SOLAR ENERGY FOR TEA PROCESSING IN SRI LANKA

by

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Abstract

Certain features of tea processing thermal loads and the solar radiation climate in the tea growing areas make the application of solar heating for tea processing technically attractive. In South India solar energy systems have been tried at experimental level or installed in tea factories with government subsidies during the last decade. In Sri Lanka, very little progress has been made in this area. The performance of solar energy systems depends on design factors related to the solar resource, tea processing thermal loads and type of solar system. These factors have to be carefully considered in the design of solar energy systems for tea processing in Sri Lanka which has a reputation for quality tea. A major feasibility study in 1983 on the development of solar energy for tea processing in Sri Lanka has failed to consider these factors. This feasibility study and the South Indian experience are reviewed. The present authors have done a comprehensive study on the potential of solar energy in tea processing. To highlight the difference in approach of this study, it's essentials are presented along with the reviews. A methodology for the evaluation of economic performance of solar systems is also presented. The results identify the direction for further research and development work and draw attention to the need for a national strategy to develop solar energy for tea processing.

1.0 Introduction

Sri Lanka produces about 200 million kg of black tea annually using an equivalent of over 400 million kg of fire wood for heat generation which is required for withering and drying operations. Tea industry accounts for 33% of the national industrial fuel wood consumption and it is also the second largest consumer of oil. Electricity and fuel bill accounts for 5 to 12% of the total manufacturing cost (Van der Knijff, 1990). This fact has probably discouraged any efforts in the tea industry to improve energy efficiency and to introduce energy substitution. However, from a national perspective tea industry seems a strong candidate for energy conservation and substitution efforts.

Solar energy can be used to substitute a significant fraction of the heat energy in tea processing using relatively simple technologies. This has been demonstrated in South India (Palaniappan and Kumar, 1994 and UPASI, 1990/1992). Most of the tea manufacturing areas in Sri Lanka enjoy good sunshine varying from 1400 hours a year in Nuwara Eliya to 2300 hours a year in Kandy. These factors are definite advantages for the introduction of solar energy for tea processing.

A study was undertaken by LAING Design and Development Centre (UK) in 1983 to examine the feasibility of developing solar energy to reduce energy consumption in tea factories in Sri Lanka. After field trials they proposed a pilot tea manufacturing plant to utilize solar energy to meet an estimated 80% of the thermal energy requirements. This proposal however was not implemented.

The contribution of a solar energy system to a tea processing plant depends basically on three factors. They are the availability of the solar resource, the solar system design and the tea processing thermal loads. The main objective of this paper is to present a discussion on these. These factors have been considered in detail in a research study by the authors to assess the potential of solar energy in tea processing. A brief review of this work and previous work in this area are presented. The evaluation of the economic performance of solar energy systems is also discussed.

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2.0 Solar Energy resource in the tea growing areas

An estimation of the solar radiation availability in the tea growing areas is essential in the evaluation of this resource as well as for the design of solar energy systems. These are available as global radiation measurements from some agro-meteorological stations and also as sunshine data from some agro-meteorological stations and from tea research stations. Global radiation could be estimated from sunshine data using correlations by Samuel and Srikanthan (1981). Global radiation values are given in table 1 for six stations in the tea growing areas. These stations belong to different regions of tea manufacture to be discussed in the next section. The seasonal solar radiation variability can be seen from this table.

3.0 Tea processing thermal loads and Solar Energy

Unlike in conventional energy systems, the performance of a solar energy system supplying heat to tea processing is influenced by a variety of factors related to the heat loads. These are discussed in this section.

Heat energy is used for withering and drying; the two dehydration operations in tea manufacture. Withering is done either naturally using ambient air if it is sufficiently dry or artificially using moist ambient air after heating it by a few degrees. In orthodox manufacture withering reduces moisture in the green leaf from about 80% to about 55% on the wet basis and this corresponds to the removal of 2.7kg of moisture for every kg of made tea. In the CTC manufacture a softer wither is obtained where the withered leaf moisture is kept at 70% with corresponding moisture removal of 1.62kg per kg black tea. Final drying gives a black tea of 3% moisture (Samaraweera, 1986).

Hot air temperature for drying is 85 to 90C for ECPDs (Endless Chain Pressure Dryers).and 127C for FBDs (Fluidized Bed Dryers). Orthodox manufacture could use either a ECPD or a FBD for final drying but a FBD is a must for CTC manufacture.

The collection of solar energy could be done more efficiently, and therefore more economically, at lower temperatures. Hence tea manufacture with higher withering loads are more attractive for solar energy applications. In this view orthodox manufacture has an advantage. Since ECPD operate at lower temperature than FBD solar energy could be supplied more economically to maximize fuel savings in ECPD.

The preceding observations are based purely on the quantity and the temperature of heat loads. But there are additional factors which influence the performance of a solar system. Ideally, a solar energy system should be able to operate at its design capacity always. The intermittent nature of solar radiation and its seasonal variation makes it impossible for the operation of a solar energy system to reach this ideal. In tea manufacture, a significant seasonal variation of the tea production occurs due to seasonal weather.

Table 1.

Monthly mean global radiation (in MJ/m2/day) at few stations in the tea growing areas.

Month	Ratnapura	Kandy	Talawakellem	Nuwara Eliya	Diyatalawa	Passara
Jan.	14.97	16.50	16.53	10.54	11.48	12.61
Feb.	16.78	16.43	18.75	11.75	13.29	17.47
Mar.	16.29	15.78	19.98	13.24	14.67	17.84
Apr.	13.97	14.79	18.24	11.40	12.87	16.62
May	13.95	15.83	15.63	8.18	13.34	16.00
June	14.10	13.72	11.58	7.28	13.94	16.27
July	13.35	13.32	10.90	6.34	13.29	16.00
Aug.	14.70	13.22	12.52	6.77	14.45	15.88
Sept.	14.50	13.28	14.18	7.50	12.53	14.93
Oct.	13.26	12.57	14.52	8.64	11.59	14.27
Nov.	11.34	12.93	15.17	8.65	10.25	11.63
Dec.	12.20	13.83	14.38	9.13	9.24	7.50

This results in an uneven load pattern over the year thus lowering the performance of a solar energy system. Unlike drying heat loads, the withering heat loads exhibit an additional feature related to the local weather. Normally on sunny dry days, withering loads are low and on gloomy, wet days they are high thus showing an inverse relation to the solar radiation.

The diurnal distribution of the tea processing heat loads is another factor influencing the performance of a solar system. Tea manufacturing practices which determines the distribution of withering and drying loads, vary in the different regions due to quality and management requirements. For instance, the quality manufacture in the Uva region during the south west monsoon starts between 10pm and 1am. But the non-quality manufacture in the low country starts around 8 am throughout the year.

The seasonal variation of tea production, withering loads, manufacturing practices and solar radiation all have an identifiable pattern in a particular region of the tea country. These factors together influence the performance of a solar energy system. Therefore it is desirable to identify the different regions of tea manufacture in the consideration of solar energy applications. Six regions are identified according to a regional differentiation suggested by Marby(1972) which is based on the altitude, on the change of environmental factors from west to east, that is so prominent in Sri Lanka under the impact of monsoons, and on the seasons. The regions are as follows.

1. The south-western low-country (altitude up to 600m) - LL
2. The southern, western and northern mid-country (altitude from 600 to 1200m) - WM
3. The eastern mid-country with the dry centre of Uva (altitude from 600 to 1200m) - EM
4. The western up-country and the Knuckels range (altitude from 1200 to 1800m) - WU
5. The eastern up-country (altitude from 1200 to 1800m) - EU
6. The central top-country (altitude from 1800 to 2250m) - CT

A solar energy system would perform differently in these six regions.

4. 0 Solar Energy Systems for tea processing

A solar energy system is designed to substitute a part of the energy supplied by a conventional source such as oil. The installation of a solar system will reduce the fuel bill and the resulting savings is the economic return from the solar investment. Solar systems are generally designed to supply only a part of the heat load to avoid the economic penalties associated with a system supplying the full process heat load. The fraction of the heat load supplied by the solar system is known as the solar fraction (Duffie and Beckman, 1991).

$$\text{Solar fraction } (F_r) = \frac{\text{annual solar energy supplied to the process } (L_s)}{\text{total annual process thermal load } (L_r)}$$

In majority of places, energy efficiency in tea manufacture has been found to be low (Van der Knijff, 1990). More often than not, the energy efficiency could be improved with higher returns on investment than would be obtained from an equivalent solar investment. Therefore the introduction of solar energy would be desirable only after the energy efficiency of tea manufacture has been improved. Such measures should include good house keeping practices (routine maintenance of the air heater and furnace, drying of fuel wood etc.), installation of efficient air heaters, and improvement of withering heat utilization. The installation of more efficient dryers may also be tried as a final measure.

The solar designer could design the whole manufacturing process selecting from efficient withering systems and drying systems and then incorporating suitable solar systems with them to achieve the highest reduction of conventional energy use. Alternately, he could also design solar systems that could appropriately be incorporated in to the existing manufacturing process.

In general there are four possible modes for the application of solar energy to tea processing.

(1). Solar augmentation without storage:

Solar system supplies heat to the process at the required temperature during sunshine hours. Conventional air heater works during non-solar hours as a back up supplying heat to the process in parallel with the solar system.

(2) Solar augmentation with storage:

Solar fraction can be improved over case (1)

(3) Solar pre-heating without storage:

Solar energy is used to pre-heat air for drying. Conventional air heater works in series with the solar energy supply to bring air to final process temperature.

(4) Solar pre-heating with storage:

A heat storage could supply solar heat even during non-solar hours and improve the solar fraction over case (3).

Selection of the mode and the type of solar system will depend on the process load requirements and economics of operation.

Withering requires very low grade heat (i.e. few degrees above the ambient) and therefore solar energy could best be utilized for augmentation. Withering heat loads are generally distributed over the non-solar hours and hence the solar systems will require an energy storage. To account for the inverse relation of these loads to solar radiation a solar system must have adequate storage for a few days of operation if a significant solar fraction is to be achieved. Solar systems for tea drying could operate in any one of the four modes given above.

5.0 Previous work on solar energy applications in tea processing

Solar air pre-heating systems and hot water storage systems have been tried in Southern India during the last decade. This experience clearly demonstrates the technical feasibility of these solar energy systems in tea processing. A number of air pre-heating systems have been installed with government subsidies to promote solar energy applications in tea processing.

The research study by the present authors to assess the potential of solar energy in tea processing in Sri Lanka is so far the most comprehensive study in this area. In addition to this LAING Design and Development Centre (UK) (1983) undertook a study on the application of solar energy in tea processing on behalf of the Commission of the European Communities. These are discussed next.

5.1 Solar energy trials at UPASI Tea Research Institute

United Planters' Association of Southern India (UPASI) had undertaken a project on Integrated Energy Systems for tea manufacture at their Tea Research Institute which included a test on a solar hot water system and a solar hot air system (UPASI 1990 and 1992). The solar hot air system consisting of 20 collector panels of 2m2 each was designed to supply 2000kg of hot air per hour at 55 to 60C for an average 5.9 hours per day. Solar hot air was used for drying as well as for withering during day time. The solar hot water system consisted of 20m2 of water collectors which were designed to supply 1250 liters of hot water per day at 60C. Solar hot water was used during night hours for heating air for withering. Any heat in excess of the demand for withering would be used for pre-heating air for drying.

The performance of the two solar systems have been monitored at UPASI- TRI in Annamalais area which has an annual sun shine of 2149hrs. The energy gain E, (in kcal/m2/day) of the two systems have been empirically correlated to the daily sunshine S (in min) using the following equations.

Solar hot air system: $E = 4.045*S + 779.63$

Solar hot water system: $E = 4.873*S + 827.68$

The pay back period for the solar hot air system was found to be 6.1 years. The system cost about IRs 1.2 million excluding any subsidy (ie. approximately US$ 223/m2 of collector area) (Ramasamy and Rajendiran, 1993).

5.2 Solar air pre-heating systems for tea processing in India

A number of air pre-heating systems have been in operation in south India (Palaniappan and Kumar, 1994). In this region there are no serious quality considerations in the manufacture and tea drying is normally done during the daytime throughout the year. A schematic of such a system is shown in figure 1. During solar hours they supply pre-heated air for drying and hot air for withering. These systems incorporate roof integrated air collectors and a black painted roof area with a ceiling space for heating air entering the collectors. One of these systems with a 212m2 of collector area cost US$74.4 per square metre of collector. And in one year of operation this system is claimed to have saved a 35% of the conventional energy bill.

5.3 CEC study on solar energy systems for tea processing in Sri Lanka

The Commission of the European Communities (CEC) funded a study in Sri Lanka in 1983, to examine the feasibility of developing solar energy to reduce energy consumption in tea processing plants. LAING design and development centre (UK) who commissioned this study attempted to design a combined solar heat collection and tea drying process to satisfy the technical, economic and quality considerations simultaneously. The schematic of this system is given in figure 2. A continuous fermentation system and a improved two stage dryer have been included to improve the energy efficiency. The solar system consists of air collectors and a heat storage capable of storing heat from the solar collectors, heat recovered from the dryer exhaust and heat generated in the conventional heater. Solar energy is supplied to the dryer during solar hours in the augmentation mode whenever the radiation levels are adequately high. At other times collected solar energy is supplied to the storage. The full withering heat is supplied by the heat storage.

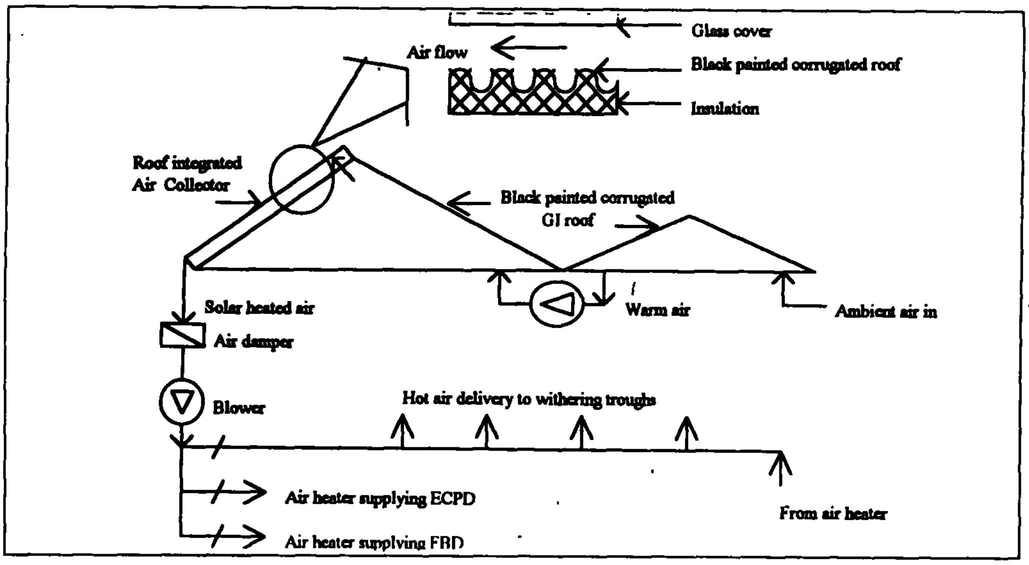

Figure 1. Schematic of a roof integrated solar air heating system at a tea factory in Tamil Nadu, South India.

Solar energy system designs which are capable of supplying 80% of the energy for a factory producing 800kg of tea over a 8 hour period using the energy efficient tea manufacture would cost US$390 per square metre of collector area.

Though this is the first substantial study on solar application in Sri Lankan tea processing, it has failed to consider in detail some of the most important factors. First, this study has neglected the significant variations of solar energy resource in the tea country and the differences in manufacturing practices in different regions. Average conditions for the whole of the tea growing area have been considered in the study. Then their choice of a single solar system for both withering and drying is not technically the best option due to the significant differences in the process temperatures. Their objective of the development of solar energy to reduce energy consumption in tea processing has lost sight of the economic aspects in the selection of the designs. They have tried to overcome the negative effect of different manufacturing requirements in the different areas on the operation of the solar system by introducing a controlled fermentation system which

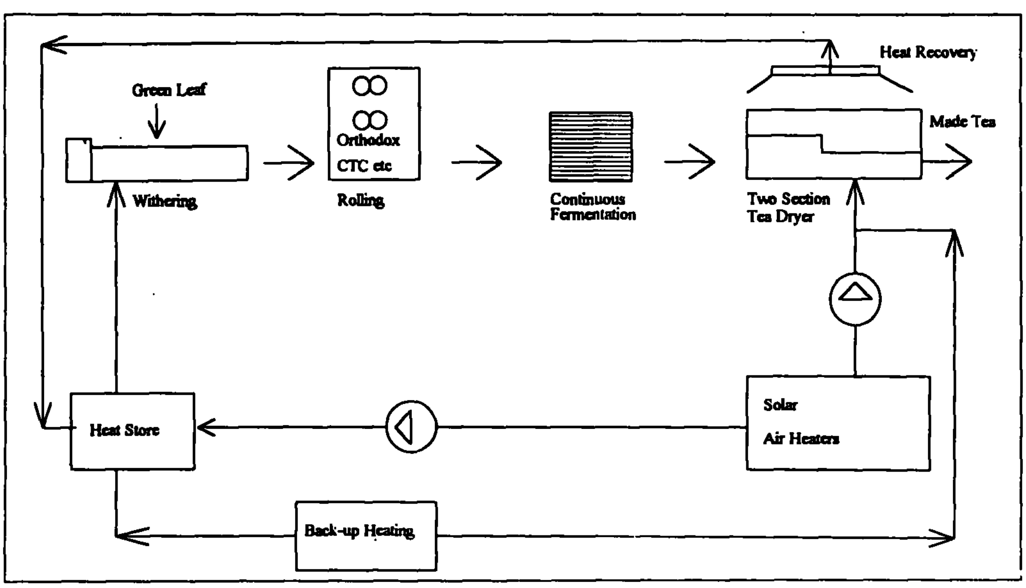

Figure 2. Schematic of the energy efficient tea processing method using solar heating.

allows the tea to be dried during solar hours. The acceptability of such an arrangement is yet to be proved in the Sri Lankan tea manufacture which have a reputation for quality.

5.4 SAHAGS for tea processing in Sri Lanka

A research study was carried out by the present authors to assess the potential of solar assisted hot air generating systems (SAHAGS) in tea processing (Weeratunga Arachchi, 1997). This study considered the regional and temporal variations of solar radiation, crop yield and the manufacturing practices as described in the preceding sections.

Considering the different process temperatures (warm air at 5C above the ambient for withering of the green tea leaf and hot air at 90C for drying of the fermented tea) and tea processing schedules, two types of solar systems were selected; one for withering and another for drying. Solar air pre-heating systems using flat plate air collectors were considered for drying. Solar hot water systems using flat plate collectors and large storages were selected for withering. These systems were integrated into the existing manufacturing process with minimum modifications.

Solar pre-heating systems show certain advantages over the augmenting systems. They will operate whenever the dryer is in operation even under low radiation conditions. Augmentation systems will have to dump some energy during high solar radiation hours to maintain a constant temperature of the air supply. The pre-heating systems will utilize all the solar energy collected since there is no energy dumping. These systems operate at lower temperatures than augmentation systems and hence attain higher collection efficiencies. These factors make pre-heating systems more economical than augmentation systems.

Solar hot air systems with rock bed storage would be a feasible alternative to the solar hot water storage system for withering heat supply. Storage of solar heat in water offers many advantages over the rock bed storage. Due to high heat capacity of water, hot water storage would require smaller volumes. Storage and extraction of heat in a rock bed require handling of large volumes of air which in turn require greater amounts of electrical energy. Large ducts will be required between the rock bed storage and the withering troughs for the transport of air and this can cause space problems in some cases.

The performance of the two types of systems in the different regions of manufacture were obtained using computer simulations. Model factories producing orthodox tea were considered. A model factory has a capacity to manufacture a maximum 1000kg of black tea per day and its daily output will be dictated by the typical crop yield pattern in the region. Diurnal distribution of the tea processing thermal loads in a model factory is determined by the typical manufacturing requirements in that region. Withering heat loads are estimated from a typical factory in the region. The solar radiation data in table 1 were used in the simulations.

(a). Air pre-heating systems for drying

The schematic of the air pre-heating system is given in figure 3. This system does not include a solar energy storage and supplies pre-heated air for drying only during solar hours. An induced draft fan moves the air through the air collectors to the auxiliary heater. A rock bed storage which is installed after the conventional auxiliary air heater acts only as a buffer taking care of the intermittent solar radiation.

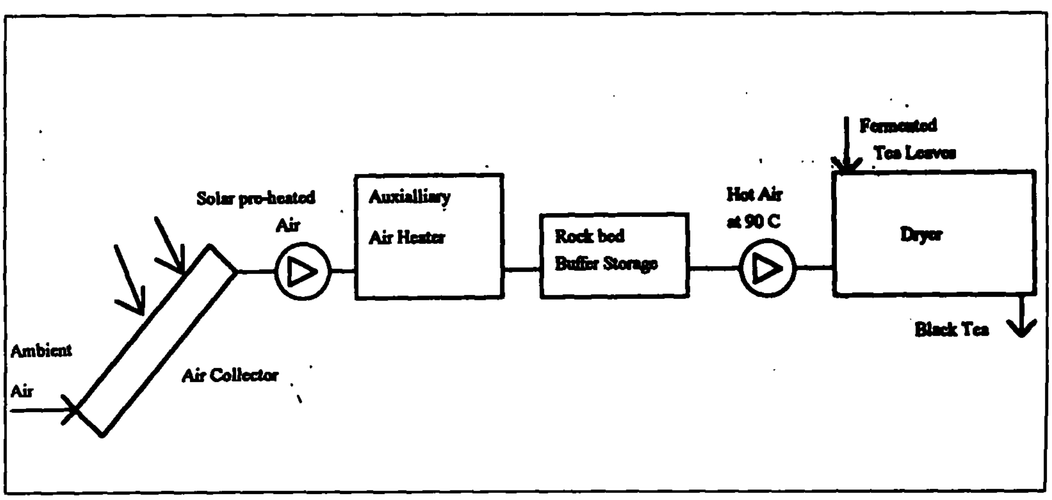

Figure 3. Schematic of the air pre-heating systems for tea drying.

The air collectors are of rear duct type with a single glass cover and a black absorber. The collector duct size has been optimized based on a collector pressure drop of 150Pa. The collector efficiency curve obtained from such optimizations is given in figure 4. This graph shows the efficiency as a function of the collector specific flow rate m/Ac (indicated at the end of radial dotted lines) and the abscissa shows the ratio of the degree of air pre-heat to the incident radiation.

The performance of these air pre-heating systems in model factories in different regions of manufacture are shown in figure 5. ECPD supplied with hot air at 90C have been considered. Tea production and heat loads for the model factories from the six regions are shown in table 2.

The graph gives the variation of the solar fraction with the size of the solar system that is indicated by the area of the solar collectors. The contribution of solar systems in the region CT seem to be poor and it would be impractical to obtain a solar fraction greater than 10%. Very significant solar contributions can be achieved in the regions LL, WM, EM, and WU. The simulation studies also show that the addition of heat storage would increase the performance only marginally. Hence it will be more economical to operate solar pre-heating systems without storage.

(b) Solar hot water storage systems for withering

The solar system (figure 6) consists of an array of hot water collectors and a hot water storage. Withering heat is completely supplied by this water storage. A water to air heat exchanger installed at the trough mouth heats up the ambient air used for withering.

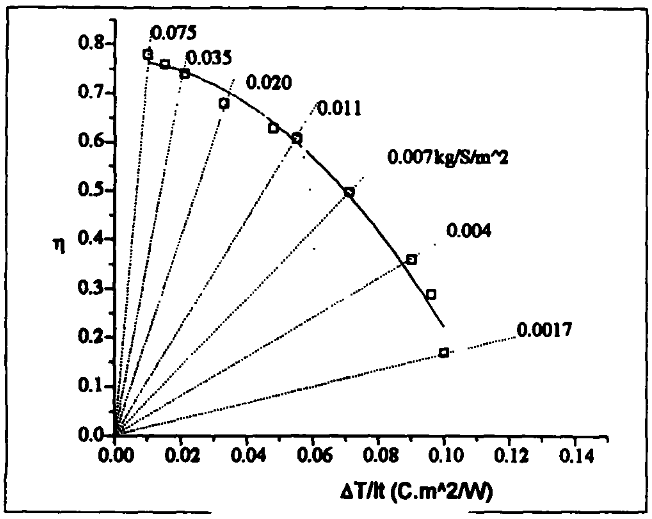

Figure 4. Variation of optimum air collector efficiency with the specific flow rate.

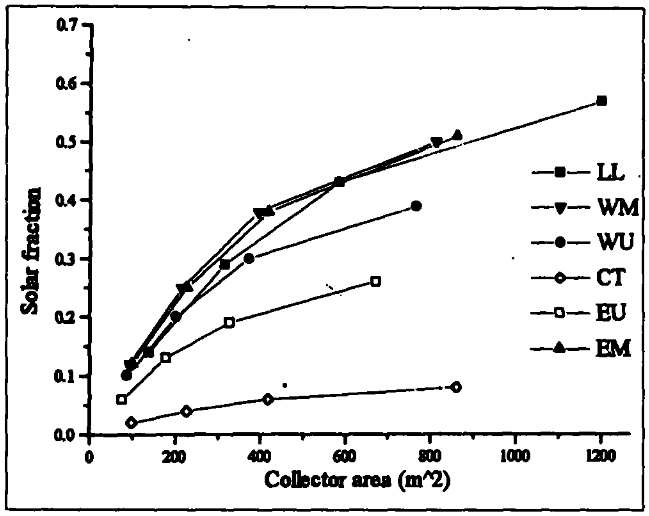

Figure 5. Performance of the solar air pre-heating systems in different regions.

Table 2.
Tea production, drying and withering heat loads for the model factories in different regions.

Region	Tea Production (kg/year)	Drying heat load (GJ/year)	ECPD air flow rate (kg/S)	Withering heat load (GJ/year)
LL	310,200	2812	4.56	1885
WM	266,450	2245	3.09	557
WU	277,890	2678	2.91	1944
CT	250,500	2594	3.27	1720
EU	254,400	2440	2.55	788
EM	254,000	2250	3.27	892

Heat is supplied to the water storage either from solar collectors or from a fired water heater. This arrangement also facilitates the recovery of waste heat from the dryer exhaust and better control of the temperature of withering air supply over the existing arrangement. Simulation modeling of these systems have shown that storage capacities in the range of 150 to 300kg of water per $1m^2$ of collector area are adequate.

The performance of these systems in model factories in the different regions of manufacture have been obtained by simulation techniques. The results are shown in figure 7. However no heat recovery from the dryer exhaust is assumed. Tea production and heat loads for the model factories from the six regions are shown in table 2. The estimation of the withering loads, however, do not include the heat supplied from dryer exhaust which constitute a significant fraction of the usual withering heat supply in tea factories.

In all the regions very high solar fractions could be achieved. Therefore in the application of solar energy for tea processing, the hot water systems for withering have a higher potential than the air pre-heating systems for drying.

6.0 Economic considerations

The application of solar energy in tea processing would have to be finally determined on the basis of its economic merits. There are various indicators for judging the economic performance of solar energy systems such as simple pay back period, internal rate of return and life cycle savings etc, (Duffie and Beckman, 1991). An indicator derived from the life cycle savings method is presented here and this indicator is then used to compare the economic performance of SAHAGS studied by the authors (Weeratunga Arachchi, 1997).

To derive this indicator, we consider the total amount of conventional fuel saved by the solar system over its life time, the investment required for its installation and its operation and maintenance costs over the life time. In this method a "fuel substitution cost" could be determined by equating the initial solar investment and life long operation and maintenance costs with the monetary value of the fuel substituted by the solar system over the life time. The values of the annual fuel

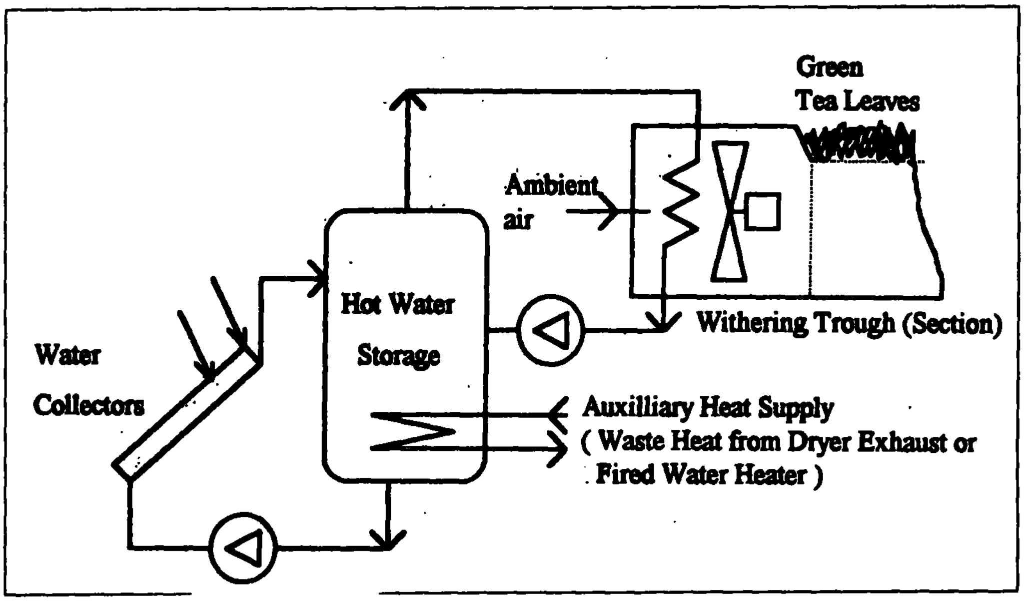

Figure 6. Schematic of solar hot water storage system for withering heat supply.

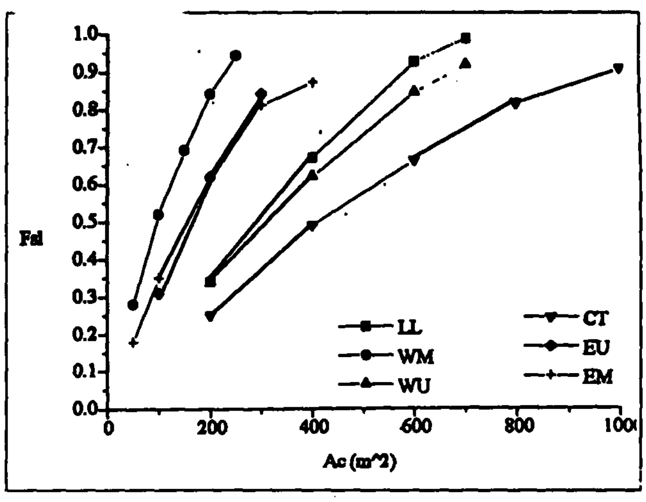

Figure 7. Variation of the solar fraction (Fsl) with the system size (Ac) in the six regions of manufacture.

savings are to be discounted to the present value using an appropriate market discount rate. A realistic treatment of the economics must also consider the annual inflation of the cost of fuel. If the estimated "fuel substitution cost" is lower than the current fuel cost then the introduction of a solar system would be considered economical.

This can be written in the form

$$C_s \{1 + \lambda * PWF(d, i_m' N)\} = C_f * Es * PWF(d, i_f, N)$$

where ,

Cs = solar system cost (Rs)
λ = annual operation and maintenance costs as a fraction of the solar system cost
Cf = fuel substitution cost (Rs/GJ)
Es = annual savings of conventional fuel due to solar energy (GJ/year)

The present worth factor (PWF) discounts a series of future cash flows over N years which are inflating at a rate of i per year to the present worth using a discount rate of d per year.

$$PWF(d,i,N) = \frac{1}{(d-i)} \left\{1 - \left[\frac{1+i}{1+d}\right]^N\right\}; \text{ if } i \neq d$$

$$PWF(d,i,N) = \frac{N}{(1+i)}; \quad \text{if } i = d$$

if and im are the annual inflation rates for fuel price and for operation and maintenance costs of the solar energy system respectively.

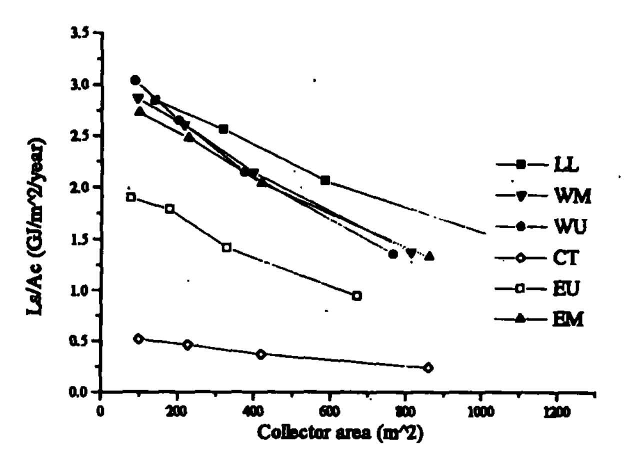

Figure 8. Variation of (Ls/Ac) with the system size in the six regions of manufacture for solar pre-heating systems.

The annual solar energy supplied to the process by one square metre of collector area (i.e. Ls/Ac) is an indicator of the economic performance of a solar energy system. This corresponds to the annual fuel savings from a solar investment proportional to a square metre of collector area. This parameter is compared for both air pre-heating systems and water storage systems in the figures 8 and 9. These graphs show the general trend that Ls/Ac reduces as the size of the solar system increases. The air pre-heating systems in the regions LL, WM, EM, and WU exhibit similar economic performance.

In comparison the economic performance in the CT region is very poor. The economic performance of water storage systems between the six regions seems less differentiated when compared to pre-heating systems. However a comparison between the two types of solar systems cannot be made because the cost of the systems differ substantially.

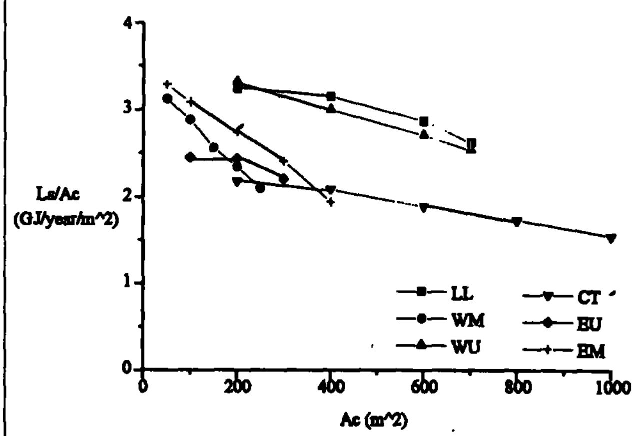

Figure 9. Variation of (Ls/Ac) with the system size in the six regions of manufacture for solar water storage systems

A detailed study of the economic performance of these systems have shown that fuel substitution cost of pre-heating systems which give a solar fraction of 30% in the four regions LL, WM, WU, and EM, would be in the range of 275 to 310 Rs/GJ. The fuel substitution cost of water storage systems which give a solar fraction of 70%, would be in the range of 400 Rs/GJ in LL region to 660 Rs/GJ in the CT region. Solar energy system costs are conservatively estimated to be Rs 5,000/m2 of collector area for air pre-heating systems and Rs 10,000/m2 of collector area for solar hot water storage systems. For both systems, annual operation and maintenance costs are assumed to be 10% of the system cost and the life time is assumed to be 20 years. Annual discount rate, annual inflation rate for operation and maintenance costs and annual inflation rate for fuel are assumed to be 12%, 0% and 5% respectively. Oil is the more expensive fuel used in the tea industry and currently it costs about 266 Rs/GJ. Hence solar air pre-heating systems for tea drying and solar hot water storage systems for withering are currently not economical unless their costs are brought down substantially.

7.0 Discussion and Conclusion

In this paper we have discussed the major design factors that determine the contribution of a solar energy system to a tea processing plant. We have also briefly reviewed the South Indian experience and the local efforts in the solar applications in tea processing. The evaluation of economic performance of solar systems is also a very important factor since the development of solar energy will finally depend on this.

The feasibility study by LAING Design and Development Centre on the development of solar energy for tea processing in Sri Lanka, which is the first study in this area, has not considered the above design factors and economic factors adequately. Therefore this study has not identified the most appropriate solar systems for Sri Lanka.

On the other hand, our research study on the potential of solar energy in tea processing is a comprehensive one. Here we have given due consideration to the quality aspects of tea manufacture and no changes in the manufacturing practices are anticipated to suit the operation of the solar systems. Our findings could properly guide the future solar energy development efforts in tea processing. The major findings can be listed as follows.

(1) Two different solar systems should be used for withering and drying operations of tea manufacture, because of the significant differences in the process temperatures. Solar air pre-heating systems are the most economical option for drying. Solar hot water storage systems offer many advantages over the solar hot air systems in the supply of solar heat for withering. The technical feasibility of both air pre-heating systems and hot water storage systems have been proven in South India.

(2) Substantial seasonal variations in tea production, in tea manufacturing requirements and in the solar energy resource occur among the different regions in the tea growing areas. Therefore the performance of solar systems vary substantially in the different regions. This fact has to be considered in the development of solar energy for tea processing. Marby (1972) has identified six regions in the tea growing areas and this is found to be sufficient for differentiating the performance of solar systems.

(3) Solar air pre-heating systems with black painted collectors which are operating at 34% efficiency could supply more than 50% of the drying thermal load in the three regions; the south western low-country (LL), the southern, western and northern mid-country (WM) and the eastern mid-country with the dry center of Uva (EM). Low ambient temperatures and solar resource coupled with the local manufacturing requirements results in very poor thermal performance in the central top country (CT). In the other two regions solar fraction is less than 50% for the same solar collector efficiency.

(4) To improve the performance of solar air pre-heating systems, tea manufacturing could be modified by shifting the tea drying to day time hours possibly by using controlled fermentation beds. Alternately rock bed storages could be coupled to the pre-heating systems. However, either method will not improve the thermal performance appreciably in any of the regions.

(5) Solar hot water storage systems for withering with solar heat collection efficiencies of about 50%, could supply more than 80% of the withering heat loads in all the regions.

(6) Solar hot water storage systems for withering have a greater potential in the development of solar energy for tea processing.

(7) The indicator "Fuel Substitution Cost" could be used for the evaluation of the economic performance of the solar systems in tea processing. The fuel substitution cost for both air pre-heating systems and hot water withering systems are higher than the current fuel prices even in the regions that give best thermal performance. Hence these solar systems are currently uneconomical.

(8) Development of solar energy must initially be tried in the south western low-country (LL) where the potential is highest. In this region the solar resource is high, manufacturing practices are most favorable and withering energy requirements account for an estimated 40% of the total

(9) The challenge in the development of solar energy for tea processing is to overcome the economic barriers due to the high costs of solar systems. Our efforts must be directed towards the lowering of these costs through local design and

development of solar collectors. Shallow pond solar collector may prove to be a viable alternative to the solar hot water storage system employing water collectors. Roof integrated solar air collectors and solar air collectors constructed upon the ground could also lower the cost.

Finally, as with any solar energy technology, the application of solar energy for tea processing would require a national program with proper leadership which will provide funding for local research and development work and then adequate subsidies for the promotion of appropriate technologies at initial stages. This strategy is being followed successfully in India. We can hardly do better than to follow them.

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