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Short Communication

Design and fabrication of a solar power operated cooking device for softening of tasar cocoons

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A cooking device has been designed and fabricated, by which tasar cocoons can be softened as per standard procedure using solar power plant generated electricity. Cooking efficiency of tasar cocoons remains at par with existing processand no difference of single cocoon reeling parameters and reeling performance softened by newly developed cooking device is observed. Due to difference of solar radiation in different seasons, the cost of cooking/softening varies between Rs. 50/- and Rs. 58/-, while using this device. Although, there is no difference in cooking cost as compared to normal/grid electricity consumption, but 17-30% expenditure can be reduced as compared to existing firewood usage. Utilization of preheated water from solar geyser enhances saving of energy by 12-55% vis-à-vis normal supply of water. In addition to cost effectiveness, this device also reduces the environmental pollution as compared to softening of cocoons using firewood.

Keywords: Bi- voltine, Cocoon cooking device, Epprouvette, Solar power, Tasar cocoon

Tropical tasar cocoons are spun by *Antheraeamylitta* Drury species silkworm of family *Saturnüdae*and order *Lepidoptera*. Due to presence of mineral calcium oxalate and natural colour tannin in addition to sericin, it is difficult to soften tasar cocoons in plain boiling water like mulberry and hencealkaline medium is essential[1-3]. Different alkalis, like sodium carbonate with or without neutral soap[3,4], hydrogen peroxide along with neutral sosp[5] and combinations of sodium carbonate and sodium bi- carbonate[6], are commonly used for tasar cocoons softening. Cocoons are boiled only for sodium carbonate process, whereas in other techniques boiling followed by pressurized steaming is carried out. For all these degumming/ softening process, firewood, rice husk, coal, etc. are used as fuel during boiling and steaming.

The temperature required in silk sectors for drying, cooking, reeling, degumming, bleaching, dyeing and finishing ranges between 45°C and 150°C. Degumming of mulberry cocoons and silk fabric wet processing can be easily carried out using solar energy[7,8]. Utilization of preheated water from solar geyser can save about 25% firewood consumption for cooking and reeling process of mulberry cocoons to produce 10 kg raw silk yarn using multiend reeling machine[9]. Also, utilization of solar drier facilitates saving of electrical energy by about 0.75 kW/kg of mulberry cocoons vis-à-vis electrical drier without affecting yarn productivity and quality[10]. Hot air (50-100°C) produced from solar oven,which consists of half circular trough concentrator along with black coated cylindrical absorber, can be used for drying, printing and finishing of fabrics[11].

Studies have been reported on partial utilization of solar energy to save energy consumption in textile industries[8]. Savings of conventional grid electricity by utilization of solar power generated electricity ranges between 15% and 45% in different seasons for operating tasar silk cocoons reeling and spinning machines[12].

Literature review[7-10] shows studies on utilization of solar energy for cooking/softening and reeling of mulberry cocoons as well as dyeing, printing and finishing of fabrics. Also, it is observed that textile industries are using solar energy to reduce the production expenditures[8,11]. Tasar reeling and spinning units are located in remote rural areas where scarcity of grid/supply electricity exists. About one hour is required during cooking for softening of tasar cocoons, where firewood/LPG is used as fuel. Hence, in this research study, an attempt has been made to design and fabricate a cooking device which can be operated by both solar plants generated electricity as well as grid electricity according to solar radiation availability in different seasons.

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Experimental

Installation of Photovoltaic Solar Power Plant

Solar photovoltaic power plant of 10kW capacity, installed by M/s Solace Renewable Energy Private Limited, Kolkata, India, was utilised for the power supply of new fabricated tasar cocoon cooking device.

Development of Cooking Device usingSolar Power Plant

The schematic diagram of new cooking device, developed for softening of tasar cocoons, is illustrated in Fig. 1. The water is preheated to the extent of 40 - 50^{o}C using solar geyser and then supplied by pipeline for cooking. The cooker consists of a chamber for boiling and steaming. During boiling, the bottom segment is used and for steaming the container is lifted to the top position. On the top position, there is a lid which is kept openduring boiling of tasar cocoons without pressure, and then closed during steaming under pressure in which electrical coil heater is used. After stipulated boiling time, the cocoons are lifted up by circular perforated tray and kept in upper portion by fixing in slot of holders. The lid is closed and steaming is pursued over same solution as per the required duration. Drainage provision exists at bottom of the apparatus for discharging the solution. The solar cooker is made of stainless steel which is operated by 4.50 kW electrical coil heater from either solar power plant or normal (grid) electricity. The capacity of the apparatus is 1500 tasar cocoons for boiling and steaming, where about 50 litres water is filled in half portion of the chamber. Chemicals are added to the preheated water as per the requirement.

Raw Materials and Chemicals

Dababivoltine tropical tasar of cocoon (12.50g) and shell (1.50 g) weight was utilized for assessment of new developed solar power operated cooking device. Sodium carbonate and sodium bicarbonate of laboratory reagent grade, procured from Merck India Limited, Mumbai, were used for experimental trials.

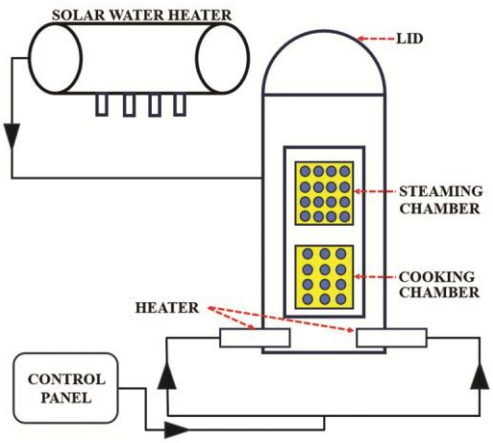

Fig. 1 — Schematic diagram of solar operated tasar cocoon cooking device

Cooking / Softening of TasarCocoons

Cooking / softening of Daba BV (bivoltine) tropical tasar cocoons was carried out following newly developed non- peroxide technique using sodium carbonate and sodium bicarbonate[6]. Five hundred cocoons were softened for each trial and for proper immersion, and 50 litres water was taken. Sodium carbonate and sodium bicarbonate of 5 g/L each was added in water with proper stirring for dissolution. The cocoons were kept in netted nylon cloth, which was immersed in solution and boiled for 20 min without pressure followed by pressurized steaming for 30 min. After cooking, the cocoons were taken out from chamber, subjected for reeling to produce yarn. The remaining solution from chamber was discarded through exhaust pipe. Total five observations were made for cooking /softening trials.

Single Cocoon Quality Parameters

After softening of tasar cocoons, filament was withdrawn from single cocoon under semi- moist condition using a device 'Epprouvette' and breaks were noted. The total length of yarn from single cocoon was estimated from the number of revolutions noted from counter meter of Epprouvette. Total 30 observations were made for each experimental trial and five replications were carried out. After drying using hot air dryer for 20 min at 105±3^{o}C[13], yarn weight was measured using precision electronic balance. Yarn denier and non- broken filament length (NBFL) were estimated as per standard procedures[4], as mentioned in Table 1.

Reeling Performance

Reeling performance for each experimental trial was conducted using Motorized Reeling cum Twisting Machine (MRTM), which consists of 4 ends. The yarn withdrawal was carried out following dry reeling technique from six numbers semi moist cocoons with reeling speed of 30 m/min. Breakages during the reeling were recorded and 50 cocoons were used for each experimental trial and five replications were done. Yarns as well as different wastes eliminated during filament withdrawal like floss, reeling and basin/pelade were collected. Yarns as well as wastes generated during reeling were dried using hot air oven at 105±3^{o}C[13]. The reelability (%), raw

Table 1 — Estimation procedure of single cocoon quality parameters and reeling performance

Parameter	Expression/Equation
Filament length, m	No. of revolution in Epprouvette × 1.125*
Yarn denier	$\frac{\text{Weight of yarn (g)} \times 9000}{\text{Length of yarn (m)}}$
Non- broken filament length (NBFL), m	$\frac{\text{Total filament length (m)}}{\text{No. of cocoons**} + \text{No. of breaks}}$
Reelability, %	$\frac{\text{No. of cocoons taken for reeling} \times 100}{\text{No. of cocoons taken for reeling} + \text{No. of breaks during reeling}}$
Raw silk recovery, %	$\frac{\text{Yarn weight (g)} \times 100}{\text{Yarn weight (g)} + \text{Waste weight (g)}}$
Yield/1000 cocoons, g	$\frac{\text{Yarn weight (g)} \times 1000}{\text{No. of cocoons reeled}}$

*Circumference of Epprouvette. ** One for single cocoon reeling using Epprouvette.

silk recovery (%) and yield/1000 cocoons (g) were estimated by standard procedures[4], as mentioned in Table 1.

Conditioning of Yarn and Waste Samples

The yarn as well as waste samples were kept under standard atmospheric conditions (65±2% relative humidity and 27±2°C temperature) for 24h[14] and then subjected for assessment of filament yarn and waste weight.

Analysis of Experimental Data

The experimental data were analysed for parameters,such as cooking efficiency, filament length, filament denier, non- broken filament length (NBFL), reelability (%), raw silk recovery (%) and yield/1000 cocoons (g) using Minitab 20 software.

Results and Discussion

Cooking Efficiency

The cooking efficiency of tasar cocoons is given in Table 2. It is observed that about 95% cooking efficiency can be achieved by using newlydeveloped solar operated cooking device which is at par with existing open bath or pressurized cooking/softening process[4,6]. This may be due to control of temperature profile and adequate steaming provision in this cooking device for effective elimination of sericinusing both sodium carbonate and sodium bi- carbonate.

Single Cocoon Quality Characteristics and Reeling Performance

Single cocoon quality parameters and reeling performance of Daba BV tropical tasar cocoons are depicted in Table 3. It is observed that the single cocoon quality characteristics and reeling performance remain at par as compared to the cocoons softened by open bath process following either sodium carbonate and sodium bi- carbonate process or hydrogen peroxide and neutral soap combination process. Student 't' test for filament length, non- broken filament length, denier and yield/1000 cocoons as well as chi- square test for reelability and raw silk recovery also confirm the findings. Since the cooking/softening process remain same as per the existing technique, single cocoon quality parameters and reeling performance remain at par.

Table 2 — Cooking efficiency of tasar cocoons softened using new developed device

Observation	No. of cocoons taken for reeling	No. of cocoons softened	Cooking/softening efficiency, %
1	500	473	94.60
2	500	476	95.00
3	500	480	96.00
4	500	474	94.80
5	500	471	94.00
Average	-	-	94.90
Chi- square value	-	-	0.023^{NS}

In case of existing hydrogen peroxide and neutral soap cooking/softening process, the cooking efficiency can be achieved at about 95%. Table value of chi- square at d.f. 4: 11.143 (5% level) and 14.860 (1% level). NS- Not significant.

Techno-economic Analysis of Cooking Device using Solar Power

The cost of cooking for 1000 tasar cocoons using developed solar operated device are given in Table 4. It is observed that the cost of cooking remains at par while using solar operated cooking device, i.e. about

Table 3 — Single cocoon quality characteristics and reeling performance of Daba BV cocoons softened by new solar operated cooking device

Obs.	Single cocoon reeling parameters			Reeling performance		
	Filament length m	Non- broken filament length, m	Filament denier	Reelability %	Raw silk recovery %	Yield/1000 cocoons, g
New developed solar operated cooking device						
1	1060.00	175.20	10.80	31.90	59.90	970.00
2	1168.00	215.00	11.00	32.80	62.10	1056.00
3	1185.00	240.20	9.50	35.10	64.60	1071.00
4	1098.00	212.60	9.60	34.20	64.25	990.00
5	1210.00	227.50	10.70	34.60	65.00	1100.00
Average	1144.20	214.10	10.32	33.72	63.20	1037.40
Std. Dev.	62.82	24.38	0.71	*	**	55.19
S.E (5%)[b]	80.75	31.34	0.92	*	**	70.95
Open bath process using sodium carbonate and bi- carbonate						
Average[a]	1098.00	209.20	10.14	32.50	62.30	1075.00
Open bath process using hydrogen peroxide and neutral soap process						
Average[a]	1032.00	198.70	9.90	35.10	64.00	1150.00

[a]From earlier trials' data.
[b]Standard error of standard deviation.
*Chi- square value = 0.436; **Chi- square value = 0.540 (Not significant).
Chi- square table value at 4 d. f. = 11.143 (5% level) and 14.860 (1% level).

Table 4 — Cost (Rs.) of cooking for tasar cocoons/1000 no. using solar power operated device

Particulars	Months		
	April, May, September & October	June, July & August	November to March
Solar power utilization*, %	30.00	15.00	45.00
Power cost			
Total power requirement, kW	4.50	4.50	4.50
Solar plant power, kW	1.35	0.68	2.03
Supply/grid power, kW	3.15	3.82	2.47
Cost of grid power (@ Rs. 6/- per unit), Rs	19.00	23.00	15.00
Cost of chemicals**, Rs	30.00	30.00	30.00
Battery maintenance cost***, Rs	5.00	5.00	5.00
Total cost, Rs	**54.00**	**58.00**	**50.00**

*Results of study report Khan & Chattopadhyay[12].
**Following developed sodium carbonate and sodium bi- carbonate process with duration of cooking 1 hour.
***For installed solar power plant.

Rs. 55.00/1000 cocoons, following new developed sodium carbonate and sodium bi- carbonate technique[6]. The cost of cooking differs from Rs. 50/- to Rs 58/- due to difference of solar power utilization from minimum 15% to maximum 45% in different months[12]. Due to maximum solar radiation during November to March, the utilization remains better, whereas due to cloudy sky and rainy seasons, the minimum benefit is obtained during June to August. From a study[12], it is revealed that minimum 600 W/m^2 radiation is required for battery charging as well as 45% utilization of solar power for post cocoon machinery operations. Also, the cost of cooking using normal grid electricity and firewood is depicted in Table 5. It is revealed that the cost of cooking is at par while using grid/normal electricity, as well as solar power plant generated electricity,whereas substantial saving of 17-30% against usage of firewood in different seasons. For other eco races like Modal and Raily, the cost of cooking will be higher by 30-50% due to usage of more quantity of sodium carbonate and sodium bi- carbonate[6].

Saving of Energy using Preheated Water from Solar Geyser

The saving of energy while using preheated water from solar geyseris depicted in Table 6. The energy required for raising the temperature from existing condition to boiling stage has been estimated as per standard procedures using the following relationship.

Table 5 — Cost of cooking for tasar cocoons/1000 no. using normal/grid electricity and firewood

Particulars	Value
Supply/grid electricity	
Power required, kW	4.50
Cost of power (@Rs. 6.00 per unit),Rs	27.00
Cost of chemicals*, Rs	30.00
Total cost, Rs.	**57.00**
Firewood	
Quantity required, kg	4.00
Cost of firewood (@Rs 10.00 per kg.), Rs	40.00
Cost of chemicals*, Rs	30.00
Total cost, Rs	**70.00**

*Following developed sodium carbonate and sodium bi- carbonate process with duration of cooking 1 hour.

Table 6 — Saving of energy using preheated water

Water temperature from normal supply, ^oC	Water temperature from solar geyser, ^oC	Energy required for boiling, kW	Saving of energy kW	Saving of energy, %
20	*	5.00	-	-
**	40	3.50	1.50	30.00
**	50	3.00	2.00	40.00
**	60	2.30	2.70	54.00
30	*	4.00	-	-
**	40	3.50	0.50	12.50
**	50	3.00	1.00	25.00
**	60	2.30	1.70	42.50

*No. water supply from solar geyser. **No. normal water supply.

$$\text{Energy required for raising temperature} = \frac{m \times \text{Sp. heat} \times (t_2 - t_1)}{860}$$

where m is the mass of water in kg; Sp. heat , the specific heat of water, 1 kcal/kg/^oC; t_1, the initial temperature of water,^oC; t_2, the boiling temperature (100^oC); and 1 kwh , 860 kcal.

Water capacity is 50 litresandthe mass is 50 kg considering density 1 g/cc or 1 kg/L. Cooking for 1 h is required inclusive of boiling and steaming.

$$\text{Saving of energy (\%)} = \frac{(E_n - E_{sg}) \times 100}{E_n}$$

where E_n is the energy required for rising up to boiling temperature for normal water; and E_{sg}, the energy required for rising up to boiling temperature for solar geyser water.

Table 6 depicts the additional energy savings achieved through the use of preheated water from a solar geyser as compared to normal water supply at various temperature profiles. While utilizing water from solar geyser, significant increase of savings is evident. For 40^oC preheated water from solar geyser, 30% savings can be achieved and there is an ascending trend for increasing of energy saving for higher initial temperature of both preheated water from solar geyser as well as normal supply water. This is because of less power requirement to raise the temperature of water up to boiling stage. Hence, it can be opined that potential saving of additional energy 12- 55% can be possible using preheated water from solar geyser.

A cooking device is designed and fabricated by which tasar cocoons can be softened following standard cooking procedures using either solar power plant electricity or normal/grid electricity. The power required for operating the cooking device is 4.50 kW and maximum 1500 cocoons can be processed in single batch. About 95% cooking efficiency can be achieved by this device, which is at par with existing open bath or pressurized cooking/softening process. No significant difference has been observed for single cocoon quality characteristics (filament length, non-broken filament length and denier) as well as reeling performance (reelability, raw silk recovery and yield/1000 cocoons) between newly developed solar operated cooking device and open bath process. The cost of softening per 1000 tasar cocoons differs between Rs. 50-58/- in different seasons due to variations in solar radiation and thereby utilization of solar power plant generated electricity with average value of Rs. 55/-. The cost needs to be incurred as Rs. 57/- while using normal/grid electricity and Rs. 70/- in case of firewood usage.

Although, no difference exists between solar plant electricity and normal/grid electricity usage, but 17-30% saving in cost of cooking in different seasons is obtained as compared to firewood utilisation.Usage of pre heated water from solar geyser enhances substantial saving of energy by 12-55%, depending upon the existing temperature of water. So, the developed solar operated cooking device can be well utilized in tasar reeling and spinning production centres located in rural areas, where scarcity and high interruption of supply electricity exist. In addition to cost effectiveness, this device also reduces the environmental pollution as compared to softening of cocoons using firewood.

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