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Study of stoves used in the silk-reeling industry

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Abstract

The present study aims at evaluating the performance of the stoves used in the silk-reeling industry for the cocoon-cooking operation, in order to identify bottlenecks in achieving higher fuel efficiency and the ways and means to overcome these. The paper describes in detail the present process and stoves used in the silk-reeling industry, the findings of the survey of 236 cooking ovens in the field giving the present energy-use pattern. The details of energy and water balancing experiments, carried out for evaluating stove performance and to identify various heat and water streams to arrive at the useful heat required for the present cocoon-cooking process, are also given, along with possible energy-saving potentials. The results show that the useful energy required for the present cooking technique/practice is about 5440 and 3660 kJ/kg cocoon for cooking in the charka and the cottage basin oven, respectively.

Keywords: Silk-reeling; Biomass stoves; Energy consumption

1. Introduction

Silk holds a unique place in the textile world and is regarded as the 'Queen of Textiles'. India is a traditional sericultural country and ranks only next to China in silk production. Mulberry silk production accounts for the major (about 90%) share which is mainly concentrated in the states of Andhra Pradesh, Karnataka, and Tamil Nadu. While the states of Assam, Jammu & Kashmir, Uttar Pradesh and West Bengal produce non-mulberry silks like Tasar, Muga and Eri. India produces around 14 500 metric tons of natural silk annually. The majority of the silk is reeled either in the charka oven or in the cottage basin oven; both may be referred to as small-scale cottage industries. At present there are about 35 000 charka ovens and 26 000 cottage basin ovens installed in different states [1]. There are various fuels used and are mainly firewood for cottage basin ovens and local available loose biomass (such as groundnut shell, tamarind husk, rice husk, coffee bean husks, etc.) for charka units. It is estimated that about 100 000 tons of loose biomass and 125 000 tons of fuelwood are

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being consumed every year for the production of silk yarn. The distribution of silk-reeling units in different states is given in Table 1.

1.1. Process description

The worm rearer feeds the silkworms (pupae) with mulberry leaves and they grow rapidly. After the fifth instar (stage of worm growth), the worms are placed on bamboo mounts to allow them to spin their cocoons [2]. After the spinning is complete, the cocoons are sold to the reelers. The reelers buy the cocoons from the government-regulated cocoon markets and produce raw silk yarn. The reeling industry is predominantly a cottage-based one.

There are several steps involved in the production of raw silk yarn from cocoons [2]: (i) stifling; (ii) cooking; (iii) reeling; (iv) re-reeling; (v) skeining; (vi) bookmaking and bundling.

Thermal energy is needed for the first four steps; the first two steps are more energy intensive, accounting for the major share of total energy requirement. Stifling is a process used for killing the pupae and drying the cocoons for storage. There are two ways of stifling, namely with the help of steam (either in a basket or a barrel) or by using hot air. The stifled cocoons are then stored until they are needed for cooking. The processing of stifled cocoons, consisting of cooking, reeling, and re-reeling, is the main activity of the silk-reeling units. Prior to the reeling of silk from cocoons, they are cooked to unwind the continuous silk filament. Cooking is the process of locating the end of the silk baves by placing the cocoons in boiling water, contained in an aluminium or a copper cooking vessel, for about 1–2 minutes, with continuous, vigorous stirring with wooden rods. The sericin and part of the gum is dissolved in this operation, and the cocoons are then ready for continuous unwinding of the silk filament in reeling basins [3]. Two types of oven are used for cooking, namely the charka oven and the cottage basin oven.

The located ends of cooked cocoons are then placed onto the reels. Three types of reeling units exist, namely charka reeling units, cottage basin/domestic basin reeling units and multi-end reeling units. In re-reeling, the already reeled raw silk is re-reeled on to standard-size reels. The raw silk is then skeined and bundled.

Table 1
Distribution of silk-reeling units in India [1]

State	Number of ovens installed	
	Cottage basin	Charka
Karnataka	19 284	26 020
Andhra Pradesh	1 193	1 646
Tamil Nadu	3 379	590
West Bengal	1 200	6 000
Madhya Pradesh	40	97
Uttar Pradesh	115	–
Jammu & Kashmir	392	–
North-eastern states	156	237
Other states	110	65
Total	25 869	34 655

2. Stove designs

2.1. Charka oven

The majority of the charka units use non-woody, biomass fuels, such as groundnut shell, paddy husks, etc. This is the simplest mechanism for silk-reeling, in which both the cooking and reeling operations are carried out in the same basin. First, the water in the basin is brought to boiling temperature using higher burning rates of the fuel. The cocoons are then cooked for a few minutes, with simultaneous stirring and mixing. After the cooking is over, the temperature in the basin is reduced by adding cold water and simultaneously reducing the burning rate of the fuel by closing a damper to cut off the air supply. The manual reeling operation starts with the reeler rotating the charka by hand and an assistant attending to the process of feeding the silk threads to the charka. In some units, several charka ovens are installed under the same shed and the reel is power driven by a common shaft. After all the cocoons are reeled, the cooking operation starts again by increasing the burning rate and the process continues. The quality of yarn produced in charka units seems to be poor but the charka units account for nearly 50% of the raw silk produced in India.

Although charkas are not made according to any specifications of measurements, they are all similar in design and constructional detail. Generally each charka establishment installs five to six charkas and each consists of three distinct parts; the mud platform, the distributor and the reel. The mud platform is rectangular in shape usually measuring about 40–50 cm high, 70–80 cm wide and 120–130 cm long. The forepart has a built-in fireplace with a basin fitted over it. The other part of the platform is solid with a flat top which is intended for the reeler to sit on and attend to the reeling operations. The basin is of thick copper sheet and is generally of circular shape measuring about 45–50 cm in diameter and 20 cm in depth. Occasionally, instead of a copper basin which is comparatively costly, one half of a vertically bisected earthenware pot is used. Even the use of an aluminium basin is quite common. The basin is buried up to its brim in the mud platform with a spacious part of the basin's underside exposed to the fireplace below. The basin is used for both the cooking and the reeling operations (Fig. 1).

The fireplace, which is not provided with a grate or ash pit, is generally built for burning firewood or dry twigs. In some places it is designed for burning paddy husks or groundnut shells. At the opposite end of the opening there is a chimney provided for the flue gases to escape.

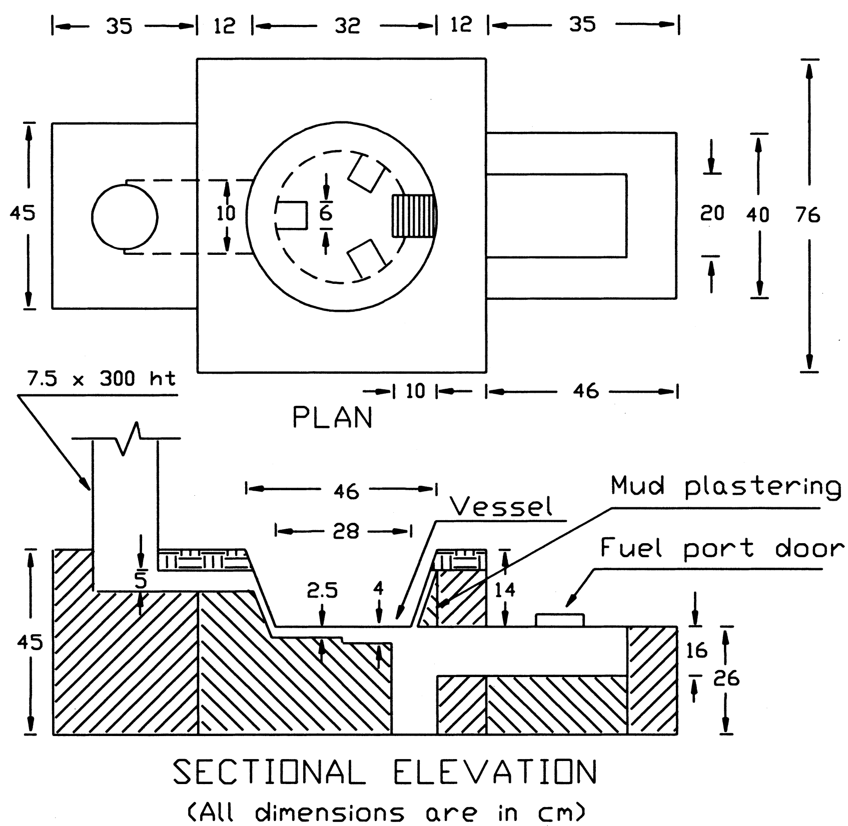

Fig. 1. Technical drawing of a charka oven.

2.2. Cottage basin oven

In the cottage basin system the cooking operations and the reeling operations are carried out separately. The cocoons are first cooked and then taken to the reeling basins.

The cooking unit consists of a masonry structure of a convenient height in which several — usually four — cooking pans are embedded in rows. The basins are normally made of copper. They are 20–22 cm in diameter and about 20 cm in depth. The oven is well constructed with an ash pit, grating and chimney for the flue gases to escape. In the path of the exhaust gases a fairly large metallic water drum is embedded to serve as a hot-water source to the reeling basins. The cooking unit is located a little distance away from the reeling unit to prevent the heat and smoke from causing disturbance to the reelers. The average water temperature in the cooking vessels is 87–96°C. A handful of cocoons are taken each time and put into the cooking pans. A stick is used to brush the cocoons to separate the floss and locate the ends of the filaments. The cocoons are now ready for reeling. The whole operation takes about 1–2 minutes.

There is a great variety, both in overall design and in dimensions, in the traditional ovens. Some of the varieties are shown in Figs. 2–5. The variations are as follows.

- Some ovens have a horizontal grate (Figs. 2 and 3) whereas others have an inclined step grate (Fig. 4).
- Many ovens have two chimneys, as shown in Figs. 2 and 3 and some have only one (Figs. 4 and 5).
- The dimensions of the combustion space vary widely. For example, the height of the combustion space varies from 30–40 cm and width varies from 80–95 cm.
- The hot-water drum is only partially buried into the oven structure, implying low waste-heat recovery. A metallic drum, made of cop-

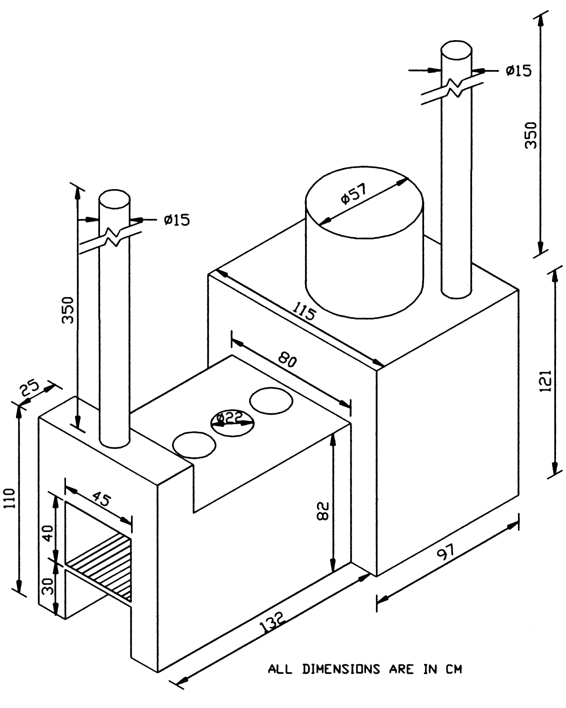

Fig. 2. Traditional cottage basin oven with two chimneys and single row of cooking basins.

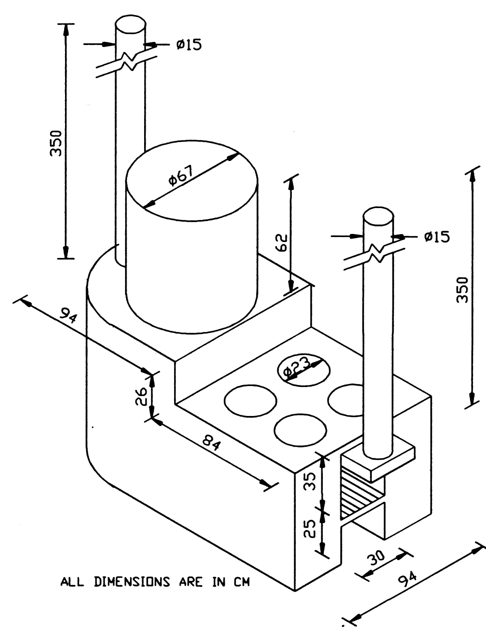

Fig. 3. Traditional cottage basin oven with two chimneys and two rows of cooking basins.

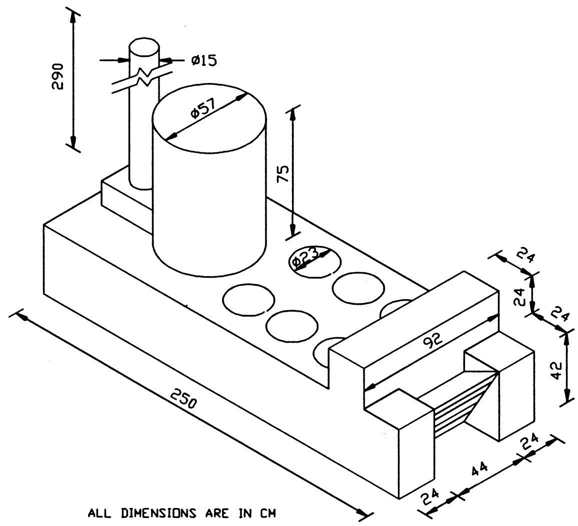

Fig. 4. Traditional cottage basin oven with stepped grate.

per or steel is generally used (Figs. 2–4) but sometimes it can be of a different shape (Fig. 5).

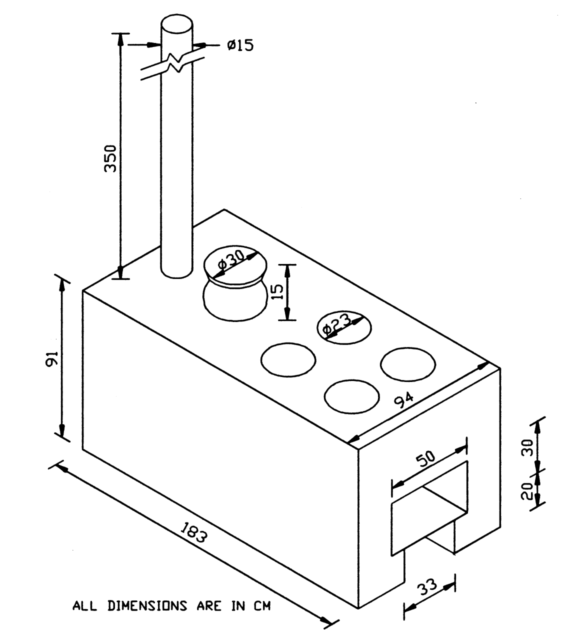

Fig. 5. Traditional cottage basin oven with different size and shape of water preheater.

- The arrangement of the vessels in the oven structure varies a lot. Sometimes the vessels (up to 5) are in a single row (Fig. 2), whereas in some ovens they are evenly spaced (Figs. 3–5).

3. Energy-use patterns

A detailed field survey was carried out in order to establish the energy-use pattern in the various types of ovens used in the silk-reeling industry. Traditional and improved charka and cottage basin ovens, spread over the traditional mulberry silk states of Andhra Pradesh, Karnataka, and Tamil Nadu, were covered in the survey [4].

3.1. Charka ovens

In all 72 traditional charka ovens, spread over three major southern states, were surveyed. It was observed that different types of locally available biomass fuels are used in different regions, e.g. tamarind husk (Kanakpura, Ramanagaram), paddy husk plus coffee-bean shell (Kollegal), paddy husk and groundnut shell (Chintamani, Kolar), groundnut shell (Madanapally) and eucalyptus leaves (Hossur and Palacode). Most of the reelers in the charka sector are poor and depend solely on the returns of the proceeds of the previous day for purchasing fresh cocoons. It is quite common in this sector for the reelers to take up piece-work jobs from bigger and more affluent reelers. Also, many reelers concentrate on processing second-grade cocoons. All these factors contribute to the variation in cocoon consumption. The survey findings for charka ovens are summarized in Table 2. The following broad observations can be made.

- The charka ovens do not use firewood, but use a variety of locally available loose biomass.
- Daily fuel consumption in charka units ranges from 17 to 27 kg for slow-burning fuels and 26–37 kg for fast-burning fuels.
- A variety of low cost, locally available, loose-biomass fuels are used.

Table 2
Summary of survey findings: charka ovens

Fuel type	Traditional			
	Number of units	Cocoons processed (kg/day)	Specific fuel consumption (kg/kg cocoon)	Specific energy consumption (MJ/kg cocoon)
Groundnut shell	16	10.6 (3.61)[a]	2.44 (0.83)	50.0 (17.0)
Paddy husk and coffee-bean shell	2	12.88 (1.63)	1.58 (0.01)	26.7 (0.1)
Coffee-bean shell	–	–	–	–
Eucalyptus leaves	20	11.42 (3.02)	3.26 (0.88)	72.7 (19.6)
Saw-mill waste	14	24.75 (5.40)	1.93 (0.27)	25.9 (3.6)
Paddy husk	17	18.94 (5.06)	1.87 (0.2)	31.0 (3.3)

[a] *Note*: Numbers in parentheses indicate standard deviation.

- The specific fuel consumption seems to be higher (2.44–3.20 kg/kg cocoon) for fast-burning fuels such as groundnut shells or eucalyptus leaves compared with slow-burning fuels (1.58–1.93 kg/kg cocoon) such as paddy husk or saw-mill waste.
- The variation in specific fuel consumption is low for slow-burning fuels (3–10%) and high for fast-burning fuels (21–34%).

3.2. Cottage basin ovens

During the course of the study, 113 traditional cottage basin ovens were surveyed. The surveyed traditional ovens had 2–6 cooking vessels. Table 3 summarizes the survey findings of cottage basin ovens for different types of fuels used. The following broad observations can be made.

- Woody biomass in the form of wood logs is predominantly used as fuel.
- The daily fuel consumption in cottage basin units ranges from 50 to 285 kg.
- If comparison is made for the same fuel use, the cottage basin oven consumes 50–55% less for groundnut shell (fast-burning fuel) and about 25–30% less for saw-mill waste (slow-burning fuel) as compared with charka ovens.

Table 3
Summary of survey findings: cottage basin ovens

Fuel used	Traditional cottage basin			
	Number of units (Number of pans)	Cocoons processed (kg/day)	Specific fuel consumption (kg/kg cocoon)	Specific energy consumption (MJ/kg cocoon)
Tamarind wood	60 (3–6)[a]	82.34 (26.25)	1.65 (0.50)	33.5 (10.2)
Eucalyptus wood	1 (4)	75.00 (0.00)	1.89 (0.00)	38.4 (0.0)
Pong Pinnat	7 (4–6)	90.14 (7.49)	1.60 (0.18)	28.1 (3.2)
Neem wood	22 (2–6)	44.26 (35.28)	1.71 (0.57)	33.9 (11.3)
Saw-mill waste	1 (2)	30.00 (0.00)	1.45 (0.00)	32.3 (0.0)
Maize cobs	4 (4)	72.00 (17.00)	1.48 (0.17)	23.1 (2.6)
Paddy husk	3 (3–6)	79.50 (17.53)	1.54 (0.21)	25.4 (3.4)
Groundnut shell	4 (2–5)	45.00 (35.00)	1.07 (0.09)	21.8 (1.9)
Eucalyptus leaves	2 (3–4)	48.25 (1.25)	2.55 (0.38)	34.2 (5.1)
Tamarind husk	9 (4–6)	88.67 (41.41)	1.74 (0.80)	31.9 (15.0)

[a] *Note*: Numbers in parentheses indicate standard deviation and number of pans.

4. Performance of stoves

In present cooking operations there is bound to be minimum water carryover, along with cooked cocoon, spillage and drainage losses, depending on the variation of operation from unit to unit. As the process duration is hardly 2–3 minutes, and cocoons have to be stirred continuously in water with a stick in order to locate the thread ends, evaporation loss is unavoidable. The heat loss due to spillage, carryover of hot water and evaporation loss is not actually useful heat, but can be, depending on the type of process [4]. A water-boiling test usually establishes the thermal efficiency of a stove-pot combination, but such an entity as ‘thermal efficiency’ cannot be defined for silk-reeling units in a straightforward manner. Probably useful energy, and possibly minimum energy, requirement can be worked out by a detailed energy and water balance.

In the silk-reeling unit the useful heat includes evaporation from the cooking vessels, the water quantity exchanged from the cooking basins to the reeling basins and also unavoidable drainage loss at the end of each batch to replace dirty hot water with fresh clean water. The unutilized part of the heat consists of various heat streams representing loss of heat by different routes. These heat streams include:

1. Flue gas loss (heat carried away through the chimney in the form of hot flue gas).
2. Heat loss through oven openings (heat transfer by radiation mode from fuel bed and flame to ambient, through fuel port and other oven openings, if any).
3. Surface heat loss (loss of heat by conduction, convection and radiation due to the temperature gradient existing between the hot oven surface and the cool surrounding air).
4. Heat loss due to oven thermal mass (loss of heat accumulated by oven structure, due to heat capacity of oven material, resulting rise in oven temperature, which is liberated back to ambient temperature bringing it back to room temperature) when oven is not in operation.
5. An unaccounted portion of heat loss, including loss through hot ash and heat content of charcoal formed during the operation, which could not be monitored as it was used in the re-reeling operation or for igniting a stifling oven.

Hence, in order to understand the performance of the ovens, detailed energy-balance experiments were undertaken for calculation of the above heat streams and water balance for the cooking process at a few selected ovens in the field.

4.1. Water-balance experiments

Since the cooking basin is the component of the silk-reeling unit where the majority of heat-input energy is given through fuel combustion, a water-balance exercise was carried out considering cooking basins as the ‘control volume’. All the energy and water balance is done for this control volume. The water-balance chart for cooking basins is shown in Fig. 6.

In order to conduct the water-balance studies on the ovens the following parameters were monitored.

1. Total water consumption for the batch.
2. Water quantity in and out of the cooking basin.
3. Water quantity drained after the batch for refill with fresh water.
4. Cocoon consumption for the batch.
5. Quantity of pupae (secondary cocoons) recycled for the next batch.
6. Fuel consumption for the batch.
7. The temperature of the cooking basin and the feed water.
8. Quantity of waste silk produced.

Total water consumption for the batch was monitored by weighing a known quantity of water before the start of the batch. The weight of fresh cocoons was recorded every time the person cooking was about to put them into the basin. Along with this the recycled cocoons coming from the reeling basins were also weighed. This was done for a batch in order to know the ratio of fresh cocoons to recycled cocoons entering the cooking basin. Cooked cocoons were again weighed immediately after removal from the cooking basin, before taking them to the reeling basin. This gives the quantity of water carryover from cooking basin to reeling basin. The pupae from the cooking basin were collected separately in order to know the free water going out with them. At the end of the batch the drain-off water was weighed, as were the cocoons remaining for recycling in the next batch.

The main difficulty encountered during the experimental work was to monitor or measure the spillage losses and evaporation losses as there was no definite means to measure them. Therefore, evaporation loss was calculated by using formulas from the water temperature and surrounding air condition (temperature and humidity) and spillage was calculated by difference.

The findings of the water-balance exercise can be summarized as follows.

- The specific water consumption for the cocoon-cooking operation is higher (6–12 kg/kg cocoon) in the case of the charka oven than the cottage basin oven (4.5–9 kg/kg cocoon).
- Drainage loss (50–67%) and loss due to water carryover from the cooking basin to the reeling basin (19–45%) are a major part of water consumption for the charka oven and the cottage basin oven respectively.
- In some cottage basin ovens spillage loss also forms a significant (as high as 30%) portion of water consumption due to the poor operation practice followed.
- Under the present operation practice followed in the reeling units, the useful heat required for the charka and the cottage basin cooking operations works out to be about 5440 and 3660 kJ/kg cocoon, respectively. The reason for the higher energy requirement for charka ovens can be attributed to the slower operation and large evaporation area available resulting in much heat loss due to evaporation. Also water consumption/kg of cocoon, and hence heat loss due to drainage of hot water, is more in the case of charka ovens.

4.2. Energy-balance experiments

In order to conduct the energy-balance experiments the following parameters were monitored for each batch of silk production.

1. Oxygen, carbon dioxide (volume %) in the flue gases.
2. Flue-gas temperature.

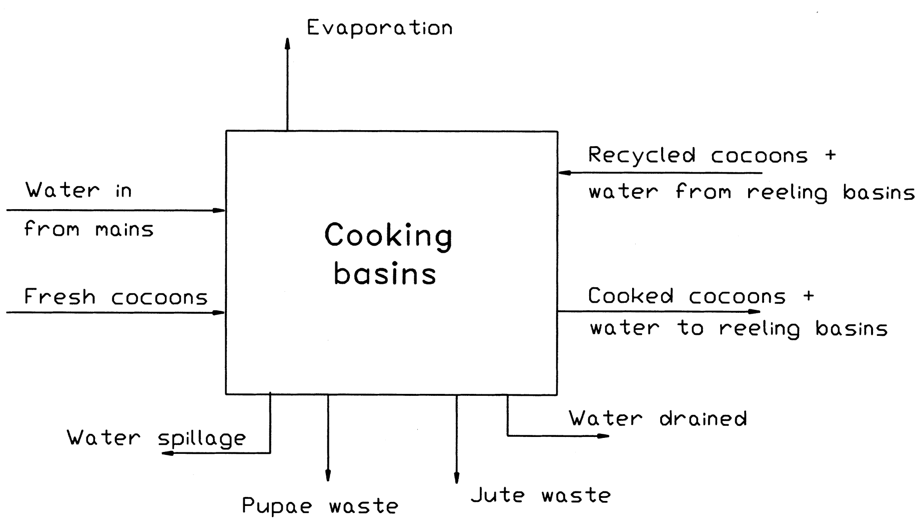

Fig. 6. Water-balance chart for cooking basins.

3. Cooking-basin temperatures.
4. Drum-water temperature.
5. Reeling-basin temperature.
6. Dry-bulb and wet-bulb temperatures.
7. Temperatures of the oven surfaces.
8. Cocoon consumption.
9. Silk production.
10. Oven dimensions.

On the basis of the various operating parameters recorded, heat-balance calculations were carried out to estimate the heat losses in different heat streams. This also helps in assessing the magnitude of each type of loss and scope for its reduction. The results of the energy balance are summarized in Fig. 7 in the form of a Sankey diagram, showing various heat streams. The fraction of heat loss in ash plus charcoal is substantial in the cottage basin oven as compared with the charka oven, as hot charcoal, which is required for the re-reeling operation, is removed from the cottage basin oven. It is spread below the re-reeling shaft to maintain warm air to dry the yarn while it is re-reeled on a standard-size reel.

5. Potential for energy saving in the silk-reeling sector

The specific fuel-consumption levels in charka units are higher for loose fast-burning fuels (2.44 and 3.26 kg/kg cocoon respectively for groundnut shell and eucalyptus leaves) compared to about 1.5–2.0 kg wood/kg cocoon in the case of cottage basin ovens and, therefore, offers greater scope for improvement. The flue-gas losses are higher (32–37%) in the case

the yarn while it is re-reeled on standard size reel.

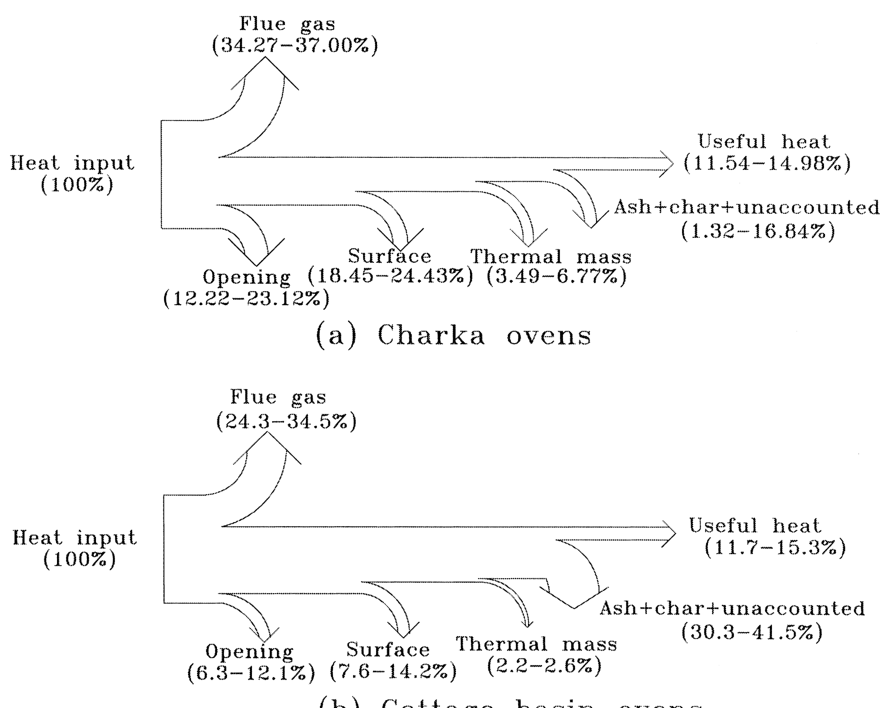

Fig. 7. Sankey diagram showing various heat streams of stoves.

of charka ovens than of that in cottage basin ovens (24–34%) offering greater scope for energy saving by way of reducing flue-gas loss.

Based on the water-balance exercise, it was found that the useful heat requirement to cook 1 kg of cocoons, under the present operating practice, is about 5440 kJ in the case of charka ovens and 3660 kJ in the case of cottage basin ovens. The reason for the higher value of the charka oven can be attributed to longer periods of operation and larger cooking-vessel area. The energy consumption can be brought down if cooking and reeling processes are carried out separately, maybe on the same platform, in two vessels and utilizing flue gases to heat the reeling-basin water. This will make the operation faster, as cooking and reeling can be carried out simultaneously, and the cooking pot dimensions can be made smaller to reduce evaporation loss.

From the present energy-use pattern, it can be observed that the majority of charka units use locally available loose biomass as fuel. Seasonal variations in type of fuel used is thus expected to make it difficult to develop one common design for all charka ovens, as burning characteristics drastically change for each fuel type. Therefore, retrofitting of ovens to reduce heat loss (such as flue gas, fuel port opening and evaporation) by controlled burning will be an appropriate way to achieve energy efficiency.

Energy savings in cottage basin ovens, which consume a great deal of logs, can go a long way in easing the deforestation problem. Also, as the cottage basin reelers have comparatively good financial stability compared with charka reelers, they can go for retrofitting or even for newer designs of stove if there are economically attractive interventions. Retrofitting of ovens by way of controlled burning rate, maximum flue-gas heat recovery and reducing other losses, can result in marginal energy savings (about 25%) and, therefore, are less likely to attract reelers. Hence, there is a need to develop an alternate design suitable for meeting the energy demands of silk-reeling units with substantial fuel saving so as to make it an economically viable intervention.

6. Findings

From the extensive survey and energy-balance exercise of charka and cottage basin ovens carried out during the course of this study the following facts emerge:

- The majority of the charka ovens use locally available biomass as fuel, whereas cottage basin ovens use large wood logs as a major source of heat energy.
- The thermal performance of the charka stove, which uses several biomass residues in loose form, is affected significantly by its burning characteristic. Lower burning rates, and hence lower flue-gas losses, are associated with slow-burning fuels like rice husk, saw-mill waste, etc. whereas, fast-burning fuels such as eucalyptus leaves or groundnut shell, etc. result in higher burning rates and hence higher flue-gas loss.
- An important constraint of the cooking and reeling processes is that the cooking and reeling basins can not be covered with lids, thus allowing for continuous, and significant heat loss due to evaporation. Also, drainage loss when changing the dirty water with fresh after every batch is a necessity of the process.
- In present cooking operations there is bound to be minimum heat loss from the cooking basin due to hot water carryover (along with the cooked cocoons) from the cooking to the reeling basin (27–30%), drainage of dirty water after every batch (charka: 50–67%, cottage basin: 19–45%), evaporation (15–25%) from continuously stirred boiling water in the cooking pots, hot water wasted along with pupae waste and spillage losses depending on the procedure of the operation, which varies from unit to unit.
- Another important factor is the time pressure under which cooking takes place as the cooking operation has to be completed within 2–3 minutes, which leads people to increase the burning rate resulting in higher flue-gas temperature and hence higher flue-gas loss.
- Water-balance experiments indicate that, for the current practice of cocoon cooking, the

amount of useful heat required for cooking each kg of cocoon works out to be about 5440 and 3660 kJ for charka and cottage basin ovens respectively.

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