Available online at www.sciencedirect.com
SCIENCE DIRECT®
Biomass and Bioenergy 26 (2004) 195–203
BIOMASS & BIOENERGY
www.elsevier.com/locate/biombioe

Technology intervention to improve the energy efficiency and productivity of silk reeling sector

Sunil Dhingra*, Sanjay Mande, P. Raman, S.N. Srinivas, V.V.N. Kishore

The Energy and Resources Institute (TERI), Habitat Place, Darbari Seth Block, Lodhi Road, New Delhi 110 003, India

Received 9 February 2001; received in revised form 13 June 2003; accepted 23 June 2003

Abstract

The Energy and Resources Institute (TERI) has been actively involved in development of biomass gasifier system for thermal and power generation use. Though the basic science of gasification is well established, there have not many efforts in the past on product development. By continuous interaction with users, silk experts and consultants, TERI could able to develop a gasifier based silk reeling oven. A major thrust on this development work was to evolve marketable product by continued efforts to gain an insight of the actual process and user feedback through an extended presence and interaction at field level, and then translating this experience in product design. The present paper gives a summary of design, development and testing of gasifier based cottage basin system for cocoon cooking in silk reeling industry in order to achieve higher fuel efficiency and increase productivity of the process. The paper describes in detail the approach of different technology development stages, its testing both at laboratory and field and economic viability of the system.

Keywords: Biomass; Gasifier; Silk; Sericulture

1. Introduction

Silk holds a unique place in the textile world and is regarded as the "Queen of Textiles". India is a traditional sericulture country and ranks only next to China in silk production. India produced around 14,500 metric tons of natural silk during the year 1993–1994. Majority of the silk is reeled either in charka or in the cottage basin ovens. At present there are about 35,000 charkha basins and 26,000-cottage basin registered units [1] in different states. Various fuels used are mainly firewood for cottage basin and local available loose biomass (such as groundnut shell, tamarind husk, rice husk, coffee beans, etc.) for charka units. It is estimated that about 1.05×10^5 tons of loose biomass, and 1.2×10^5 tons of fuelwood are being consumed every year for the production of silk yarn with overall useful efficiency of 12–15%. Over the years, the profitability of Indian silk reeling industry has been affected due to cheaper raw silk import and high cocoon price, both of these factors are beyond the control of reelers. In addition overall productivity of the sector is low, as in the past there is no systematic attempts was made to upgrade technology, and improve both energy conservation and by-product recovery.

* Corresponding author. Tel.: +91-24-68-21-00; fax: +91-11-24-68-21.
E-mail address: dhingras@teri.res.in (S. Dhingra).

0961-9534/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0961-9534(03)00103-X

2. Raw silk production process description

There are various steps involved in production of raw silk yarn that consists of:

(i) silk worm seed production,
(ii) chawkie rearing,
(iii) stifling,
(iv) cocoon drying and cooking,
(v) reeling,
(vi) re-reeling,
(vii) twisting,
(viii) spinning,
(ix) dyeing,
(x) weaving,
(xi) printing and
(xii) finishing.

Thermal energy is needed for the stifling, cooking and dyeing operation of silk yarn production. Stifling is a process for killing of pupae and drying the cocoons for storage. There are two ways of stifling viz. with the help of hot air or with the help of steam (either in basket or in barrel). Cooking is the process of locating the end of the silk thread by subjecting the cocoons to boiling water. The cooked cocoons are then subjected to reeling wherein the located ends are reeled onto the reels. Two types of reeling ovens are used namely charka oven and cottage basin. In charkha oven cooking and reeling is done on the same vessel whereas in cottage basin oven the cooking and reeling is done separate vessel.

3. Survey of silk reeling ovens

A survey [2] carried out on 236 cooking oven followed by detailed energy and water balance experiments on sample units revealed that specific fuel consumption level of about 1.5–2.0 kg of wood/kg of cocoon and 2.44–3.2 kg of wood/kg of cocoon in case of cottage basin oven and charkha oven, respectively. This result in an overall efficiency of about 11.7–15.3%. Based on water balance experiments, it was found out that the useful heat requirement to cook 1 kg of cocoon, under present operating practice, is about 5.5 MJ in case of charka oven and 3.7 MJ in case of cottage basin oven. The reason for higher value of charka oven can be attributed to longer period of operation, larger cooking vessel area. The study also revealed that majority of charkha units use locally available loose biomass as fuel while cottage basins ovens consumes fire wood and the main drawback of these ovens have no control on fuel burning, large fluctuation in process parameters like water temperature and level of water in the each vessel, frequent manual interference etc. Therefore, offers larger scope for efficiency improvement and design improvement of the present system. Since, the cottage basin reelers have comparatively good financial stability compared to charka reelers and they can go for retrofitting or even for newer designs of stove if they are economically attractive interventions. Therefore it was decided to develop alternate system for cottage basin unit. Retro-fitting of ovens by way of controlled burning rate, maximum flue gas heat recovery, reducing other losses can possible result in energy saving marginally (about 25%) and therefore are less likely to attract reelers. Hence, need was felt to develop alternate design suitable for meeting energy demand of silk reeling unit with substantial fuel saving so as to make it economically viable intervention.

Considering the unavoidable evaporation losses and the necessity to have controlled burning, the gasifier system appears to be a promising option and hence a suitable gasifier based silk reeling oven development work was initiated. In the following sections different stages of development of gasifier based cottage basin oven is described.

4. Development of various prototypes

Cottage basin silk reeling units are categorized based on the number of reeling and cooking basins. Generally one cooking basin supplies cocoons to two reeling basins. Based on the survey, a six pan-cooking oven suitable for 10–12 reeling basin was found to be the average size of the silk reeling unit. Hence, a gasifier based cottage basin development work, suitable for six-pan cottage basin unit, was initiated through series of prototype fabrication and testing.

4.1. Conceptual and laboratory prototype

To prove the concept of use of gasifier technology for cocoon cooking application for cottage basin

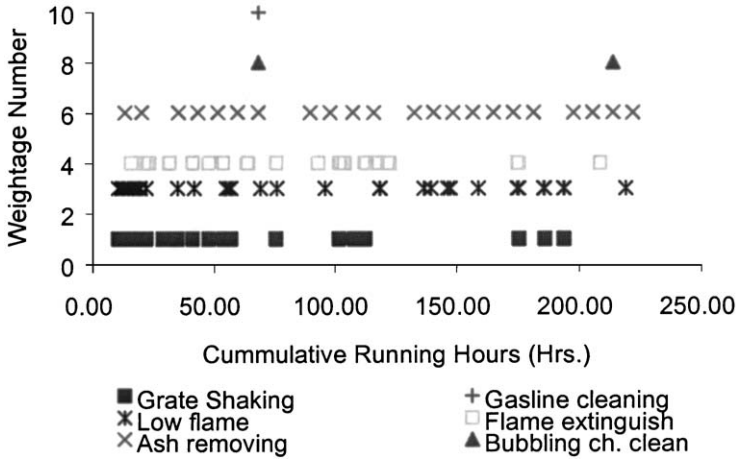

Fig. 1. Maintenance activity record during reliability testing.

ovens, a prototype was fabricated at TERI's Gual Pahari campus. After completing the necessary modifications, the prototype was continuous operated for 8 h on daily basis for about a month to assess the maintenance requirements and to test the reliability of the system. The operational and maintenance data such as pipe line cleaning, grate shaking, water bubbling chamber cleaning, etc. were recorded during the test runs. The data obtained against each of the maintenance activity is labelled by a weighted number on a scale of 1–10. The weighted number reflects the severity of the maintenance needs. The frequency of the different activities helps in framing the maintenance schedule of the system and the data was plotted against time as given in Fig. 1.

4.2. Field prototype (Hindupur)

After successful completion of long duration testing of the gasifier-based system at TERI for reliability and maintenance requirements, a field prototype was designed. The following additional points were considered in finalizing the prototype:

- Sizing of the system for field requirement.
- Ease of fabrication and installation of the system in the field.
- Possibilities of reducing the system cost.
- Possibility of reducing maintenance requirements.

A cottage basin silk reeling unit M/s Kedar Silk Reeling and Twisting unit, Hindupur A.P. was selected for field-testing. The first field prototype of gasifier based cottage basin system was installed at Hindupur on 9, November 1995 for testing performance under actual field conditions. The concept of wood gasifier system for cottage basin silk reeling ovens has been successfully demonstrated and tested at Hindupur.

4.3. Results of field testing (Hindupur)

Comparative performance tests were carried out on gasifier based systems both at Hindupur and Ramanagaram. For this purpose, the same lot of cocoons was divided into two lots and one was process in conventional oven and other in the gasifier oven. A total of 13 comparative performance tests were monitored on gasifier and conventional oven at Hindupur. The data [3] is summarized in Table 1 with regard to reduction in specific fuel consumption and renditta improvement. From this table it can be seen that the specific fuel consumption figures came down from 2.34 kg/kg cocoon to 1.34 kg/kg cocoon and along with marginal renditta [1] improvement in case of gasifier based system.

[1] Renditta is defined as the weight of cocoons needed to produce 1 kg of silk. A reduction in renditta means increase in silk production from the same raw material.

Table 1
Summary of field-testing experiments for performance comparison

Lot no.	Specific fuel consumption			Renditta		
	Existing oven	Gasifier based oven	Reduction	Existing oven	Gasifier based oven	Reduction
1.	1.95	1.37	0.58	7.27	7.20	0.08
2.	1.97	1.41	0.56	7.54	7.51	0.03
3.	2.28	1.33	0.96	7.89	7.18	0.72
4.	2.62	1.21	1.41	8.13	8.04	0.09
5.	3.85	1.63	2.23	6.86	6.82	0.04
6.	2.20	1.79	0.41	7.01	6.96	0.04
7.	2.20	1.40	0.79	6.54	6.88	−0.34
8.	1.75	0.89	0.86	8.02	7.93	0.09
9.	1.80	1.10	0.70	7.96	7.84	0.12
10.	2.04	1.26	0.78	7.28	7.27	0.02
11.	2.23	1.22	1.02	7.31	7.22	0.08
12.	3.07	1.39	1.68	10.00	9.87	0.13
13.	2.46	1.48	0.98	8.55	8.39	0.16
Average	2.34	1.34	1.00	7.72	7.62	0.10
standard deviation	0.55	0.22	0.48	0.85	0.80	0.22

5. Interaction with reelers, silk experts and IDC

After successful test the field prototype at Hindupur, efforts were initiated to develop improved field prototype for gasifier based silk reeling system. A large number of progressive reelers from other potential cottage basin clusters of Ramanagaram, Kanakpura and Channapatna were called to Hindupur for gasifier demonstration. Based on the feedback received from the reelers it was decided to further develop the system to suit the field conditions of Ramanagaram, Kanakpura.

Input from the reelers, silk experts and industrial product designers were initiated with specific aim to further develop the system and improve the man–machine relationship in actual field situation. For this purpose, Prof. Vijay Bapat of Industrial design centre, IIT Bombay was involved to suggest measure to reduce the cost and improve the overall system. Silk experts Mr. T.S. Nagaraja, Mr. Mahadevappa had been involved with the team to finalize the methodology and actual comparative testing of silk yarn quality during field testing of improved field prototypes. Effort was made in development of associated sub-system such as efficient producer gas burner with IIP Dehradun and IIT Kanpur. A co-ordination committee consisting of all the stakeholders like reelers, silk experts, project team and funding agency representatives was formed. The committee members met monthly to review the progress of the development work and to make necessary modifications in the future plan.

6. Evolution of improved field prototype

Till the field-testing of gasifier based silk reeling oven at Hindupur the attempt was made mainly to prove the concept, demonstrate the system to reelers and to obtain preliminary field testing the system in actual silk reeling industry. During the field-testing of gasifier system need was felt to develop the system further to meet the requirement of silk reeling units operating in other clusters. The development of improved field prototype is made mainly with following aims

- to meet the field process parameters,
- to increase the overall thermal efficiency and
- to reduce the maintenance requirement of the system.

In improve field prototype design, all the useful suggestions received from reelers, consultants were also taken in consideration. Later, two improved field prototype of gasifier based oven was fabricated and installed at two sites in Ramanagaram. The comparative

Table 2
Comparative wood consumption (cottage vs. gasifier) at site 1

Lot no.	Specific fuel consumption			Renditta		
	Existing oven	Gasifier based oven	% Reduction	Existing oven	Gasifier based oven	% Reduction
10.10.96				10.76	10.34	3.83
12.10.96				10.04	9.85	1.90
17.10.96				11.51	11.25	2.22
18.10.96				10.59	10.29	2.86
25.10.96				11.91	10.80	9.33
26.10.96				10.23	10.23	0.00
26.11.96	2.57	1.61	37.52	9.22	0.09	1.36
27.11.96	2.77	1.59	42.63	10.07	10.50	−4.30
28.11.96	2.84	1.97	30.62	10.10	9.37	7.22
18.12.96	2.39	1.12	53.18	11.53	11.44	0.76
21.12.96	2.40	1.22	48.98	10.53	10.36	1.59
22.12.96	2.50	1.33	47.00	11.05	10.26	7.18
6.1.97	2.11	1.11	47.37	9.13	8.57	6.10
7.1.97	2.10	1.11	47.09	8.56	8.53	0.29
10.1.97	1.89	1.38	27.21	8.49	8.37	1.44
20.1.97	2.89	1.40	51.54	11.69	11.69	0.00
23.1.97	2.28	1.21	46.77	9.30	9.17	1.44
24.1.97	2.13	1.04	50.83	9.13	8.66	5.13
7.2.97	2.38	1.38	42.11	8.51	8.21	3.49
8.2.97	2.46	1.26	48.84	8.84	8.71	1.49
12.2.97	2.53	1.25	50.50	8.46	8.02	5.21
13.2.97	2.27	1.24	45.59	8.27	8.18	1.03
14.2.97	1.95	0.80	59.25	8.55	8.41	1.67
19.2.97	2.13	1.10	48.30	7.65	7.60	0.59
20.2.97	2.14	1.01	52.63	8.01	7.76	3.14
30.03.97	1.91	0.99	48.22	8.08	7.58	6.10
Average	2.33	1.26	46.31	9.62	9.36	2.73
Std. Dev	0.30	0.26	7.48	1.28	1.25	2.91

data was collected in order to quantify the benefits of the gasifier-based oven over conventional oven. The data collected on fuel wood consumption, silk yield, and cocoon processing rate. The specific fuel consumption was identified in terms of wood consumed to process 1 kg of cocoons. Thus the wood saving was assessed based on the SFC. Wood consumption details were taken for cottage and gasifier-based systems both the units from September 1996 to March 1997. There are about 39 data points for cottage basin oven and 50 data points on gasifier-based oven.

6.1. Site 1

The comparative data cocoons processed, wood consumption and silk produced on gasifier and conventional oven were collected on both the systems. Based on data collected specific fuel consumption, renditta and percentage improvement was calculated and given in Tables 2 and 3 for sites 1 and site 2, respectively.

It can be seen from Table 2 that average 46.3% fuel consumption reduction and 2.7% reduction in renditta is achieved with gasifier system. The improvement in renditta means extra silk yield of 310-g/100 kg of cocoons in gasifier oven. The variation in specific fuel can be attributed to the variation in the batch time, moisture content in the wood and the species of wood used.

6.2. Site 2

The details of specific fuel consumption and renditta along with percentage reduction are given in

Table 3
Comparative wood consumption (cottage vs. gasifier) at site 2

Date	Specific fuel consumption			Renditta		
	Existing oven	Gasifier based oven	% Reduction	Existing oven	Gasifier based oven	% Reduction
29.9.96				11.36	11.07	2.63
11.10.96				11.21	10.08	10.08
13.10.96				10.65	10.94	−2.69
15.10.96				10.08	9.25	8.23
19.10.96				10.98	12.16	−10.81
26.10.96				10.26	9.89	3.57
29.10.96				10.59	9.45	10.76
6.11.96	2.06	0.97	52.70	9.47	9.35	1.30
14.11.96	2.08	1.35	35.33	9.35	9.11	2.53
19.11.96	1.94	1.39	28.55	10.65	10.00	6.11
20.11.96	2.08	1.26	39.33	10.98	9.86	10.14
21.11.96	2.08	1.19	42.67	9.16	8.78	4.15
7.12.96	1.99	1.27	36.15	8.86	8.45	4.67
8.12.96	2.00	1.46	26.98	8.82	8.56	2.99
9.12.96	2.54	1.08	57.50	9.84	9.00	8.57
10.12.96	2.38	1.27	46.67	9.40	9.13	2.90
11.12.96	2.22	0.83	62.50	9.94	9.47	4.74
17.1.97	2.39	1.28	46.63	9.10	9.00	1.13
29.1.97	2.56	1.33	47.83	8.45	8.37	0.93
30.1.97	2.61	1.31	49.88	8.93	8.67	2.80
21.2.97	1.81	1.19	34.12	8.83	8.74	0.99
22.2.97	1.84	0.78	57.76	9.05	8.78	2.99
24.2.97	1.89	0.97	48.53	8.72	8.72	0.00
25.2.97	1.87	0.79	57.66	8.56	8.49	0.88
26.2.97	1.97	1.00	49.30	8.37	8.28	1.15
27.2.97	1.94	0.97	50.00	9.94	9.23	7.18
Average	2.12	1.14	45.79	9.68	9.34	3.38
Std. Dev	0.25	0.21	10.14	0.92	0.93	4.50

Table 3. It can be seen from table that the average 45.8% fuel consumption reduction is achieved. The average reduction in renditta comes to 3.3% which means additional silk yield of 370-g/100 kg cocoons in gasifier oven.

7. Discussions

The gasifier based cottage basin oven development work was initiated with an objective of improving the profitability of the silk reeling system by reducing the consumption of wood. The technology development path chosen to reach the goal is shown in Fig. 2. The path for system development followed here is through a series of steps such as proof of concept, development of field prototype, design review, development of commercial prototype, extended field testing, industrial design input, test market and review, and finally development of the commercial product for fabrication. In a majority of R& D or technology development projects, it is generally assumed that once a laboratory prototype is developed, commercialization automatically follows. This has never been the case, therefore the laboratory prototype undergo several stages of metamorphosis through field trials, material optimization, user satisfaction, etc. till a commercial model is evolved.

It was observed during comparative field testing of gasifier system over conventional system that apart from fuel saving, silk yield and silk yarn quality is also improved. This is probably due to controlled

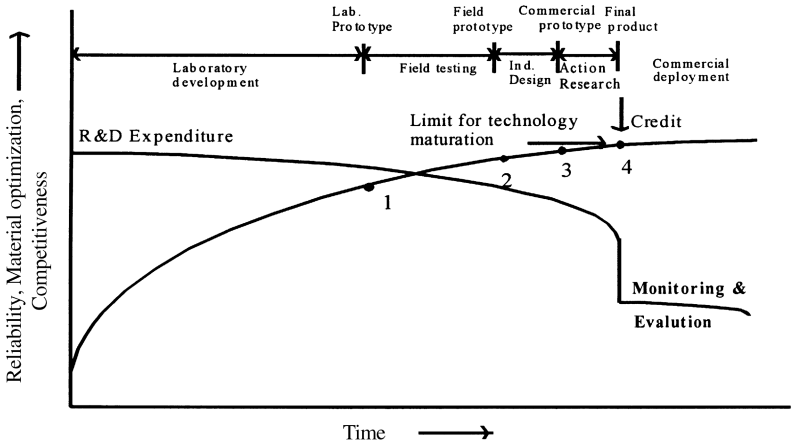

Fig. 2. Time, temperature profile during cocoon cooking in conventional and gasifier oven.

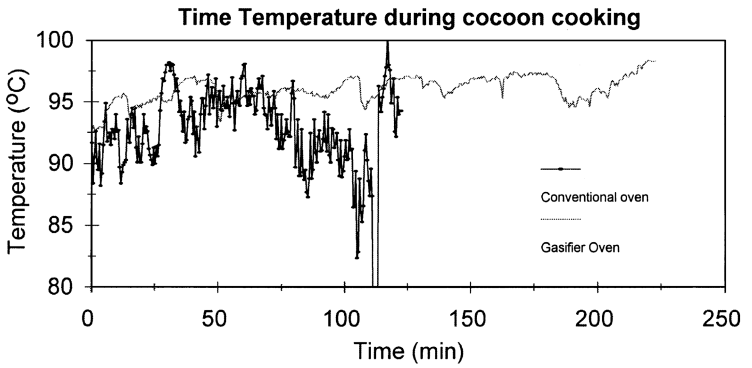

Fig. 3. Time, temperature profile during cocoon cooking in conventional and gasifier oven.

process parameters like temperature and level of cooking water in cooking vessel compared with conventional oven. Temperature activity profile of one of the vessel in conventional oven was also observed and shown in Fig. 2. It can be seen from the figure that temperature of the water varies from 80°C to 98°C whereas recommended temperature during cocoon cooking should be 92 ± 2°C. The same data is also collected for gasifier based oven and plotted as shown in Fig. 3. The temperature of the cooking water is always maintained between 93°C and 97°C throughout the cooking. The level of water in the cooking vessel of gasifier oven is automatic maintained.

In order to assess the quality of silk yarn produced in both the ovens, samples of silk yarn from six lots was sent to the Central Silk Board (CSB) laboratory at Dharmavaram for analysis. The test data is summarized in Table 4. It can be seen from the table that there is a definite improvement in silk yarn quality though both got equal points for visual examination and maximum deviation. There was definite improvement in winding test and size test for the gasifier silk. Probably, due to controlled process parameters the improved silk yield and quality was obtained on gasifier based oven. Economic viability of the gasifier-based oven was assessed based on the field testing of systems at Ramanagaram. The simple payback of investment calculated based on two different scenarios. First scenario is considering only wood saving benefit and second scenario considering both wood saving and silk yield

Table 4
Silk yarn quality test results

Oven type	Gasifier based oven						Existing oven					
Lot no.	1	2	3	4	5	6	1	2	3	4	5	6
Particulars	Marks (points out of 100)											
M1: Visual examination	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
M2: Winding test	29.0	29.0	22.0	32.0	24.0	22.0	29.0	27.0	22.0	22.0	24.0	22.0
M-3: Size test	35.0	29.0	33.0	21.0	29.0	27.0	26.0	25.0	15.0	22.0	25.0	17.0
M-4: Max deviation	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total (M1+M2+M3+M4)	80.5	74.5	71.5	69.5	69.5	65.5	71.5	68.5	53.5	60.5	65.5	55.5
Overall grade	I	II	II	II	II	II	II	II	III	II	II	III

Table 5
Cost benefit analysis of gasifier based oven

A.	*Capital investment* (*Rs*)	
	Total cost of the gasifier based oven system	65,000
	Total cost of conventional oven system	9000
	Addition capital investment on gasifier-based oven system (12)	56,000
B.	*Running cost* (*Rs*)	
	B1. Conventional oven	
	Fuelwood consumption per day (220 kg @ 1.00)	220.00
	B2. Gasifier oven	
	Fuelwood consumption per day (120 kg @ 1.00)	120.00
	Addition fuelwood cutting cost per day (120 kg @ 0.15)	18.00
	Cost of electricity for running blower per day (0.4 kW 10h @ 1.5)	6.00
	Total cost	140.00
C.	*Benefits* (*Rs*)	
	Running cost saving with gasifier oven per day (B_1 B_2)	80.00
D.	*Additional benefits from gasifier-based oven (Rs)*	
	Silk yield improvement per 100 kg cocoons (0.330 kg @ 1300)	429.00
	Total benefits (*C*+*D*)	509.00

improvement. However, other benefits like improvement in processing rate, improvement in silk yarn quality and environment improvement were also observed during the testing but not quantified. Therefore, these benefits are not considered in cost benefit analysis. The cost benefit analysis of gasifier based system is given in Table 5. Based on fuel-wood saving only the payback of investment comes to 700 days, i.e. $2\frac{1}{4}$ years. However, considering silk yield improvement also the payback of investment comes to 138 days, i.e. less than 6 months only. In financial terms this implies that the investment is very attractive. However, silk reeling being a micro-level industry, big investments may be difficult to come by easily, at least in the initial period of commercialization. Hence, a mechanism of commercialization involving more demonstration, setting up supply chain mechanism including finance, after sales service, etc. will have to be placed for gradual commercialization of the system.

Acknowledgements

The work described in this paper is developed under a project sponsored by Swiss Agency for Development & Cooperation (SDC) and authors are grateful to them for sponsoring this work. The support and encouragement of reclose, consultants, manufacturers and SDC staff throughout course of the project is high crucial for successful completion of the project and authors are thankful to all of them. The constant

support and encouragement of Dr. R.K. Pachauri, Director General TERI is gratefully acknowledged.

References

[1] Biennial Statistics Journal of the Central Silk Board, India, 1992.

[2] Mande S, Pai BR, Kishore VVN. Study of stoves used in the silk-reeling industry. Biomass and Bioenergy 2000;19: 51–61.

[3] Development of gasifier based silk reeling oven, project report submitted by Tata Energy Research Institute (TERI) New Delhi to Swiss Agency for development and Co-operation (SDC), New Delhi, January 1997. p. 53–5.