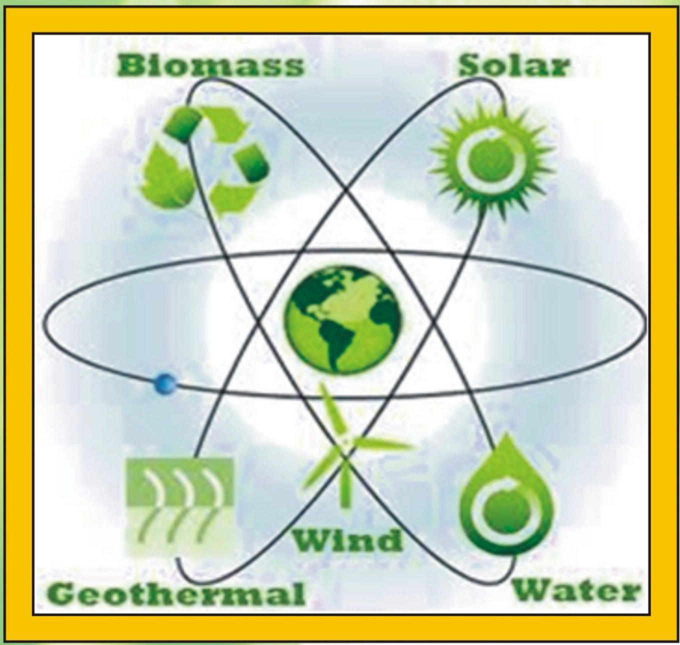
Compendium of Lectures



Renewable Energy for Sustainable Agriculture and Environmental Protection

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Renewable Energy for Sustainable Agriculture and Environmental Protection

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Compendium of Lectures

Organised by:

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Cooking under the Sun: A renewable energy concept for ensuring clean environment

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Introduction

Many methods have been developed to utilize the available sunshine in sun-rich regions of the world for different end-uses. With fast growing population and rapid growth of industries, the consumption of energy is increasing enormously. At the present rate of energy consumption the world energy resources will be exhausted in 50 to 100 years. Therefore, there is need to harness solar energy and other alternative energy sources. Solar cooker is an environmental friendly and cost effective device for harnessing solar energy. Solar cooking has proved to be one of the simplest, the most viable and attractive options for solar energy utilization. As the system is very useful for the common people in the developing world and it coincides with the availability of the sun and drudgery of the people involved in cooking in these regions its importance is even more. Also a major portion of total available energy resource is utilized for cooking in these regions. This cooking energy is supplied by non-commercial fuels like fuel wood, agricultural waste, cow dung and kerosene in rural areas. Fifty percent of the total energy consumption in India is used for cooking purpose. Most of the cooking energy requirement is met by non-conventional fuels such as firewood, (75%) agricultural waste and cow dung (25%) cakes in rural areas. During the survey of rural arid areas, it was found that huge amount of firewood, cow dung cake and agriculture waste are burnt for boiling of animal feed. In rural areas firewood crisis is far graver than that caused by rise in oil prices. Small and marginal villagers have to forage 8 to 10 hours a day in search of firewood as compared to 1-2 hours; a decade ago. One third of India's fertilizer consumption can be met if cow dung is not burnt for cooking and instead is used as manure. The cutting of firewood causes deforestation, which leads to desertification. Fortunately India is blessed with abundant solar energy. During winter from November to February most of the Indian stations receive 4.0 to 6.3 $kWhm^{-2}$ day^{-1} solar irradiance, while in summer season this value ranges from 5.0 to 7.4 $kWhm^{-2}$ day^{-1}. The arid and semi-arid parts of the country receive much more radiation as compared to rest of the country with 6.0 7.4 $kWhm^{-2}$ day^{-1}mean annual daily solar radiation having 8.9 average sunshine hours a day at Jodhpur.

1. Principle of cooking

The different methods of cooking of food are boiling, frying, roasting, and baking. For boiling of rice, lentils etc. the temperature of food being cooked is about 100^{o} C while for other methods, high temperatures are required. Heat is supplied at the bottom of the vessel for frying and boiling purposes in conventional cooking. Roasting and baking is generally performed on open fire or in ovens, wherein food is surrounded by hot surfaces and heat is transferred to the food by radiation and convection. The first step in cooking is to raise the temperature of the food to about 100^{o} C that is the cooking temperature for most of the food in which water is present during cooking. If pressure cooker is used this temperature becomes 120^{o} C. After food has attained cooking temperature, lesser heat is required to continue the cooking process. At this stage heat is supplied only to meet various heat losses taking place during cooking. The heat losses consist of evaporation loss from the food and convection and radiation losses from the surface of the cooking vessel. The relative proportion of these losses may very significantly depend upon the type of place (indoor or outdoor) of cooking. Estimating an hourly convection loss (outdoors), at boiling water temperature of about 6.8 MJ m^{-2} of utensil and a surface area of 0.1 m^2 kg^{-1} of container contents, the energy inputs for 1 h of food boiling, if one fourth of the water present is vaporised, would be distributed roughly as follows (Lof 1961):

Heating food for boiling temperature	20 %
Convection losses from the vessel	45 %
Vaporization of water	35 %

The heat losses can be reduced by insulating the sides of the cooking vessel and keeping the vessel covered with lid. Even though cooking temperature of most of the food is normally 100^{o} C, the temperature of the heat source should be precisely higher to achieve satisfactory heat transfer rates. In the conventional cooking with direct fire, the heat transfer rate is very high, because of very high temperature of the heat source. Where electric or gas cooking is used, the normal burner supplies energy at the rate of approximately 1 kW and is capable of bringing 2 litre of water to boil in about 10 minutes. Therefore a solar unit should have to have an energy delivery rate of roughly 1 kW, to be compared with existing systems. The alternative would be accepting longer cooking periods and possibly cooking smaller amounts of food at one time. A solar cooker area of about 2 m^2 would be necessary (at 50 % collection efficiency) to give comparable normal cooking rates.

The first solar furnace was fabricated by naturalist Georges Louis Leclerc Buffon (1707-1788). But Horace-de-Saussure (1740-1799) was first in the world to use the sun for cooking. Augustin Mouchot, a French physicist, described a solar cooker in his book “La Chaleur Solaire” published in Paris, in 1869. He has also reported in the same book earlier work on solar cooking by English astronomer, Sir John Herschel, in South Africa, between 1834 and 1838. Adams, an army officer, made India’s first solar cooker in 1878 and he cooked food in it at Bombay, India (Adams, 1878). Since then different types of solar cookers have been developed all over the world. The solar cookers can be classified into three broad categories (i) Reflector/focusing type (ii) Heat transfer type and (iii) hot box type. These are described below:

1.1. Reflector/focusing type

The reflector type solar cooker was developed in early 1950's and was manufactured on a large scale in India. Attempts were also made in1960's and 70’s to develop a reflector type solar cooker. However a reflector type solar cooker did not become popular due to its inherent defects e.g. it required tracking towards sun every ten minutes, cooking could be done only in the middle of the day and only in direct sunlight, its performance was greatly affected by dust and wind, there was a danger of the cook being burned as it was necessary to stand very close to the cooker when cooking and the design was complicated.

1.2. Heat transfer type

In the heat transfer type solar cooker, the collector is kept outside and the cooking chamber is kept inside the kitchen of the house. But this type of solar cooker also did not become popular because of its high cost and only limited cooking can be performed.

1.3. Hot box type

The third type of cooker is known as hot box in which most of the defects of above two types of cookers have been rectified. Though the performance of the solar oven is very good but it also requires tracking towards sun every 30 minutes, it is too bulky and is costly. Therefore, the hot box solar cooker with a single reflector is being promoted at subsidized cost by the Ministry of New and Renewable Energy, Government of India and the state nodal agencies in India since 1981-82 and 637,000 solar cookers were sold up to the September 30, 2008 (MNRE, 2008) as against potential of 200 million solar cookers. It is also not becoming popular in large scale due to its defects: it also requires tracking towards the sun every 60 minutes. Different hot box solar cookers are described below:

1.4 Solar Oven

The solar oven consists of a reflector assembly cooking chamber and an angle iron stand. The cooking chamber is double walled cylindrical vessel. Cylinders are made from 22-gauge aluminium sheet. Space between them (100 mm) is filled by glass wool insulation. Two clear window glasses are fixed over it. The inner cylinder is painted black by black board paint. One door is provided for loading and unloading of cooker for cooking. It is fixed over an angle iron stand, which is having castor wheel for azimuthal tracking and a slotted *kamani* for elevation tracking. Reflectors are trapezoidal in shape and also made from 22-gauge aluminium sheet, are fixed over it. It consists of four rectangular and four triangular mirrors. One rubber gasket has been fixed to the boundary of the door to prevent the leakage of hot air and to increase the pressure inside the chamber enabling a reduction of cooking time. To facilitate azimuthal tracking, a stand of mild steel angle having four castor wheels has been made. A slotted kamani has been fixed for following the altitude position of the sun. The cooking utensils are kept on a cradle like platform so that vessels always remain in a horizontal position, irrespective of the oven's inclination (Fig. 1). Performance of cooker was carried out by measuring stagnation plate temperature, time taken for known quantity of water for reaching boiling point and cooking trials. Cooking of vegetable, rice, roasting of potato, baking of bati is possible from 8.00 AM to 5.00 PM in winter while 7.00 AM to 6.00 PM in summer.

Figure 1: Solar Oven

1.5 Hot Box Solar Cooker

This is a double walled chamber outer tray is made from 20 gauge mild steel and inner tray is from 22 gauge aluminium sheet glass wool insulation. The inner tray is painted by black board paint. Two clear window glasses (3 mm thick) fixed in a wooden frame are hinged over it which can be lifted for loading and unloading of cooker for cooking. One mirror booster with slotted kamani on top, which acts as a lid as well, has been provided. Four castor wheels are fixed at the bottom for easy movement. The four cooking utensils are provided in the cooking chamber for cooking four dishes simultaneously. The operation of the cooker is very simple. The products to be cooked are placed in the cooking utensils with right amount of water so that after cooking whole water is absorbed. The lid is closed and utensils are kept inside the cooking chamber. The booster mirror is adjusted in such a way that all reflected solar radiation by it falls on plain glass. The tracking of cooker towards sun should be done every hour. All types of boiling, bakery and roasting operation can be performed and it takes about 2 to 3 hrs in cooking one kg of food in four utensils (Fig. 2). Soft food takes less time hard food takes more time.

Figure 2: Hot box solar cooker

1.6 Improved Hot Box Solar Cooker with Tilted Absorber

The performance of hot box solar cooker is very good during summer but it is very poor during winter in northern parts of India and difficult to cook two meals per day during winter because its glass window and absorbing surface are horizontal, which receive very much less radiation as compared to optimally inclined surface. Optimally inclined surface receives 43.8 % and 22.8 % more radiation as compared to horizontal surface during winter

(October to March) and per year respectively. Considering this, a novel solar cooker with tilted absorber (TA) has been designed, fabricated and tested. It has been found that the performance of solar cooker (TA) is better than hot box solar cooker and comparable with solar oven, and simultaneously no tracking is required as compared to 30 minute tracking for solar oven and 60 minute tracking for the hot box solar cooker. The overall efficiency of the solar cooker (TA) has been found to be 24.6%. Cooking trials have also been carried out at different times with different materials and the time taken to cook various dishes is between 75 and 120 minute for the solar oven, 90-180 minute for the hot box and 90-150 minute for the solar cooker (TA). If the cookers are partially loaded, then cooking time is less (Fig. 3). Cooking time is less around noontime and, while it is more in the morning and the evening.

Figure 3: improved hot box solar cooker with tilted absorber

1.7 Hot Box Solar Cooker with Transparent Insulation Material (TIM)

The performance of hot box solar cooker is very poor during winter in northern parts of India and difficult to cook two meals per day during winter because more heat loss due to low ambient temperatures. It has been found that the efficiency of the solar devices can be increased considerably for temperature applications between 80^{o}C to 140^{o} C i.e. for solar cooking, process heat and for refrigeration applications by using transparent insulation material (TIM) in between two glazing or between absorber and glazing. The use of TIM reduces convective heat losses from glass window. Considering this, a hot box solar cooker with 40mm thick TIM encapsulated between two glazing has been designed, developed and tested. The efficiency of the cooker with TIM is 30.4% as compared to 15.7 % without TIM. Cooking trials have also been carried out at different times with different materials. One kg of dry food can be cooked in 2 hour and 2.5 hour in hot box solar cooker with and without TIM respectively.

Figure 4: hot box solar cooker with transparent insulation material (TIM)

1.8 Double Reflector Hot Box Solar Cooker with a Transparent Insulation Material (TIM)

The popularity of hot box solar cooker promoted by MNES, New Delhi and state nodal agencies is declining due to its defects: it requires tracking towards the sun every 60 minutes, therefore, its operation becomes cumbersome and the performance of the hot box solar cooker is very poor during winter when solar radiation and ambient temperatures are very low. Considering this, double reflector hot box solar cooker with a Transparent Insulation Material (TIM) has been designed, fabricated, tested and the performance has been compared with a single reflector hot box solar cooker without TIM. Both defects of the hot box solar cooker have been removed by providing one more reflector and convective heat losses have been suppressed by using Transparent Insulation Material. The efficiencies were 30.5 % and 24.5 % for cookers with and without a TIM respectively during winter season at Jodhpur. The performance studies on the double reflector hot box solar cooker with TIM suggests that the cooker can be used throughout the year (Fig. 5).

Figure 5: Double reflector hot box solar cooker with a transparent insulation material (TIM)

1.9 Non-tracking solar cooker

The performance of the hot box solar cooker is good but it requires tracking towards sun every 60 minutes, therefore, its operation also becomes cumbersome. To eliminate tracking completely, a novel non-tracking solar cooker has been designed, developed and tested. A double glazed non-tracking solar cooker with reflector was designed and fabricated at the workshop of Central Arid Zone Research Institute, Jodhpur, India. The cooker is based on hot box principle with dimensions of 1090× 490× 290 mm (Fig.6). The cooker has been designed in such a way that the width to length ratio of the cooker has been designed as 3:1 so that maximum amount of radiation falls on the glass window at any time in a day. It helped in eliminating the need for azimuthal tracking of the cooker, which is very essential for a simple hot box solar cooker towards the sun every hour because the width to length ratio of reflector is 1. This cooker is always kept fixed, facing the equator. The device consists of a double walled hot box. The outer box is made of galvanized steel sheet (22 SWG) and inner of aluminum (22 SWG). The space between the outer box and inner box was filled with glass wool insulation. The inner tray is painted black by black board paint. Two clear window glass planes of 4mm thickness have been fixed over it with an openable wooden frame. A 4mm thick plain mirror reflector is fixed over it. The tilt of the reflector can be varied from 0^o to 120^o depending upon the season and its tilt is fixed once in a fortnight. The reflector was folded on the cooker while the device is not in use. The aperture area of the solar cooker is 0.25 m^2. Four cooking utensils of aluminum/stainless steel boxes with lid can be kept inside it for cooking four dishes simultaneously. The cooker is fixed on an angle iron stand.

Figure 6: Installation of the non-tracking solar cooker

The experimental results shows that first figure of merit (F_1), second figure of merit (F_2) and standardized cooking power (P_s) satisfied the Bureau of Indian Standards (BIS) and

American Society of Agricultural Engineers Standard (ASAE) International standards for thermal performance testing of the non-tracking solar cooker. F_1, F_2 and standardized cooking power were found acceptable and satisfying the standards (ASAE and BIS) limits. The thermal efficiency of the non-tracking solar cooker was 25.4% for the water load of 3.0 kg. The payback period varies between 1.58 to 6.00 year depending upon the fuel it replaces and is in increasing order with respect to the following fuels: firewood, electricity, charcoal, LPG and kerosene. The estimated life is about 15 years. The shorter payback periods suggests that the use of non-tracking solar cooker is economical. The present non-tracking solar cooker has shown the best performance and highest efficiency for the maximum load. Solar cooking promotes the use of renewable solar energy and represents the simplest application of solar thermal energy and has a potential to reduce conventional fuels and CO_2 pollution which will help combat desertification.

1.10 Community solar cooker

A Community solar cooker capable of cooking for about 80 persons has been designed, fabricated and tested at CAZRI, Jodhpur. The cooker is suitable for hostels, temples, canteens, restaurants, etc. The cooker is based on the hot box principle having a single reflector. The cooker has been designed in such a way that the width to length ratio for the reflector and the glass window is about 4, so maximum radiation falls on the glass window. This has helped in eliminating the azimuthal tracking, which is required in the simple hot box solar cooker, towards the sun every hour because the width to length ratio of the reflector is 1. This cooker is always kept fixed, facing the equator. This device consists of a double walled hot box. The outer tray is made of mild steel and the inner of aluminium. The space between them is filled with glass wool insulation. The inner tray is painted by blackboard paint. Two clear window glass panes of 4 mm thickness have been fixed over it with a wooden frame. Three doors have been provided in the rear side for loading and unloading the cooker. The doors have been made leak proof by rubber gaskets. A 4-mm thick plain mirror reflector is fixed over it and arrangements have been made so that it can be tilted to 120° from the glass window. Therefore, it is effective in summer as well as in winter when the altitude of the sun is very low. The absorber area of the cooker is 3.12 m^2. Specially designed cooking utensils are rectangular in shape, having dimension 560 x 540 x 75 mm^3 (Fig. 7). These are made from aluminium sheet. Twelve such utensils can be kept inside the cooker. The cooker was tested extensively. The stagnation air temperature inside the cooking chamber has been measured and compared with the hot box solar cooker. The maximum stagnation temperature inside cooking chamber during summer is 146°C and 136°C in winter. The efficiency of the cooker is 28.4%. The cooker can be used for boiling, roasting and baking. Rice, lentils, kidney beans, cauliflower, backing of bati (local preparation made of wheat flour) etc. have been cooked successfully. It takes about 2 h for soft food and 3 h for hard food. The cooker is capable of cooking 16 kg of food at a time. The performance of the community solar cooker is comparable with the hot box, though it is kept fixed while the hot box is tracked towards the sun every hour. It has been made possible because the width to length ratio is 4 for the community solar cooker, while it is 1 for the hot box solar cooker. The cooker can be used twice a day for about 254 days and once a day for about 67 days in a year at Jodhpur. The energy for cooking per person is about 900 kg of fuel equivalent per meal. The community solar cooker is capable of cooking for about 80 persons, and it will save 50 % of cooking fuel per meal. Therefore, it will save 36 MJ of energy per meal and 20,700 MJ of fuel equivalent per year.

Figure 7: Community solar cookers

1.11 Animal feed solar cooker

For boiling of animal feed, huge amount of firewood, animal dung cake and agricultural wastes are burnt using traditional fuel wood stove. Therefore, a low cost high capacity suitable solar cooker has been designed for boiling of animal feed using solar energy. The animal feed solar cooker was fabricated using locally available materials e.g. clay, pearl millet husk and animal dung. The commercial material for its fabrication are plain glass, mild steel angle and sheet, wood and aluminium sheet cooking utensils. The cocker can be made even by an unskilled worker. Technician's help has been taken for fixing glasses on a suitable angle iron and wooden frame. The body of the cooker has been fabricated by an unskilled labour. The cooker is capable of boiling 10 kg of animal feed, sufficient for five cattle per day. The thermal performance of the animal feed solar cooker was tested with standards of American Society of Agricultural Engineers and Bureau of Indian Standards. It indicates that the developed cooker falls under category "A", as per standard. The efficiency of solar cooker for animal feed has been found to be 26.4%. The performance of the animal feed solar cooker can be improved by providing an additional reflector during extreme cold days. Crushed barley (*Jau Ghat*), *guar korma*, and *gram churi* with water can be successfully boiled using the animal feed solar cooker between 9 AM and by 3 PM. Animal feed viz. cotton seed and khal have also been successfully boiled by the farmers using the animal feed solar cooker. Forty units of animal feed solar cooker have been fabricated by ICAR-CAZRI and installed in the villages surrounding Jodhpur. The solar cooker saves time of farm women and 1059 kg of fuel wood is saved per year equivalent to 3611 MJ of energy. It is easy to fabricate at village level at a cost of about Rs. 9000 per piece with the help of a carpenter will get job for the fabrication of glass frame which is also very simple. Conservation of firewood help in preserving the ecosystem and animal dung cake could be used as fertilizer, which enhances agricultural productivity. The technology developed for the animal feed preparation not only reduces the greenhouse gas emission but also helps in fuel conservation and drudgery reduction. Moreover, the use of the solar cooker for animal feed would result on the reduction of the release of 1442.64 kg of CO_2 savings/year to the environment and getting Certified Emission Reduction (CER) under Clean Development Mechanism (CDM) mechanism of United National Frame Work Convention on Climate Change (UNFCCC).

Figure 8: Animal feed solar cooker