DETAILED PROJECT REPORT ON
SOLAR FRUITS AND VEGETABLES DEHYDRATION

Submitted to

MINISTRY OF FOOD PROCESSING INDUSTRIES (MFPI)
GOVERNMENT OF INDIA

As part of project titled

“STUDY, INVESTIGATION AND DEMONSTRATION (THROUGH PILOT UNITS)
ON THE LARGE LEVEL SOLAR HEATING TECHNOLOGY TO MEET THERMAL
REQUIREMENTS IN FOOD PROCESSING INDUSTRIES”

By

Planters Energy Network
171/2, M.K.University Road
Rajambadi, Palkalainagar Post
Madurai-625 021
Tamilnadu, India

September 2000
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DETAILS OF THE PROJECT UNDERTAKEN

Name of the R&D Project: STUDY, INVESTIGATION AND DEMONSTRATION (THROUGH PILOT UNITS) ON THE LARGE LEVEL SOLAR HEATING TECHNOLOGY TO MEET THERMAL REQUIREMENTS IN FOOD PROCESSING INDUSTRIES.

Sanction Number: 1/2/97(RP)-FPI


Co-Investigator: DR.T.M.HARIDASAN CO-ORDINATOR PLANTERS ENERGY NETWORK

Advisor: Dr. C. L. GUPTA SOLAR ENERGY UNIT SRI AUROBINDO ASHRAM PONDICHERY – 605 002

Date of start: 22/04/1998 (receipt of funds)

Duration of the project: TWO AND HALF YEARS
FOREWORD

Food Processing in India is an important industry. While India stands in the third place next to USA and China in raw food production, still it is in the lowest place in value addition to raw food. A phenomenal wastage is being experienced in vegetable and fruit food chain. This is mainly due to the inadequate post harvest techniques and processing facilities. Export on processed food faces problem due to the unhygienic open sun drying practices widely followed in the country. Most part of India is blessed with abundant sunshine which is also pollution free. Apart from the usage of conventional fossil fuels for food processing, ecological considerations point to solar route for low-grade thermal requirements and solar preheating route for high-grade thermal applications. This project "Study, Investigation and Demonstration (through pilot units) on the large level solar heating technology to meet thermal requirements in food processing industries" of two-year duration, was funded by the Ministry of Food Processing Industries. This is a step towards the goal reducing the conventional energy requirement in food processing industries using renewable energy sources. The objectives set for this project were
To study the feasibility of solar air heating in food processing industries by analysing their energy requirements.

Setting up two pilot units in two different processing industries to demonstrate the success of the system.

Preparing five numbers of Detailed Project Reports (DPR) on the possibility of solar drying in five food processing industries.

The project identified five agricultural sectors namely Vegetables and fruits dehydration, Fish drying, Dal drying, paddy drying and Cardamom curing on which detailed reports were prepared. Two demonstration units were installed, one for vegetables dehydration and another for fish drying. To complete the project, an additional six months was taken making the project duration to two and a half years. We hope that this project will serve its purpose of improving Indian food processing sector with the help of environmental friendly sources of energy.

C. PALANIAPPAN
T. M. HARIDASAN
EXECUTIVE SUMMARY

In India, the agricultural sector accounts for 60 – 65% of the Gross National Domestic Products and remains the backbone of our economy. India stands second in the world both in production of vegetables and fruits and the annual production is estimated to be about 128 million tonnes – 18 % of the country’s total agricultural produce. The government has projected an increase in 70 % of the production (that is 180.2 million tonnes) of fruits and vegetables for the 9th plan period ending 2001. Fruits are cultivated in 3045 thousand hectares and vegetables in 4490 thousand hectares of the total cropped area of 186561 thousand hectares according to statistics in 1995 – 96. This remarkable achievement in the field of production cannot be celebrated, as nearly 30 % of the hard-earned produce is lost as they are not processed. It is indeed sad to say that India processes only 2 % of its fruits and vegetables compared to 30 % -the world average.

One of the chief reasons for this state of affair is the huge energy requirement that has to go down in dehydrating these products. Even though other processed items like jams, jellies and fruit concentrates are being processed in our country, mechanised dehydration as a mode of preserving is still in its nascent stage.
Open sun drying is practised in our country for dehydrating fruits and vegetables for personal consumption and the problems associated with open drying like impurity sedimentation is widely existent. The theoretical energy requirement for dehydration of fruits and vegetables varies for each variety and on an average $1.5 \times 10^6$ kJ/tonne of energy is required for dehydration assuming evaporation at 50°C. Since India lies on the tropical zone, good insolation ($4 – 7 \text{kWh/m}^2/\text{day}$) is received fairly for a longer time say 290 days in a year. With such nature’s blessing it is worthwhile to study the utilisation of solar heating for dehydrating fruits and vegetables.

Terra Agro Technologies Ltd., a 100% export oriented vegetable dehydration plant in Tamilnadu was selected to be the model industry for testing the suitability of solar air heating to dry vegetables. After an extensive study of the location and operating parameters, two nos. of 212 m$^2$ roof integrated flat plate collectors were installed. The collectors were overflow systems with solar black painted corrugated aluminium sheets as absorber. The system provides hot air for second (85 –95°C) and third stages (75 –85°C) of a drier and a bin drying unit (around 65°C). The solar heating system’s performance was analysed over a year and it is found working at an average efficiency of 53 %. The Industry is recording fuel savings of 29 litres if furnace oil/hr or around 52,200 litres of furnace oil per
year. This system has proved the feasibility of solar drying in dehydrating vegetables. Extrapolation of the operating parameters in Terra industry using the solar radiation data has shown that the north Indian States, particularly Uttar Pradesh, Orissa, Bihar and Chandigarh offer good scope for solar drying of vegetables. Projection of the energy requirement has shown that adaptation of this technology by the Vegetable-processing sector for processing 30% of the produce will save an estimated 3840 million litres of furnace oil per annum and this will protect the atmosphere from 11.136 million tonnes of CO$_2$ added to it.

A feasibility study on the dehydration of fruits in the Ladakh region receiving 32% more solar insolation than Calcutta is also made which too shows the clear advantage of solar heating in fruits dehydration (Apricots and Apples). A detailed economic analysis for application of solar heating for fruits and vegetables was made and the expected fuel saving is around Rs. 4 lakhs per annum. The advantages like fuel conservation, increased efficiency etc. and disadvantages like need for backup of solar air heating are dealt in length and ways to overcome the disadvantages are also outlined. Recommendations for further development in solar drying of vegetables and fruits are also presented.
CHAPTER 1

INTRODUCTION

A. Background

India is essentially an agricultural country with 70% of its population living in the villages and 60-65% of the gross national domestic product emanating from rural agricultural sector. Fruits and vegetables, due to their nutrition and health value occupy a prominent place in our food chain. From the point of view of the agriculturist also, they are of great importance as the farmer is assured of high returns from their cultivation even on a small area. Out of the total cultivated area of 185 million hectares in India, 6.23 million hectares is under vegetable cultivation. The fruits and vegetable production in India is estimated to be the second highest in the world (5). The food production has increased three folds during the last thirty years to the present production of 180 million tons. However, there has not been corresponding development in the post harvest technology particularly in preserving the products for a longer time. It has been estimated that nearly 15% of food grains and 25-30% of vegetables and fruits are lost due to lack of post harvest processes. In other words Rs. 30,000 million worth of vegetables and fruits go waste in our country out of which 50% are vegetables (3). This is because of inadequate storage facilities and non-availability of
processing facilities. Loss of dry matter and degradation in the quality of the agricultural produce occur due to fungus growth, respiration and micro floras, insect and mite attack, rodent attack etc. An accelerated rate of deterioration occurs within a certain temperature range and also when the moisture content in the product is at higher level. Hence, it is important to develop post harvest technology for agricultural products to prevent the losses. The greatest emphasis has to be given to the dehydration of the food products. India is the largest producer of fruits after Brazil but processes only 2% of the produce compared to 30% of total world production (5).

In this report, we will discuss the fruits and vegetables production, processing techniques and improvements in processing techniques for the various vegetables and fruits dehydration. One of the ways of boosting the vegetable and fruits dehydration technology is by reducing the energy required for the process. One such energy conservation technique is by opting for solar air heating to dehydrate the products. The report will present a detailed case study of one pilot unit installed in Terra Agro Technologies Ltd., Udumalpet for vegetable dehydration using Solar Hot Air Technology. The case study includes the application of solar air heating in drying various vegetables and the details attributed therewith. The advantages of
solar heating will be equated in terms of financial gains by application of this system. The technical and economic viability of the system will be dealt in detail. A solar feasibility report for fruits drying (apple and apricot) in the Ladakh region is also presented.

B. Objectives

The objective of this project is to determine the suitability of roof integrated Solar Air Heating System in vegetables drying by installing a model collector for an industry. The project also enables to generate more data, which can be used to analyse the performance of SAHS. This project explores the economical benefits obtained by SAHS and also extends the feasibility study for fruit dehydration using SAHS.

C. Significance

The outcome of this project will demonstrate the usefulness of solar heating in vegetables and fruits drying. The data obtained will also help in the further development of the system to suit the dehydration operation. The results of this technology will enable us to justify the benefits in terms of savings of conventional energy and reduced pollution to the atmosphere. These economic advantages will serve as a forerunner to many foods processing industries to take advantages of this non-polluting Renewable Energy technology.
CHAPTER 2
FRUITS AND VEGETABLES OVERVIEW

A. Production and distribution

The annual production of fruit and vegetables is estimated about 128 million tonnes a year--around 18% of the country’s total agricultural produce (4). India accounts for about 9% of the total world fruits production. Fruit production in India estimated at 29 million tonne stands next to Brazil. On global basis, India accounts for 65% of the mango production, 11% of the banana production and 12% of the onion production. India is also the second largest vegetable producer in the world. Tomatoes, Cauliflower, onions and cabbages are the major vegetables and account for one third of the total production. The Annual potato production in 1997 was 18 million tonnes. The average production of fruits and vegetables in India is very low compared with other countries (Ref. Table 2.1 and 2.2) and as far as the yield of finished products is concerned, India lags far behind other countries. During 1998-1999 only about 8.94 lakh tonnes of fruit and vegetable products were processed and 48,900 tonnes were exported. The Government has projected an increase of 70% in production of fruits and vegetables during the 9th plan period ending 2001 with the target fixed at 180.2 million tonne (5).
Table 2.1 Yield of vegetables in India compared to other countries

<table>
<thead>
<tr>
<th>Vegetables</th>
<th>India (Tonnes/hectare)</th>
<th>Other countries (Tonnes/hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>Peas</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Onions</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Potatoes</td>
<td>12</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 2.2 Yield of fruits in India compared to other countries

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Indian Yields (tonne/hectare)</th>
<th>World Average Yields (tonne/hectare)</th>
<th>Indian Yields in % of the World average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>20.3</td>
<td>34.5</td>
<td>59</td>
</tr>
<tr>
<td>Mango</td>
<td>08.8</td>
<td>30.0</td>
<td>29</td>
</tr>
<tr>
<td>Citrus</td>
<td>07.3</td>
<td>24.5</td>
<td>30</td>
</tr>
<tr>
<td>Apple</td>
<td>05.9</td>
<td>14.0</td>
<td>42</td>
</tr>
<tr>
<td>Pineapple</td>
<td>13.5</td>
<td>60.0</td>
<td>23</td>
</tr>
<tr>
<td>Tomato</td>
<td>15.7</td>
<td>25.9</td>
<td>61</td>
</tr>
</tbody>
</table>

(Source—7)

The total cultivation in India has gone up from 1.22 million hectares in 1961 to 3.22 million hectares in 1991. The area under major fruits and vegetables is estimated to be 5.5 million hectares constituting only about 2.98% of the countries estimated cropped area of 185 million hectares. The vegetables and fruits production details in India during 1997 are given in Table 2.3.
Table 2.3 Fruit and Vegetable production in India during 1997 (million tonnes)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Production</th>
<th>Commodity</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mango</td>
<td>12.0</td>
<td>Tomatoes</td>
<td>5.3</td>
</tr>
<tr>
<td>Bananas</td>
<td>9.90</td>
<td>Cauliflower</td>
<td>5.0</td>
</tr>
<tr>
<td>Citrus</td>
<td>3.30</td>
<td>Onions</td>
<td>4.5</td>
</tr>
<tr>
<td>Apples</td>
<td>1.30</td>
<td>Cabbages</td>
<td>4.2</td>
</tr>
<tr>
<td>Pineapples</td>
<td>1.10</td>
<td>Eggplants</td>
<td>3.4</td>
</tr>
<tr>
<td>Grapes</td>
<td>0.70</td>
<td>Promekins, Squash</td>
<td>3.2</td>
</tr>
<tr>
<td>Papayas</td>
<td>0.50</td>
<td>Gourds, Okra</td>
<td>2.5</td>
</tr>
<tr>
<td>Others</td>
<td>8.00</td>
<td>Peas, Green</td>
<td>2.2</td>
</tr>
<tr>
<td>Total fruit</td>
<td>37.20</td>
<td>Total vegetables</td>
<td>55.0</td>
</tr>
<tr>
<td>(Excl.Melons)</td>
<td></td>
<td>(incl. Melons)</td>
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</tr>
</tbody>
</table>

[Source—8]

Fruits and vegetables are grown throughout India and its quantity varies with state. The major fruits and vegetables producing states are Uttar Pradesh, Tamilnadu., Bihar, Andhra Pradesh, Karnataka, Kerala, Maharashtra, Orissa, Gujarat, Assam, West Bengal and Madhya Pradesh.
## Figure 2.1 Peak Availability Seasons of Vegetables in India

<table>
<thead>
<tr>
<th>Vegetables</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<tbody>
<tr>
<td>Cabbage</td>
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<td>Carrots</td>
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<td>Onion</td>
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<td>Peas</td>
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<td>Potato</td>
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<tr>
<td>Spinach</td>
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<td>Tomato</td>
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</tbody>
</table>

## Figure 2.2 Peak Availability Seasons of Fruits in India

<table>
<thead>
<tr>
<th>Fruits</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
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<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
<tbody>
<tr>
<td>Apple</td>
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<tr>
<td>Apricot</td>
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<tr>
<td>Banana</td>
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<tr>
<td>Cherry</td>
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<tr>
<td>Grapes</td>
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<tr>
<td>Guava</td>
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<td>Mango</td>
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<tr>
<td>Orange</td>
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<tr>
<td>Papaya</td>
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<tr>
<td>Pear</td>
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<tr>
<td>Pineapple</td>
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<td></td>
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</tr>
</tbody>
</table>

*Figure 2.1 Peak Availability Seasons of Vegetables in India*

*Figure 2.2 Peak Availability Seasons of Fruits in India*
B. Market for dehydrated vegetables and fruits

There is a good demand for the food industry sector in overseas markets, particularly for dehydrated vegetables and fruits. Although the market for dehydrated vegetables and fruits is in a very nascent stage in India, a good potential is envisaged in the near future. The estimated installed capacity of fruit and vegetable processing industries has increased from 2.04 lakh tonnes in 1997 to 2.08 lakh tonnes in 1998, while the production of processed fruits and vegetables increased from 9.1 lakh tonnes in 1997 to 9.4 lakh tonnes in 1998 (5). The whole sale rate of raw vegetables as on September 2000 is given in the Table 2.4. Dehydrated vegetables and fruits in one form or the other are used in soup, meat, fish, pre-cooked food and baby food processing industries etc. Western countries are the major importers of dehydrated vegetables and fruits.
Table 2.4: Whole sale rate of vegetables as on 6/9/2000

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Vegetables</th>
<th>Market price/tonne Rs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Potato</td>
<td>6,300</td>
</tr>
<tr>
<td>2.</td>
<td>Hybrid tomato</td>
<td>4,500</td>
</tr>
<tr>
<td>3.</td>
<td>Country tomato</td>
<td>2,500</td>
</tr>
<tr>
<td>4.</td>
<td>Cabbage</td>
<td>2,000</td>
</tr>
<tr>
<td>5.</td>
<td>Carrot (Ootacamund)</td>
<td>5,500</td>
</tr>
<tr>
<td>6.</td>
<td>Onion (Palladam)</td>
<td>2,750</td>
</tr>
<tr>
<td>7.</td>
<td>Country Red beet</td>
<td>2,000</td>
</tr>
<tr>
<td>8.</td>
<td>Hybrid Red beet</td>
<td>3,250</td>
</tr>
<tr>
<td>9.</td>
<td>Cauliflower (Ootacamund)</td>
<td>12/piece</td>
</tr>
<tr>
<td>10.</td>
<td>Lady’s finger</td>
<td>4,000</td>
</tr>
<tr>
<td>11.</td>
<td>Spinach</td>
<td>3,500</td>
</tr>
<tr>
<td>12.</td>
<td>Red Bell Pepper</td>
<td>14,000</td>
</tr>
<tr>
<td>13.</td>
<td>Green Bell Pepper</td>
<td>13,000</td>
</tr>
<tr>
<td>14.</td>
<td>Paprika</td>
<td>12,500</td>
</tr>
<tr>
<td>15.</td>
<td>Chillies</td>
<td>11,000</td>
</tr>
</tbody>
</table>

C. Processing techniques

Processing of vegetables and fruits involves cleaning by water to remove sludge, shredding and drying. Drying constitutes the vital operation in the processing of vegetables and fruits. By drying the moisture level is brought down to the extent wherein the attack by insects or decomposition is prevented. The procedures adopted for processing of variety of fruits and vegetables are explained in the following section:

C.1. Fruits processing
Most of the fruits follow similar way of processing sequences of washing, peeling, shredding and spreading on flat-bottomed wooden trays with the trays arranged inside a shed. They are then treated with sulphur fumes to maintain their colour and also to avoid spoilage by micro organisms. This is done in a small room by burning a known quantity of sulphur in a receptacle placed on the floor. The trays filled with the fruit are stacked with a vertical gap of around 5-cm in this room. After spraying at the rate of 1.8 to 3.6 kg of sulphur per ton of fruit, the trays are kept in the sun with occasional turning of the fruit till it is dried. The dried fruit is then stacked in boxes or in bins to equalise the moisture content (2).

Even though the steps described above are invariably followed, the preparatory methods vary according to the variety of fruit. Preparing section of the various fruits is as follows:

**C.1.1. Apricot:**

The small white apricot, especially the Shakarpara variety is dried whole in Afghanistan. Apricots are allowed to ripen on the tree. They are then picked, cut into halves, and the pits removed. The halves are then placed on trays with the cup facing upward. They are then sulphured for about three hours and subsequently dried. The dried fruits are filled into bags for despatch.
C.1.2. Banana

The ripe fruit is peeled, sliced length wise, sulphured and dried in the open yard. Unripe bananas are peeled after blanching in boiling water and cut into discs for drying.

C.1.3. Date fruit

Dates are picked in the ‘dung’ stage, which is when the tip of the fruit has turned translucent brown. They are spread on the mats for 5 to 8 days for curing or the dates are picked 3 to 4 days before the ‘dung’ stage and then dipped for 1/2 to 2 minutes in 0.5 to 2.5 percent caustic soda solution before placing them for drying. The effects of rain and dust storms are minimised by this method.

C.1.4. Grapes

Ripe bunches of grapes are hung inside dark rooms till the berries acquire a greenish or light-amber tint. These shade dried grapes are considered to be far superior to the ordinary sun dried or dehydrated grapes. For efficient drying, grapes should have a high sugar content of 20 to 24 degrees brix. The high sugar content grapes are dried without any sulphuring till there is no exudation of juice on pressing the dried grape between the fingers.
Some grapes are lye-dipped prior to sun drying. Lye-dipped grapes are sometimes treated with sulphur fumes for 3 to 5 hours for bleaching them, because certain markets prefer such glossy product. In some other cases grapes are dipped for 3 to 6 seconds in caustic soda and sodium bicarbonate, covering the surface of the solution with a thin layer of olive oil. This treatment removes only the wax and the bloom on the grapes without cracking the skin. The dried product has a glossy appearance.

C.1.5. Jack fruit

Jack fruit bulbs of ripe fruit are sliced and the seeds are removed. The edible portions of the slices are dried with or without sulphuring. The bulbs can also be made into fine pulp, which can be dried in the form of sheets or slabs.

C.1.6. Mango

Unripe, green mangoes are peeled, sliced and dried in the sun. Ripe mangoes are taken and the juicy pulp squeezed by hand. The pulp is spread on bamboo mats and a small quantity of sugar sprinkled over it. When the first layer has dried, another layer of pulp is spread over it for drying. This process is repeated until the dried slab is 1.2 to 2.5 cm thick.
C.1.7. Apple

Apples are peeled, cored and cut into cubes or slices. These are then sulphured for 15 to 30 minutes and dried.

C.2 Vegetables processing

The similar procedure adopted for fruits is used for vegetables processing. Some of the vegetables processing procedures are given below.

C.2.1. Cabbage

Outer leaves and the cores are removed and the rest is shredded into pieces of 0.5cm thickness. The shreds are either blanched with steam for 5 to 10 minutes or in boiling 2 percent sodium bicarbonate solution for 2 to 3 minutes. Blanching in water, containing ½ percent of sulphite and bisulphite gives a product with better colour. The shreds are dried at 60°C to 66°C for 12 to 14 hours. The drying ratio is approximately 18:1.

C.2.2. Cauliflower

The flowers are separated and cut into smaller pieces. The pieces are blanched for 4 or 5 minutes in boiling water, steeped in a 0.5 percent SO₂ solution for about an hour, drained and washed.
They are then dried at $60^0$C to $66^0$C for 10 to 12 hours. The drying ratio is about 35:1.

**C.2.3. Onion**

The outer leaves are removed and the peeled onions are cut into 0.25cm thick slices. The slices are immersed in a 5 percent solution of common salt for about 10 minutes and then drained. They are dried at $60^0$C to $65^0$C for 11 to 13 hours. It is however, preferable to keep the drying temperature below $57^0$C. The drying ratio is about 10:1.

**C.2.4. Spinach**

The leaves are washed thoroughly and dried as such or after steaming them for 4 to 5 minutes. The drying temperature is $63^0$ to $68^0$ C and the drying time 7 to 8 hours. The drying ratio is approximately 22:1.

**C.2.5. Tomato**

The ripe tomatoes are scalded in boiling water for 30 to 60 seconds to facilitate the removal of the skin manually by means of a pointed knife. The peeled tomatoes are cut into slices, 0.6 to 0.9 cm thick, which are then dried at $60^0$ to $65^0$C for 9 to 10 hours. The drying ratio is 27:1.
CHAPTER 3

DRYING AND ENERGY CONSUMPTION

A. Conventional drying methods for fruits and vegetables

Preservation of foods by drying them is a time old process. Large quantities of fruits and vegetables are dried in different parts of the world such as Asia Minor, Greece, Spain and other Mediterranean countries, Arabia, Afghanistan, Australia, etc.

Open sun drying of fruits and vegetables is practised widely in tropical and sub-tropical regions where there is plenty of sunshine and practically little or no rain during the drying season. The equipment essentially consists of drying trays and few other items like knives, lye-bath, etc. Most of work is done in a drying yard, which is kept free from dust, flies, bees etc. The fruits and vegetables are washed, peeled, prepared and spread on flat-bottomed wooden trays and the trays are arranged in sheds, sulphured and allowed to dry in sun with occasional turning till the products are dried. Open sun drying is characterised by prolonged drying periods, sedimentation of impurities and the process is at the mercy of prevailing climatic conditions.
Mechanical dehydration is the process wherein the product is subjected to regulated temperature, relative humidity and airflow rate. Some of the commonly used driers are

1. Home made drier
2. Commercial dehydrators
   i) Kiln drier
   ii) Tower or stack type drier
   iii) Oregon tunnel drier and
   iv) Forced draught tunnel

B. Energy requirement for drying one tonne of products

The energy requirement for drying vegetables and fruits depends on the initial and final moisture content required. From this data the water to be removed and hence the energy requirement are calculated. Table 3.1 gives the theoretical energy requirement for drying various fruits and vegetables.
Table 3.1 Energy requirement for drying one tonne of products

<table>
<thead>
<tr>
<th>Product</th>
<th>Moisture content</th>
<th>Drying Temp. (°C max.)</th>
<th>Water removed (Kg/tonne)</th>
<th>Energy reqd. (10^6 X kJ/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VEGETABLES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cauliflower</td>
<td>80</td>
<td>6</td>
<td>65</td>
<td>787.2</td>
</tr>
<tr>
<td>Carrots</td>
<td>70</td>
<td>5</td>
<td>75</td>
<td>684.2</td>
</tr>
<tr>
<td>Onions</td>
<td>80</td>
<td>4</td>
<td>55</td>
<td>791.7</td>
</tr>
<tr>
<td>Garlic</td>
<td>80</td>
<td>4</td>
<td>55</td>
<td>791.7</td>
</tr>
<tr>
<td>Cabbage</td>
<td>80</td>
<td>4</td>
<td>55</td>
<td>791.7</td>
</tr>
<tr>
<td>Potatoes</td>
<td>75</td>
<td>13</td>
<td>75</td>
<td>712.6</td>
</tr>
<tr>
<td>Spinach</td>
<td>80</td>
<td>10</td>
<td>-</td>
<td>777.8</td>
</tr>
<tr>
<td>FRUITS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apples</td>
<td>80</td>
<td>15</td>
<td>30</td>
<td>705.9</td>
</tr>
<tr>
<td>Apricots</td>
<td>85</td>
<td>18</td>
<td>65</td>
<td>817.1</td>
</tr>
<tr>
<td>Peaches</td>
<td>85</td>
<td>18</td>
<td>65</td>
<td>817.1</td>
</tr>
<tr>
<td>Grapes</td>
<td>80</td>
<td>15-20</td>
<td>70</td>
<td>750-823.5</td>
</tr>
<tr>
<td>Bananas</td>
<td>80</td>
<td>15</td>
<td>70</td>
<td>823.5</td>
</tr>
<tr>
<td>Guavas</td>
<td>80</td>
<td>7</td>
<td>65</td>
<td>784.9</td>
</tr>
<tr>
<td>Pineapple</td>
<td>80</td>
<td>10</td>
<td>65</td>
<td>777.8</td>
</tr>
</tbody>
</table>

(Source: 6)

C. Scope of solar energy

Since vegetable dehydration is a low temperature operation (60-70°C) there exists a strong potential for installation of SAHS to cater to the hot air requirement. Moreover India is located in the tropical zone and hence receives good solar Insolation (Refer Table 4.1) fairly
for a longer period (say 300 days in a year). Solar energy application can aid in the saving of fuel consumption substantially. During sunny days, the drying operation can be taken over by solar dryers thereby cutting fuel costs. Since the solar heaters are integrated with the rooftops, there is no need for any extension in processing area.
SOLAR AIR HEATING

A. Introduction to solar heating

Sun is a natural source of energy. The solar energy is so abundant that the fear of losing this energy source never exists. Unlike the fossil fuels this energy never produces any toxic emissions and hence is called clean energy source. Sun radiates the energy formed in the core of the sun due to thermonuclear reactions. This radiation comes mostly as high energy waves with short wavelengths. This radiation is absorbed by the materials and gets heated up. With proper combination of materials, it is possible to build a solar collector to collect this heat. There are two basic types of solar systems - active and passive.

Active Systems

In active solar systems, pumps or fans move the working fluid. Some applications require extra pumps or fans, but others-- like preheating grain drying air or livestock building ventilating air -- use existing fans. The pressure drop in the solar collector reduces system airflow and increases energy input to the fan motor.
Passive Systems

In passive solar systems, the working fluid moves with little or no pump or fan power. Natural convection and radiation distribute the collected solar energy. Passive solar systems can be simple and can provide heat at low operating and maintenance costs. Disadvantages include poor temperature control, wide temperature fluctuations in the heated space, and fading and deterioration of fabrics exposed to direct sunlight.

B. Insolation levels

The intensity of solar energy, or solar radiation, decreases with increasing distance from the sun. The sun is not at the centre of the earth’s orbit and hence the earth’s distance from the sun varies during the year and so does the intensity of the radiation reaching the earth. About 1353 W/m² the solar constant reaches a surface facing the sun just outside the earth’s atmosphere, 24 hrs/day. Only a fraction of this energy is available to the solar collector surface depending on time of the day, the time of year, the weather, the latitude of the collector site and the collector’s tilt angle. Table 4.1 gives the details of location and inclined surface Insolation levels for various stations in India.
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>Latitude (deg)</th>
<th>Longitude (deg)</th>
<th>Elevation (MASL) (Metres)</th>
<th>Average Sum of Global Solar Radiation per day, $G_t$ (kWh/m²) on Horizontal Surface</th>
<th>Inclined Surface (slope = latitude)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ahmadabad</td>
<td>23.07 N</td>
<td>72.63 E</td>
<td>55</td>
<td>5.786</td>
<td>6.323</td>
</tr>
<tr>
<td>2</td>
<td>Allahabad</td>
<td>25.45 N</td>
<td>81.73 E</td>
<td>98</td>
<td>5.121</td>
<td>5.755</td>
</tr>
<tr>
<td>3</td>
<td>Bangalore</td>
<td>12.95 N</td>
<td>77.63 E</td>
<td>897</td>
<td>5.357</td>
<td>5.511</td>
</tr>
<tr>
<td>4</td>
<td>Baroda</td>
<td>22.30 N</td>
<td>73.25 E</td>
<td>34</td>
<td>5.828</td>
<td>6.387</td>
</tr>
<tr>
<td>5</td>
<td>Bhopal</td>
<td>23.27 N</td>
<td>77.42 E</td>
<td>503</td>
<td>5.758</td>
<td>6.157</td>
</tr>
<tr>
<td>6</td>
<td>Bhubaneshwar</td>
<td>20.25 N</td>
<td>85.87 E</td>
<td>26</td>
<td>5.725</td>
<td>6.163</td>
</tr>
<tr>
<td>7</td>
<td>Calcutta</td>
<td>22.65 N</td>
<td>88.45 E</td>
<td>6</td>
<td>4.971</td>
<td>5.385</td>
</tr>
<tr>
<td>8</td>
<td>Coimbatore</td>
<td>11.00 N</td>
<td>87.00 E</td>
<td>431</td>
<td>5.699</td>
<td>5.812</td>
</tr>
<tr>
<td>9</td>
<td>Cudappah</td>
<td>14.48 N</td>
<td>78.83 E</td>
<td>130</td>
<td>5.514</td>
<td>5.711</td>
</tr>
<tr>
<td>10</td>
<td>Hyderabad</td>
<td>17.45 N</td>
<td>78.47 E</td>
<td>545</td>
<td>5.741</td>
<td>6.047</td>
</tr>
<tr>
<td>11</td>
<td>Jaipur</td>
<td>26.82 N</td>
<td>75.80 E</td>
<td>390</td>
<td>5.720</td>
<td>6.449</td>
</tr>
<tr>
<td>12</td>
<td>Jammu</td>
<td>32.67 N</td>
<td>74.83 E</td>
<td>367</td>
<td>5.507</td>
<td>6.484</td>
</tr>
<tr>
<td>13</td>
<td>Kodaikanal</td>
<td>10.23 N</td>
<td>77.47 E</td>
<td>2345</td>
<td>5.579</td>
<td>5.677</td>
</tr>
<tr>
<td>14</td>
<td>Kottayam</td>
<td>09.53 N</td>
<td>76.50 E</td>
<td>73</td>
<td>5.643</td>
<td>5.742</td>
</tr>
<tr>
<td>15</td>
<td>Leh</td>
<td>34.15 N</td>
<td>77.57 E</td>
<td>3514</td>
<td>5.881</td>
<td>7.157</td>
</tr>
<tr>
<td>16</td>
<td>Lucknow</td>
<td>26.75 N</td>
<td>80.88 E</td>
<td>128</td>
<td>5.565</td>
<td>6.185</td>
</tr>
<tr>
<td>17</td>
<td>Nagpur</td>
<td>21.15 N</td>
<td>79.12 E</td>
<td>311</td>
<td>5.443</td>
<td>5.930</td>
</tr>
<tr>
<td>18</td>
<td>Patna</td>
<td>25.50 N</td>
<td>85.25 E</td>
<td>52</td>
<td>5.592</td>
<td>6.217</td>
</tr>
<tr>
<td>19</td>
<td>Pune</td>
<td>18.53 N</td>
<td>73.85 E</td>
<td>563</td>
<td>5.669</td>
<td>6.025</td>
</tr>
<tr>
<td>20</td>
<td>Vishakapatnam</td>
<td>17.72 N</td>
<td>83.23 E</td>
<td>3</td>
<td>5.626</td>
<td>5.958</td>
</tr>
</tbody>
</table>

(Source: 1)
C. Flat plate collectors

A solar collector is one which
- Intercepts radiation from the sun;
- Convert this solar energy into thermal (heat) energy;
- Transfer the heat energy to a fluid

The basic types of solar collectors are flat plate collectors and concentrating collectors. A flat plate Collector with reflectors has characteristics of both plate and concentrating collector. The concentrating collector and flat plates with reflectors are more efficient than the flat plate collectors, as they enclose a larger area. But the economic indicators point flat plate collectors to be more feasible than the other two. An added advantage of flat plate collector is that it can be integrated with the existing roof itself. Since we are concerned with the economical aspect that accompanies any industry, we will restrict our discussion to flat plate collectors. Flat plate collectors can collect both direct and diffuse radiation and can make small amount of heat even on overcast days.

The Solar Air Heating Systems (SAHS) using flat plate collector traps the solar energy and converts the same into useful energy. Since our discussion is centred on the application of Flat plate collectors, an introduction about the same will be briefed. An energy
flow diagram of the flat plate collector is provided in the Figure 4.1.

The important components of flat plate collectors are:

![Energy flow diagram of flat plate collector](image)

**Figure 4.1. Energy flow diagram of flat plate collector**

**C.1. Absorber**

This forms the important part of the flat plate collector. The absorber is essentially flat, but can also be perforated, corrugated, finned or crimped. It absorbs solar energy, heats up and then
transfers the heat to the fluid moving over or through it. They collect both direct and diffuse radiation, so they may produce small amounts of heat even on overcast days when all solar radiation is diffuse.

A good absorber in a solar collector:
• Absorbs a high percentage of incoming solar radiation.
• Loses minimum energy to the collector’s surroundings.
• Efficiently transfers absorbed energy to the collector fluid.

It can be made up of copper, aluminium or GI sheets. Dark surfaces have high absorptance and hence collector absorbers should be black painted if they are not naturally dark. “Selective surfaces” have both high solar absorptance and low long-wave emittance. Most of them are special factory-applied coatings and can be quite costly. Selective surfaces can reach higher temperatures because they lose less energy by radiation.

Well-weathered galvanised metal with a rough, dull grey surface is a natural mildly selective surface. Painting the metal flat black increases the solar absorptance, but destroys the selective surface—the unpainted surface is probably more cost effective.

C.2. Cover

Solar collectors are covered by covers or glazing which are fitted to
- Reduce convection heat losses by shielding the absorber from the wind;
- Admit solar or short-wave radiation to the absorber;
- Reduce radiation heat losses by preventing the escape of long-wave radiation from the collector.

Adding cover layers reduce energy losses from a collector, but also reduces the radiation transmitted to the absorber. Glass is most common on collectors with re-circulated working fluids. It has excellent transmittance that does not change over time. The biggest disadvantage of glass is its brittleness. Fibreglass reinforced plastics (FRP) are one of the most efficient cover materials for low-temperature agricultural collectors.

Other cover materials include polyester, polycarbonate and poly-vinyl fluoride. Polyester and polyvinyl fluoride are cheaper than FRP and have higher solar transmittance, but they also have higher long-wave transmittance, are less durable than FRP, and are harder to work with. Polycarbonate has good transmittance and can withstand ultraviolet radiation better than FRP, but it has high thermal expansion and is very expensive.

**C.3. Insulation**

In addition to losing heat by radiation, absorbers in solar collectors lose heat to the side and back plates by conduction,
natural convection in liquid-type collectors, and forced convection in air-type collectors. The inside walls of the collector warm up and the heat is conducted through them to the outside, where it is carried away by the wind. Insulation reduces these heat losses. Some of the insulators used are rockwool, polyurethenes, polystyrenes etc.

C.4. Efficiency

Converting solar energy from radiation to heat is not cent percent efficient. Efficiency shows how well a collector converts available solar energy into useful heat energy. The efficiency of the collector is determined by the following formulae

Collector Efficiency

\[ \text{Collector Efficiency} = \frac{\text{Heat Energy Output over a given time period}}{\text{Solar Energy incident on the collector surface over the same time period}} \]

The performance equation of the flat plate collector is given by

\[ \eta = F_R \left[ (\tau \alpha)_n - U_l (T_{av} - T_a) / I_T \right] \]

Where

- \( \eta \) -- Efficiency
- \( \tau \) -- Transmittance of glass
- \( \alpha \) -- Absorptance of the absorber.
- \( \tau \alpha \) -- transmittance - absorptance product.
U_l—Overall heat loss coefficient of collector (W/m²K)

F_R—Heat removal Factor of the collector

I_T—Intensity of solar radiation (W/m²)

T_av — Average of Inlet and outlet temperatures (°C)

T_a — Ambient temperature (°C)

C.5. TYPES OF FLAT PLATE COLLECTORS

There are different modes by which the fluid is passed through the collector to get optimum heat out of it. It is based on the flow of the fluid with the absorber as the reference point. The various modes of fluid flow as described in Figure 4.2 are

C.5.1) Flow above the absorber

In this, the fluid is allowed to pass through the spacing between the cover and the absorber. This is the cheapest mode of flow as there is no additional cost involved other than the cover, absorber plate and insulation. The top loss in this mode of operation is more than the other flow patterns due to conduction and convection.

C.5.2) Flow below the absorber

In order to reduce the heat losses, the flow below the absorber model was developed. In this model, the fluid flows below the
absorber plate and thereby removing heat. Since the area between the cover and absorber has cold air, the losses are minimised. But this set-up will require another plate between the absorber and the insulation, which increases the cost.

**C.5.3) Suspended absorber**

Another model is the suspended absorber in which the fluid flows first through the space between the cover and the absorber and then through the spacing below the absorber. This two-pass model is too costly and requires more parasitic pumping cost due to increased pressure drop.

A new concept developed by Planters Energy Network – PEN for installing the solar air heating system is the Roof integrated solar hot air system. A schematic of the roof-integrated system is explained in Figure 4.3. The advantages of the system are its compact structure and reduced investment. The cost reduction is due to the reduced additional roof requirement.
Figure 4.3 concept of roof integrated flat plate collector
CHAPTER 5

MODULAR DESIGN FOR DEHYDRATION OF VEGETABLES

A model roof integrated flat plate collector was installed to test the suitability of SAHS technology for vegetable dehydration. The technical details of the construction are dealt below.

A) Factory Profile

Terra Agro Technologies limited is a 100% Export Oriented Unit. This is an integrated agro project that performs scientific cultivation mainly Organic Farming of vegetables in its farm and the harvested products from this farm are dehydrated for better shelf life. This is a joint venture promoted by Premier Instrument & Controls Limited (PRICOL) and associates of Elgi equipments and Elgi Tyre and Tread Ltd.

B) Location

The project site is situated at 11° latitude, 77° longitude and 352 m above the mean sea level, adjacent to Amaravathi River near Udumalpet in Coimbatore District of Tamilnadu. This area comes under the tropical zone and hence tropical climate with light showers during south west monsoon and good sunshine during the rest of the year prevails over this region. The Clear Sky Radiation (CSR) data for
all the days in a year are obtained from the simulation programme in PEN and given in Annex-I.

C) Vegetables Processing

The factory is dehydrating vegetables like tomato, paprika, onion, red-beet, cabbage, cauliflower and carrot. The harvested vegetables from the farm are brought into the factory. The factory has a net floor area of 2,100 m$^2$. The vegetables are washed thoroughly with running water. After washing, the vegetables are cut into small pieces using a shredder. These shredded pieces are fed to the drier with an approximate m.c.w.b (moisture content wet basis) of 85 to 95%. This moisture content is to be reduced to 5% m.c.w.b in the drier by hot air heating by steam in a sterile atmosphere. The details of the drier are explained later. The vegetables are subjected to three stages of drying were the moisture content is reduced gradually. After the drying process in the drier the final drying of the vegetables is done in the bin drier and then taken to the next stage of processing. The dried vegetables after cleaning and sorting are packed either as flakes or granules or powers.

D) Drying and energy consumption

The drier is a continuous cross flow type drier. The drier consists of three stages namely stage I, stage II and stage III. The cut
vegetables are introduced into the drier through perforated sheet conveyor arrangement. The output product from the drier is again subjected to final drying in bins. The fresh air is taken from within the factory to maintain the air quality. Adjustable dampers and exhaust fans control the volume of air required for drying. All the vegetables are dried to the final m.c.w.b of 5%. The plant capacity, drier capacity and dried output (kg/h) and % of moisture reduction along with their efficiency calculation are reported in Annex IV. The detailed processing flow diagram is provided in Figure 5.1.

In the first stage the temperature requirement is around 95 – 105°C and volumetric airflow rate is 20,227 m³/hr. The approximate thermal energy requirement for 1100 kilograms of water removal per hour and to increase the temperature to the required level is 390 kWh.

In the second stage the temperature requirement is around 85 – 95°C and volume requirement of air is 5,500 m³/hr. The approximate thermal energy requirement for 550 kilograms of water removal per hour and to increase the temperature to the required level is 90 kWh.

In the third stage the temperature requirement is around 75 – 85°C and volume requirement of air is 5,500 m³/hr. The approximate
thermal energy requirement for 193 kilograms of water removal per hour and to increase the temperature to the required level is 73 kWh.

In the final bin stage drying the temperature requirement is around 65°C and volume requirement of air is 13,000 m³/hr. the approximate thermal energy requirement for 26.5 kilograms of water removal per hour and to increase the temperature to the required level is 119 kWh.

A low-pressure boiler operating between 8-10 bar pressure, produces saturated steam to satisfy the whole thermal requirement for the drying and pre-cooking of the leafy vegetables like (cabbage & cauliflower). The boiler is switched on three hours before the drying operation starts to produce the steam to build up the required pressure and runs periodically to hold the right steam pressure. At the end of drying process the boiler is switched off three hours earlier. Furnace oil is used as fuel in the boiler to produce saturated steam.
Figure 5.1. Flow chart for vegetables processing

- Raw Vegetables
  - Washing
    - Sterile Water
  - Grading
  - Carving
  - Peeling
  - Shredding
  - Cooking (Leafy Vegetables)
    - DRIER
      - Stage I (95–105°C)
      - Stage II (85–95°C)
      - Stage III (65–75°C)
    - Bin drying (Around 65°C)
  - Waste vegetables
    - Cleaning, grading, powdering (optional) and Packing
Furnace oil is stored in subsidiary tanks inside the boiler room, which is having the capacity 1000 litres. When the level of the fuel in the tank reaches 400 litres, it refills again to 1000 litres. The water used in the boiler is pumped from the well and it is demineralised. The demineralised pure water is fed into the boiler for steam production.

**D.1 Thermal energy requirement**

In the first stage of drying a temperature of 95-105°C is maintained within the drier with an air circulation rate of 20227 m³/hr. The total energy requirement in the first stage is around 390 kWh per hour of operation. In the second stage of the drier the air flow rate required is 5,500 m³/hr and the energy requirement works out to be 90 kWh for one hour at a temperature of 75-85°C. In the final stage of the drier the energy requirement is 73 kWh and the temperature maintained in this stage is 65–75°C. From the drier the product is transferred to the bin drier. In the bin drier an air flow rate of 13,000 m³/hr is maintained. The temperature is maintained at 65°C for the product to dry completely. The total energy required in this stage for an hour of drying is found to be 119 kWh.

**D.2 Electrical energy requirement**
The electrical energy consumption in the factory total connected load is 300 kWh. 162 kWh out of 200 kWh is used for drying purpose alone.

**D.3 Total energy requirement**

The total energy requirement for the processing of vegetables per hour is 846 kWh. Bulk quantity of this energy (say 778 kWh out of 846 kWh energy) is utilised for the drying purpose.

**D.4 Specific energy consumption:**

The specific thermal energy (i.e. the energy required per kg of vegetables processing) requirement for various vegetables are given in the following table:

*Table 5.1 Specific energy consumption for vegetable dehydration*

<table>
<thead>
<tr>
<th>VEGETABLES</th>
<th>DRIED OUTPUT Kg/h</th>
<th>SPECIFIC THERMAL ENERGY kWh/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARROTS</td>
<td>300</td>
<td>0.94</td>
</tr>
<tr>
<td>ONION</td>
<td>300</td>
<td>0.94</td>
</tr>
<tr>
<td>CAULIFLOWER</td>
<td>180</td>
<td>1.57</td>
</tr>
<tr>
<td>CABBAGE</td>
<td>200</td>
<td>1.41</td>
</tr>
<tr>
<td>TOMATO</td>
<td>130</td>
<td>2.17</td>
</tr>
<tr>
<td>RED BELLPEPPER</td>
<td>160</td>
<td>1.76</td>
</tr>
<tr>
<td>RED BEET</td>
<td>330</td>
<td>0.85</td>
</tr>
<tr>
<td>PAPRIKA</td>
<td>400</td>
<td>0.71</td>
</tr>
</tbody>
</table>
E) Report on design parameters

The three stage drier utilised in the factory is shown in Figure 5.2. The drier has the capability to evaporate 1500 kilograms of water per hour thereby consuming around 220 litres of furnace oil per hour. The photograph of the drier is provided in Figure 5.2. There are 13 centrifugal fans in the drier having a total volume rating of 1,85,000 m$^3$/hr. In the first stage the volume of air requirement is $(12,136 + 8,091) \times 20227$ m$^3$/hr. The temperature requirement is very high around 95 to 105$^\circ$C so as to reduce the moisture of the product to 50% for which steam heating is utilised. In the second stage the volume of air requirement is 5,500 m$^3$/hr and the temperature requirement is around 75 to 85$^\circ$C. The third stage volumetric air requirement is 5,500 m$^3$/hr with the temperature requirement at around 65 to 75$^\circ$C. After drying in the drier, further drying is carried out in open bin drier where the hot air requirement is 13,000 m$^3$/hr at 65$^\circ$C. Since the thermal energy requirement in the second, third and final bin stage of drying are within the ambit of solar heating, it is feasible to provide the hot air required for drying by solar air heating system. For the first stage, solar heating for preheating of the air could be used in future project.
F) CONSTRUCTION AND CONTROLS

Based on the hot air requirement in the drier of the final 2 stages of 5,500 m$^3$/hr each and bin stage of 13,000 m$^3$/hr, two SAHS of collector area 212 m$^2$ and 212 m$^2$ are designed. The two collectors have the same type of construction in all respects.

The SAHS is constructed over the existing south facing roof of the factory. The roof is converted as the base of the system and rockwool insulation is laid on the top of the roof. Over the insulation, a dull black painted corrugated aluminium sheet is installed to form the absorber. Using aluminium support frames, a 4 mm thick tempered glass cover is fixed over the roof. The edges are closed air tight with two layers of aluminium sheet. The 212 m$^2$ collector area is divided into 4 units of 53 m$^2$ area each. The effective area obtained from the 212 m$^2$ collector is 186 m$^2$. Since the drier room itself is maintained dirt free, the fresh air is taken from the inside of the factory drier room. The hot air from each panel is drawn through an insulated duct by two separate centrifugal blower of 5HP capacity and then distributed to the second and third stages of the drier and to the bin drier through a common plenum. From this common plenum 22,000 m$^3$/hr the hot air is drawn by the axial fans located inside the drier via four ducts connecting the II stage, two ducts
connecting the III stage and one duct connecting the bin drier blower. All ducts are connected with adjustable damper controls.

Figure 5.2 Photograph of the three-stage drier for vegetable dehydration

Damper control facilitates the solar hot air when there is sufficient radiation and in case the temperature exceeds the required temperature the damper is opened to allow ambient air to mix with the hot air. During rainy seasons the temperature could not be achieved by the solar hot air system because of very low Insolation and at that time, then damper is fully opened to facilitate sucking the ambient air, which is subsequently heated, by the steam produced in the low-pressure boiler.
CHAPTER 6

PERFORMANCE ANALYSIS OF THE SYSTEM

A detailed investigation has been done to assess the performance of the solar collectors. The volume flow of hot air is determined by measuring air velocity after the suction point of the blower using Testo 452. The Solar radiation in W/m² is recorded using Solarimeter. The ambient inlet air and hot air outlet temperatures are measured using GTH 2000 and GTH 1500 instant reading digital thermometers.

The readings of the solar collectors were taken on clear sky days with good radiation, while all the stages of the drier were running. Both the north side and south side blowers are running for the drying purpose of vegetables in the final three stages of the drying. The damper control for the blower is fully opened and the volume flow, temperature and radiation are measured for every five minutes intervals.

Expected fuel savings through solar heating:

Feed rate = 2200 kg/h.
Dried product = 440 kg/h
Water removal per hour = 1760 kg/h
No. of solar blower capacity of each = 11000 x 2 = 22000 m³/hr.
Heat received from the solar = 7,77,719.3kJ/hr
Calorific value of furnace oil = 9,600 kcal/kg=40,195.2 kJ/kg
Efficiency of boiler = 52.5% (Ref. Annex 1V)
Furnace oil saved due to solar = \frac{7,77,719.3}{(40,195.2 \times 0.525)} = 36.8 \text{ kg/h} = 33.5 \text{ lit/hr}

A. Actual fuel savings recorded

The fuel savings are recorded on the clear sky and constant wind speed and the three stages of the drier and bin drier running continuously.

Table 6.1 Fuel savings recorded by Terra Agro Technologies Ltd.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6 to 7</td>
<td>212</td>
<td>283</td>
<td>212</td>
<td>149</td>
<td>0</td>
</tr>
<tr>
<td>7 to 8</td>
<td>196</td>
<td>236</td>
<td>197</td>
<td>165</td>
<td>118</td>
</tr>
<tr>
<td>8 to 9</td>
<td>190</td>
<td>228</td>
<td>189</td>
<td>134</td>
<td>31</td>
</tr>
<tr>
<td>9 to 10</td>
<td>180</td>
<td>221</td>
<td>173</td>
<td>142</td>
<td>63</td>
</tr>
<tr>
<td>10 to 11</td>
<td>220</td>
<td>173</td>
<td>165</td>
<td>157</td>
<td>133</td>
</tr>
<tr>
<td>11 to 12</td>
<td>188</td>
<td>211</td>
<td>165</td>
<td>150</td>
<td>159</td>
</tr>
<tr>
<td>12 to 13</td>
<td>188</td>
<td>166</td>
<td>150</td>
<td>111</td>
<td>157</td>
</tr>
<tr>
<td>13 to 14</td>
<td>189</td>
<td>150</td>
<td>118</td>
<td>157</td>
<td>164</td>
</tr>
<tr>
<td>14 to 15</td>
<td>181</td>
<td>188</td>
<td>165</td>
<td>188</td>
<td>182</td>
</tr>
<tr>
<td>15 to 16</td>
<td>157</td>
<td>166</td>
<td>149</td>
<td>188</td>
<td>188</td>
</tr>
<tr>
<td>16 to 17</td>
<td>197</td>
<td>204</td>
<td>166</td>
<td>212</td>
<td>197</td>
</tr>
<tr>
<td>17 to 18</td>
<td>166</td>
<td>190</td>
<td>172</td>
<td>188</td>
<td>166</td>
</tr>
<tr>
<td>18 to 19</td>
<td>204</td>
<td>188</td>
<td>190</td>
<td>165</td>
<td>197</td>
</tr>
<tr>
<td>19 to 20</td>
<td>197</td>
<td>196</td>
<td>181</td>
<td>235</td>
<td>166</td>
</tr>
<tr>
<td>20 to 21</td>
<td>196</td>
<td>206</td>
<td>164</td>
<td>156</td>
<td>180</td>
</tr>
<tr>
<td>21 to 22</td>
<td>228</td>
<td>204</td>
<td>182</td>
<td>220</td>
<td>196</td>
</tr>
<tr>
<td>22 to 23</td>
<td>166</td>
<td>205</td>
<td>220</td>
<td>198</td>
<td>206</td>
</tr>
<tr>
<td>23 to 24</td>
<td>196</td>
<td>212</td>
<td>204</td>
<td>188</td>
<td>125</td>
</tr>
<tr>
<td>0 to 1</td>
<td>207</td>
<td>213</td>
<td>158</td>
<td>181</td>
<td>204</td>
</tr>
<tr>
<td>1 to 2</td>
<td>218</td>
<td>236</td>
<td>212</td>
<td>197</td>
<td>198</td>
</tr>
<tr>
<td>2 to 3</td>
<td>245</td>
<td>244</td>
<td>190</td>
<td>220</td>
<td>227</td>
</tr>
<tr>
<td>4 to 5</td>
<td>267</td>
<td>212</td>
<td>172</td>
<td>205</td>
<td>237</td>
</tr>
<tr>
<td>5 to 6</td>
<td>221</td>
<td>212</td>
<td>220</td>
<td>220</td>
<td>181</td>
</tr>
<tr>
<td>6 to 7</td>
<td>-</td>
<td>213</td>
<td>166</td>
<td>213</td>
<td>188</td>
</tr>
</tbody>
</table>


\[\text{Solar heating ON.}\]
Table 6.2 Fuel Savings recorded per hour with SAHS

<table>
<thead>
<tr>
<th>Date</th>
<th>Litres/hr. Consumption</th>
<th>Consumption without solar</th>
<th>Furnace oil savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With solar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>08/03/2000</td>
<td>185.11</td>
<td>213.18</td>
<td>28.07</td>
</tr>
<tr>
<td>10/03/2000</td>
<td>185.44</td>
<td>211.75</td>
<td>26.31</td>
</tr>
<tr>
<td>17/03/2000</td>
<td>158.11</td>
<td>188.25</td>
<td>30.14</td>
</tr>
<tr>
<td>19/03/2000</td>
<td>162.70</td>
<td>199.83</td>
<td>37.13</td>
</tr>
<tr>
<td>30/03/2000</td>
<td>168.25</td>
<td>192.08</td>
<td>23.83</td>
</tr>
<tr>
<td><strong>Averages</strong></td>
<td><strong>171.92</strong></td>
<td><strong>201.02</strong></td>
<td><strong>29.10</strong></td>
</tr>
</tbody>
</table>

B) Extrapolation of the results

The expected results that are obtained by the simulation of the operating parameters are extrapolated to other parts of the country. The results are made by the assumption that the parameters recorded in this selected industry will be similar in the industries located in other parts of the country. The extrapolated results of the average insolation levels during the various months and the fraction of energy delivered by the SAHS are given in Annex-III. The extrapolated results suggest the worthiness of SAHS in states like Chandigarh, Bihar, Orissa and Uttar Pradesh. Since, these are regions where huge quantities of vegetables are grown, implementation of SAHS in these regions can yield more results and save considerable energy. A comparative histogram depicting the fraction of energy each states receives from solar heater when similar conditions in the model system exists is given in Figure 6.1.
CHAPTER 7

ECONOMICS OF SOLAR HEATING IN VEGETABLE DEHYDRATION

The feasibility study has shown that the SAHS can operate as a partial energy delivery (ped) system in the vegetable dehydration process by substituting the fuel requirement partially in the second and third stages of drying and full energy delivery (fed) system in the bin drying. The maintenance cost involved with the SAHS is the cleaning of the glasses, which can be taken care by the labourers themselves. The life of the system is estimated to be around 10-15 years. The system is to be repainted once in five years, which costs around Rs. 20,000.

A. Cost of the modular Design

The split up of the cost involved in the construction of a 212 + 212 m² solar air heating system to provide hot air for dehydrating vegetables is given in the Table 7.1.
Table 7.1 Cost for installation of SAHS

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Heads of Expenditure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aluminium Extrusions</td>
<td>3,03,778.00</td>
</tr>
<tr>
<td>2</td>
<td>Rubber Materials</td>
<td>50,028.00</td>
</tr>
<tr>
<td>3</td>
<td>Glass and absorber materials</td>
<td>2,06,506.00</td>
</tr>
<tr>
<td>4</td>
<td>Insulation materials</td>
<td>1,20,763.00</td>
</tr>
<tr>
<td>5</td>
<td>Blower and other accessories</td>
<td>99,772.00</td>
</tr>
<tr>
<td>6</td>
<td>Ducting materials</td>
<td>3,36,414.50</td>
</tr>
<tr>
<td>7</td>
<td>Pannel fabrication &amp; Solar insulation charges</td>
<td>3,94,792.00</td>
</tr>
<tr>
<td>8</td>
<td>Ducting &amp; Cladding charges</td>
<td>2,31,276.00</td>
</tr>
<tr>
<td>9</td>
<td>Instrument charges</td>
<td>2,677.00</td>
</tr>
<tr>
<td>10</td>
<td>System duct drawing charges</td>
<td>19,300.00</td>
</tr>
<tr>
<td>11</td>
<td>Supervision charges</td>
<td>35,839.00</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>18,01,145.50</strong></td>
</tr>
</tbody>
</table>

B. Energy and Cost savings by the SAHS

A theoretical feasibility study of Installing Solar Hot Air Systems at various locations in India by studying the economical gains from that location is made by the insolation in that place and is tabulated below.
Assumptions

The assumption that the same energy requirement and same operating procedures are followed is taken as the basis for this study and the economics is worked out.

Thermal Energy spend in dehydrating thirty tonnes of vegetables in the second, third and bin drying stages = 3072.00 kWh

Normal Efficiency of Solar Air Heating System (SAHS) = 50%

Area of the Collector to be installed = 424 m²
Daily hours of operation = 8 hours
Cost per kWh (based on diesel price) = Rs. 1.30/-

Table 7.2 Cost savings in various states of the country

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Location</th>
<th>State</th>
<th>Fraction of energy supplied by SAHS</th>
<th>Cost saved per year (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ahmadabad</td>
<td>Gujarat</td>
<td>0.40</td>
<td>5,77,621.00</td>
</tr>
<tr>
<td>2.</td>
<td>Bhubaneshwar</td>
<td>Orissa</td>
<td>0.42</td>
<td>6,16,305.00</td>
</tr>
<tr>
<td>3.</td>
<td>Calcutta</td>
<td>West Bengal</td>
<td>0.34</td>
<td>4,93,764.00</td>
</tr>
<tr>
<td>4.</td>
<td>Chandigarh</td>
<td>Haryana</td>
<td>0.40</td>
<td>5,90,257.00</td>
</tr>
<tr>
<td>5.</td>
<td>Chennai</td>
<td>Tamilnadu</td>
<td>0.37</td>
<td>5,45,689.00</td>
</tr>
<tr>
<td>6.</td>
<td>Jodhpur</td>
<td>Rajasthan</td>
<td>0.42</td>
<td>6,06,465.00</td>
</tr>
<tr>
<td>7.</td>
<td>Lucknow</td>
<td>UttarPradesh</td>
<td>0.43</td>
<td>6,21,512.00</td>
</tr>
<tr>
<td>8.</td>
<td>Mangalore</td>
<td>Karnataka</td>
<td>0.34</td>
<td>4,98,405.00</td>
</tr>
<tr>
<td>9.</td>
<td>Nagpur</td>
<td>Madhya Pradesh</td>
<td>0.38</td>
<td>5,50,772.00</td>
</tr>
<tr>
<td>10.</td>
<td>Patna</td>
<td>Bihar</td>
<td>0.42</td>
<td>6,12,361.00</td>
</tr>
<tr>
<td>11.</td>
<td>Pune</td>
<td>Maharashtra</td>
<td>0.38</td>
<td>5,59,489.00</td>
</tr>
<tr>
<td>12.</td>
<td>Trivandrum</td>
<td>Kerala</td>
<td>0.37</td>
<td>5,46,064.00</td>
</tr>
<tr>
<td>13.</td>
<td>Visakhapatnam</td>
<td>Andhra Pradesh</td>
<td>0.38</td>
<td>5,55,952.00</td>
</tr>
</tbody>
</table>

Radiation data- source [1]
C. Environmental Savings

The major advantage from the environmental point of view of SAHS is the reduction in green house gases particularly CO₂ due to fuel saving. It is estimated that the saving in 240 litres of furnace oil/day could result in a reduction of about 11.136 million tonnes of CO₂ emission per year. This saving is of importance to the Government because any saving in fossil fuel is a welcome step as that will reduce the burden on the government in importing fossil fuels from OPEC (Organisation of Petroleum Exporting Countries) countries at a higher price.

D. Government Incentives

The government is disbursing loans for projects in solar heating to the extent of 75% of the total cost at a lower interest rate of 8.3% (for profit oriented industries) through Indian Renewable Energy Development Agency (IREDA). Only 25% of the investment cost is to be borne by the investor. Since the payback period (including cost invested by the investor) is around 2 years, this is a profitable venture, which can start returning profits after the pay back period. The government also provides 100% depreciation of the first year of installation, which saves as corporate tax of about 40% of the investment. For the soft loan provided by the government a
moratorium of 2 years is allowed and repayment can be made within the next 8 years.
D. Pay back Analysis

Table 7.3 Pay back analysis chart

<table>
<thead>
<tr>
<th>Period (years)</th>
<th>Returns Details</th>
<th>Amount</th>
<th>Investment Details</th>
<th>Amount</th>
<th>Surplus (Rs. in lakhs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Capital</td>
<td>18,01,145</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Due to 100% depreciation, savings in corporate tax (40%)</td>
<td>7,20,548</td>
<td>Interest for investment by investor-18%</td>
<td>81,051</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interest for soft loan-8.3%</td>
<td>1,12,121</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fuel savings</td>
<td>8,16,640</td>
<td>Maintenance and parasitic cost</td>
<td>90,057</td>
<td>(-5.47)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15,37,188</td>
<td>Total</td>
<td>20,84,374</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>5,47,186</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Fuel savings</td>
<td>8,16,640</td>
<td>Interest-18%</td>
<td>24,623</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interest-8.3%</td>
<td>34,062</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maintenance and parasitic cost</td>
<td>90,057</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8,16,640</td>
<td>Total</td>
<td>6,95,928</td>
<td>(+1.20)</td>
</tr>
<tr>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>1,20,712</td>
<td></td>
</tr>
</tbody>
</table>

+ 25% of the total investment since 75% of the investment is provided by IREDA as soft loan with 8.3% interest, with a moratorium of two years and a repayment of ten years.

* Fuel savings at 6 hours a day for a period of 300 days by SAHS at 50% efficiency and a fuel savings of 29 litres of furnace oil per hour.
The pay back analysis made for a profit making company show a pay back period of Two years for the investment made by the investor for installation of SAHS
CHAPTER 8

CASE STUDY ON FEASIBILITY OF SAHS IN FRUITS DRYING

This case study describes feasibility of the solar heating system for the apricots and apples drying.

A) Background

Ladakh union territory is a high elevation desert with very low rainfall of less than 50-mm precipitation per year. The robust Ladakh people practise a time-tested system of agriculture. In summer, they use the waters from the melting snow from glaziers to irrigate their terraced agricultural lands bordering the mountain streams (figures 1 to 6). The villages are scattered widely with little vegetation and habitation. The cultivating season is brief fasting from June till September. The main crops cultivated are:

- Cereals - barley and wheat
- Fruits - apricot and apples
- Vegetables - cabbage, potatoes, cauliflower, peas, tomatoes and carrots.

The main apple variety is Mongol apart from others like Shimla Kushbu, Skurmo Kushbu etc. There is a serious problem of a pest called Coddling moth affecting the apples. Because of this, apples in fresh fruit form are banned from leaving the Ladakh valley to the lower areas and cities, for fear of contaminating the apple orchards in
the Himachal and other regions. Traditionally, dried apricots are the main export from Ladakh. The main apricot varieties are Halman, Rakchey karpo, Narmo and Khantey. Of this the Halman variety is the best quality and it is about 30% of total apricot tree population.

B) Objectives

a) To assess the current situation on agricultural crops (fruits and vegetables) cultivation, processing and usage in the area.

b) To determine feasibility of using solar energy for fruits and vegetables dehydration.

c) To recommend practical implementation of a commercial fruit/vegetable fruit dehydration unit suitable to Ladakh environment.

C) Socio-economic situation

Ladakh is sparsely populated and was rather isolated from the outside world for a long time. In recent times, a sizeable portion of the population is involved in tourism related activities, and the Indian armed forces also give employment to large numbers of able bodied men. Subsidised food and ration supplied by the Indian government, and modern chemical farming and new seed varieties have upset the old agricultural order. However agriculture still plays a key role in the life of people living in the interior areas. Efforts are needed to improve the existing situation in terms of better price realisation for
agricultural produce, which will go a long way to improve the living standard of the people of Ladakh.

**D) Fruits and vegetables processing**

Apricot is an important crop cultivated all over Ladakh. Traditionally the ripe apricots are dried. A vast market and demand exists for this product both within Ladakh and in far off markets in Delhi and Bombay. Apricot seed kernel is also a delicacy and apricot seed oil is a rare commodity.

The traditional way of drying is done by collecting ripe fruits and drying them on rooftops or on baskets in homes for nearly a week. On account of low temperature and humidity and bright sunshine through cloudless skies, drying takes place in a slow manner and extends to over a week to dry one batch of apricots. The method of apricot drying, though centuries old with a long tradition, has much scope for improvement, especially for the modern quality demands of the market. The existing drying system in the open and on straws attracts a lot of dust and flies. It results in insect infestation and the poor quality and colour of dried apricots. Moreover, untimely rains during drying time can result in total loss of the product.
The Horticulture Department has been propagating the idea of osmotic dehydration, which is basically an improvement of the existing system. The apricots are immersed in a sugar solution with citric acid and KMS (Potassium Metabisulphate) for 24 hours to bring out the colour of the product and then dried in the open on nylon nets. By this method the colour and sweetness of the dried apricot is improved and has better marketing qualities, which can get a better price. But the method is yet to gain momentum within the farming community.

E) Future improvement possibilities

It was generally observed that there was a need for processing fruits like apples also. Apples as mentioned earlier are banned from movement outside Ladakh due to the presence of Coddling moth. Drying of apples gives better price and marketability of this high value fruit. Moreover fruits like tomatoes could also be processed or dried, since this fruit is also largely used by most homes nowadays. Vegetables like spinach, carrots, cauliflower could also be dehydrated and stored and sold for use during the cold winter months. It must be mentioned that most of the vegetables come from the plains for use in the Ladakh region during winter.
F) Scope for solar dehydration

Dehydration of fruits and vegetables is an important post harvest value addition possibility. The most commonly adopted method is open air sun drying, which has many disadvantages: long drying time extending over several days, dust and insect infestation, poor quality of the finished product, more man power etc. Controlled indirect hot air drying technique using conventional solid or liquid fuels is adopted for many fruits and vegetables. On ecological considerations, as well as energy conservation aspects indirect solar drying method opens a new possibility. For effective controlled drying the air should be hot, dry and moving. The dryness of air is called humidity i.e., lower the humidity, more is the dryness of air. In this aspect Ladakh has an advantage because of the low humidity in the atmosphere compensating for the low temperature.

However it must be remembered that solar energy for drying is available effectively for only about 8 hours in the daytime. Since the cultivation is short, the fruits and vegetables for drying will be available only during a brief period and hence it is important to find a way to speed up the drying process and keep it continuous even during the night. Hence an auxiliary indirect heating system using
diesel, kerosene or coal could be added and thereby the drying capacity of the solar drier can be increased by over 150%.

G) Recommended solar hot air drying system for ladakh

A pilot scale fruits and vegetables solar assisted drying unit is recommended. This unit could have a 50 sq.m. built up processing area where the fruit preparation and drier could be located. A 50 sq.m. solar air heating system (SAHS) could be installed over the roof of the factory building. Four pillars will be raised over the flat roof on which the solar collectors of the system can be installed in a specific orientation for maximum utilisation of direct incident solar radiation.

The SAHS consists of 50-sqm solar part, ducting and insulation, hot air circulation, a cabinet drier and an auxiliary-heating unit. The solar part consists of absorber, glass cover, supporting frame and thermal insulation. A black coated copper plate will do the function of the absorber. This copper-coated plate is very efficient and chosen for its high degree of absorption of incident solar radiation and low emission of heat to the surrounding. The solar panel cover will be of tempered glass for minimising the loss of heat due to convection and radiation. The fresh atmospheric air is made to pass through the gap between the absorber and glass cover. The frame is made of polished aluminium metal to have lightweight and
reduce heat loss due to radiation. A good rockwool insulation can be made between the absorber and the frame in order to decrease the heat loss due to conduction. The ambient temperature can be increased by as much as 30° to 40° C for use in the drier by using SAHS.

The room over which the solar system will be installed can be used for locating the drier and for fruit and vegetable preparation work. The fruits and vegetables are placed in stainless steel trays inside the drier. The proposed system can dry up to an amount of 150 to 200 KGs of fruits or vegetables per day.

**H) Recommendations**

1. There is a good potential to introduce roof oriented Solar Air Heating for drying of fruits and vegetables in Ladakh region. – Apricots, apples and some vegetables. A pilot scale unit with a capacity to handle and process 250 kgs/day/batch would be ideal to start with.

2. It is advisable to locate this unit in an interior village with a captive raw material supply base for the dehydration unit. The lack of adequate transport facilities for marketing perishable agricultural products like fruits and vegetables will motivate farmers to sell their raw materials to such an unit, and get a fair price in their village itself.
CHAPTER 9

CONCLUSIONS WITH RECOMMENDATIONS

A. Advantages Of Solar Heating:

The inherent advantages in using solar air heating for drying operations are given below with examples taken from our case study and experience in the particular field.

A.1) Upliftment of the villages

The model proposed for fruits drying in the Ladakh region can go a great way in sustaining the people in that region economically by providing the fruit farmers with a fair price. They will also be relieved of the worry about wastage of the excess fruits and the transportation of the produce to far off markets in the rough terrain.

A.2) Quality maintenance

Food processing industries are bound by strict quality control procedures, which have been laid down by the Government. Unless the product is processed in a hygienic manner the product is liable to be rejected by the standards authority. The installation of solar air heating system will render quality products as the product is dried in a clean closed atmosphere. The vegetable processed in the model factory is an example since they dehydrate vegetables in a hygienic
atmosphere and they are exporting the products to foreign countries conforming to the standards.

**A.3) Fuel Conservation**

For the drying operations, the most widely used fuels are diesel and furnace oil. Both being fossil fuels, they are to be conserved as the resources are depleting at the fastest rate due to increasing demand. With the demand on the curb of over exploitation of fossil fuels raising, the search for alternative energy sources is being done on a fast pace. The conservation of fossil fuels can be done easily substituting the energy requirements during the daytime with solar energy thereby reducing fuel consumption. For prolonged drying operations like vegetable drying, SAHS is a necessity since the heater is expected to run throughout the operation, which consumes considerable fuel. The system can act as a full energy delivery (fed) system for fruits drying unit. For vegetables drying, SAHS can act as partial energy delivery system for second and third stage drying and as full energy delivery system in final bin drying.

**A.4) Increased Efficiency**

An increased efficiency can be experienced when the solar air heating system is installed. An advantage of using the solar air heating system is its lowest cost coupled with integrated roofing. The
payback period for the system is the least and has less maintenance costs as compared to conventional energy sources. An efficiency of 53% is obtained in the operating systems, which by itself is a greater achievement. Even when the SAHS delivers partial energy, it preheats the air and helps in increasing the efficiency of the conventional heater. Currently work is being carried out to boost the efficiency to a higher level at a lower cost at PEN.

A.5) Environmental Benefits

With the states making a stringent posture on the pollution control measures, the solar air heating system stands out as an exemplary model of being nature friendly in providing a cleaner atmosphere. Since the system harnesses solar energy, it never gives out any harmful chemicals thereby helping these industries adopting this system to get international environment certification (ISO 14001). This cleaner technology can also aid in a better quality management to receive the ISO certifications (ISO 9001 & ISO 9002) which are a prerequisite to compete globally. This is achieved as the products are dried in a hygienic manner under sterile atmosphere. The other major environmental benefit is the reduction in emission of CO₂-a green house gas largely by substitution for fossil fuels.
B. Disadvantages Of Solar Heating

One of the problems that ail the SAHS system is its need for a backup heater to heat air when SAHS is not working. This problem arises when clouds as rain block the natural solar energy or the operation is prolonged beyond the sunshine hours. During such time, the conventional systems alone can help. The other situation arises when the solar SAHS could not deliver the required temperature.

C. Steps to overcome the disadvantages

To overcome these problems, the SAHS is coupled with the conventional heating source such that the heating system never fails during the process as the operator can rely on conventional heater (auxiliary heating unit) when the SAHS is not under operation. In existing plants, the SAHS works coupled with the existing heater as that could get a backup at no more extra capital investment. This does not involve any complex design and is simple in installation and operation. The Plan outlay (Annex II) shows the mode by which the integrated system of SAHS and the conventional heater (backup) are operated. Since the SAHS is a partial energy delivery (ped) system, the auxiliary heating system supports the SAHS when temperature is not sufficient. A temperature indicator in the drier hot air flow duct
can help in the detection of any change in the temperature and this can work as an indicator as to whether the backup system should be used or not. All states go through a lean phase in solar radiation for two months. During these months (see radiation chart) the back up heater can provide the necessary hot air for drying.
D. Conclusions

The project involved the feasibility study on the scope of utilising Solar Air Heating System (SAHS) in vegetables and fruits drying and to study the performance of one such system for vegetable drying by installing the system in a factory. The survey on the vegetable drying industries was made to find a suitable industry for installation of the system. It was found that this industry is in its nascent stage in India with a scope of developing into a major foreign export-earning sector. The system of roof area 424 m$^2$ was installed in Terra Agro Technologies Ltd. in Udumalpet in Tamilnadu. Since the temperature requirement is very high in the First stage of drying, the Solar Air Heating system is substituted only for II, III and bin stage drying. The thermal requirement for these stages is around 256 kWh out of this 185 kWh is obtained from Solar Air Heating System which constitutes around 73% of the energy requirement for the drying of vegetables in the last three stages.

The performance analysed for a year has found the system operating at an average efficiency of 53%. On the economic front, furnace oil saving of 29 litres/hour was experienced under clear weather. This experience has proved the technical and economical viability of using SAHS for vegetables drying. The cost involved in the
construction of a solar air heater system is provided and the pay back analysis conducted has shown the period to be two and a half months and hence this is a profitable venture. The analysis of the design parameters has helped in the optimisation of the same. Projections of the existing conditions with the annual fruits and vegetables production as the datum has shown that processing of 30% of the produce will save 3840 million litres of furnace oil per annum and the atmosphere will be relieved of 11,136 million tonnes of CO₂ added to it.

A feasibility study on fruits drying using solar heating is also made. Ladakh, receives the maximum insolation compared to most other areas in India for eg. It receives 32% more insolation than Calcutta. In Ladakh apricot drying is practised in the traditional method and the project explored the possibility of applying solar heating for drying apricots. The study has found apricot drying too feasible and to optimise the usage of solar heater, apples that are grown there could also be dried during its harvesting season. The system can be extended to other parts of the country with certain modification in design parameters to suit the climatic conditions prevailing there.
E. Recommendations

1) Creation of a data bank for developments in solar energy can help in identifying the further developments required in the field.

2) This technology of solar heating should be given more publicity among the fruits and vegetable processing units. This can be achieved by publishing pamphlets and newsletters about the demonstration project and its success. More over the Ministry can advice the newer food processing industries to adapt this system for better cost savings.

3) If the system is manufactured in a large scale then the cost of the system will come down further. More R & D work on absorber materials can bring down the cost further.

4) As the initial investment is high, Ministry of Food processing Industries could provide 50% capital grant for faster diffusion of solar paddy drying technology.
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Annex

IV Boiler Efficiency calculation:

Temperature of boiler feed water = 60 °C
Total heat in boiler feed water = 60 kcal/kg
Total heat in saturated steam at Working pressure from steam table = 675 kcal/kg
Heat taken by feed water to become Saturated steam = 675–60 = 615 kcal/kg
Steam production per hour = 2206.5 kg/h
Total heat recovered in boiler = 615 x 2206.5 = 1356997.5 kcal/hr
Furnace oil consumed = 280 Ltr/hr
Weight of furnace oil/hour = 308 kg/h
Total heat available in furnace oil = 308 x 9600 = 2956800 kcal
Boiler efficiency = 1356997.5 x 100 / 2956800
= 0.4576 x 100 = 45.76%
**Calculation: I stage**

Raw material = 2200 kg/h  
Moisture per raw material = 0.85  
Dry substance = 2200 x 0.15 = 330 kg/h  
Moisture per I stage product (moisture in product after I stage) = 0.70 (experiment)  
Weight of the I stage dried product = 330/0.3 = 1100 kg/h  
Water removal in I stage = 2200 – 1100 = 1100 kg/h.

**II stage and III stage:**

Solar heater air (total) = 22000 m$^3$/hr  
Temperature of solar heated air = 65$^0$C  
Solar heater air II & III stage = 11000 m$^3$/hr  
11000 m$^3$/hr of air heated from 65 to around 90$^0$C by steam = 11000 x 0.96 x 1.005 x (95-65) = 318384 kJ

**Bin drying:**

Quantity of air to the application = 11000 m$^3$/hr  
11000 m$^3$/hr of air heated from 65 to around 70$^0$C by steam = 11000 x 1.016 x 1.005 x (70-65) = 56160 kJ

Hot air pumped by solar heater blower = 11000 m$^3$/hr  
Temperature of solar heated air = 65$^0$C  
Ambient temperature = 30$^0$C  
Heat energy required to raise 11000 x 1.005 x 30 to 65$^0$C 1.005 x 35 = 388860 kJ/hr

**II & III stage drying & recirculation**

Product moisture at III stage outlet = 7.5%  
Quantity of product after III stage = 330 x 100/92.5 = 356.75 kg/h  
Water removal at II & III stage = 743 kg/h  
Latent heat of vapour at 70$^0$C = 2334 kJ/kg  
Latent heat required for vapourisation = 1734162 kJ/hr  
Heat energy required to rise 30 to 65$^0$C = 388860 kJ/hr
Sensible heat required to rise = 11000 x 0.976 x 1.005 x [75 – 65] = 1,07,896.8 kJ/hr

Total heat energy required to vapour = 2230918.8 kJ/hr

743 kg/h

Percentage of heat energy available from Solar = 388860 x 100/2230918.8 = 17.43%

Bin drying:
Quantity of product after III stage = 356.75 kg/h
Quantity of final product = 330.00 kg/h

Water vapourised in Bin = 26.75 kg/h

Latent heat of steam at 70°C = 2334 kJ/kg

Latent heat required to vapourise = 62434.5 kJ/hr

26.75 kg/h.

Heat available through solar heated air = 11000 x 1.005 x 0.96 x 35 = 371448 kJ/hr

Heat available through steam = 11000 x 1.005 x 0.99 x 5 = 54722.25 kJ/hr

Total heat = 488604.75 kJ/hr

Percentage air available from solar = 371448 x 100 /488604 = 76.02%