentrator with a cylindrical absorber (Fig. 9). The absorber is a copper tube coated with a black selective coating on top. The absorber is heated by solar radiation directly as well as from the rays reflected by the circular trough reflector. Because of the circular reflector, the absorber is able to intercept the moving focus of the sun rays (Fig. 10), and hence, it need not track the sun at all. The energy cut-off area is minimized by keeping the inclination of the concentrator fixed at 45°C. Temperatures of the order of 100–115°C are obtained [14]. This oven can be suitably used for curing of pigment prints and finishes.

In a study, silk was printed with pigment pastes containing different cross-linking agents and low temperature curable catalysts for lowering the curing temperature [15]. Such prints are curable at low temperatures, i.e. 100–125°C, and even at room temperature in sunlight. Printed samples were cured in the solar oven at 100–115°C for 90 min, in an electric oven at 140°C for 4 min and in open sun for 2 days. Results for one of the experiments is given in Table 5. It shows that the colour value and fastness properties of samples treated in the solar oven are comparable to those treated in the electric oven. The open air treated samples showed poor fastness properties.

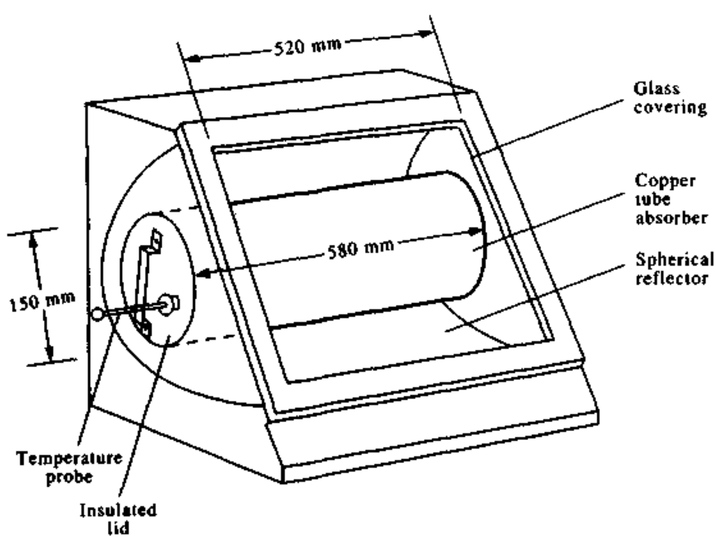

Fig. 9. Solar oven based on circular trough concentrator and cylindrical absorber.

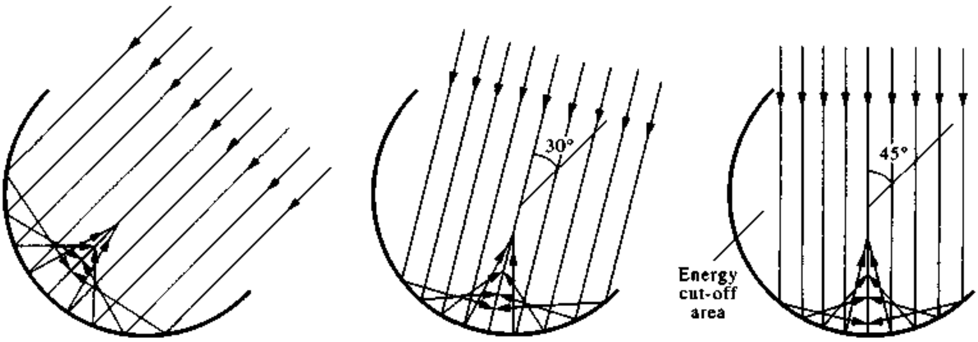

Fig. 10. Circular trough concentrator showing the path taken by solar radiations at various angles of incidence.

FUTURE STRATEGY

It has been conclusively shown above that the utilization potential of solar energy in the silk production and processing industry is significantly high and that, with a little innovation and application, solar silk processing can be made feasible. The experience already gained and the inferences obtained from the above data can provide grounds for future progress in the area.

The unorganized structure of the silk industry makes it ideal for solarization. Small silk producing and processing units, numbering in thousands and distributed all over the country, can reap maximum benefits from solar energy technology. Their production per day is low (silk being an expensive fibre) and so are their requirements for energy. The average production per day may be as low as 3–5 kg/day for small processors and can go up to 50–100 kg/day, at best, for bigger units. There are no composite mills in this sector. A unit may only be degumming and bleaching the yarn or fabric and supplying it to the dyer who may only be dyeing. Printing units get the fabric, bleached and dyed, from these units and, after printing, may send it to another unit for finishing. Furthermore, the units are usually located at isolated places with no electricity and/or steam generation capacity. They depend heavily on ecologically precious wood, biomass and other agro-residues for their energy needs. Decidedly, products like thermosyphon based solar processing machines, solar ovens and dryers, solar water heating systems and also space heating concepts can prove useful to these units. These systems can work in isolation, without power, steam and any other conventional fuel. Solarization efforts, targeted at these units, will improve the quality of silk and also the quality of life for the people.

CONCLUSION

Under the present circumstances, the use of solar energy can herald enormous economic benefits for the silk industry. There is a need for research and technology development in this area to mould the available technology for its greater exploitation. There is a need for entrepreneurs to make

Table 5. Colour value and fastness ratings of samples printed with paste containing catalyst LCP

	% Colour value against control (100%)			Fastness ratings								
	Electric oven	Solar oven	Sun curing	Dry rub fasting			Wet rub fasting			Wash fasting		
Pigment	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Red 2%	92.3	119.1	119.6	4–5	3–4	3–4	4	4	3	4	4	2–3
Red 4%	95.1	94.1	97.9	4	4	3	4	3–4	3	4	3–4	2–3
Green 2%	108.6	83.4	97.4	3–4	3	3	3–4	3–4	4	4	4–5	2–3
Green 4%	90.4	93.3	91.6	3–4	3	3	3–4	3–4	3	4	4–5	2–3
Black 2%	100.4	98.2	98.7	2–3	3	2–3	2–3	3	2	4–5	4	2–3
Black 4%	99	107.1	97.5	4	4	2	2–3	3	2	4	3–4	2–3

popular, the developed products and for the government/state agencies to support initial capital investments.

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