# SOLAR ENERGY UTILISATION RESEARCH

*BY*

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# CONTENTS

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# at
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## INTRODUCTION

The need for research in utilising solar energy in the wake of oil crisis hardly be emphasized.

India's per capita energy consumption is very low and stands 113th in ladder of per capita energy consumption of about 100 KWH. The ratiof of energies consumption from commercial sources such as coal, oil etc. to non-commercial sources such as animal waste, firewood etc. is a measure of the industrialization of the country. According to planning commission (1970-71), in India 45 per cent of the energy consumed comes from non-commercial sources while 5 per cent of the energy consumed in U.S. comes from non-commercial sources.

India is essentially an agricultural country with 60 to 70 per cent of the population lives in villages and 60 per cent of the gross national product coming from the agricultural sector. According to NCST report on fuel and power, out of the total population of 560 million in India, 250 million live in small villages with a population less than 1000 and another 200 million live in villages with a population between 1000 and 5000. Only 6 per cent of the population live in big cities consuming about 50 per cent of the energy produced.

It is estimated that the daily energy requirement of a small village with a population of less than 500 persons is about 250 KWH i.e. 100 KWH for cooking, 100 KWH for irrigation and 50 KWH for lighting and entertainment. Most of these villages still do not have basic amenities such as drinking water, electric power for irrigation, lighting arrangements etc. These villages are so largely dispersed and are inaccessible that it is uneconomical to serve them with electric power. The energy needs ofsuch villages are limited and their requirements are for (1) getting drinking water, (2) fuel for cooking, (3) electricity for lift irrigation purposes and (4) electricity for lighting their huts. Animal waste and firewood now provide the energy needs for cooking in villages. But increasing use of firewood will lead to the depletion of forest areas with their consequent deleterious results on the ecosystem.

The earth owes its origin to the sun and directly or indirectly, Sun is the ultimate energy source of nearly all of our energy. As a matter of fact, the sun god, surya-bhagvan, has been regarded in our scriptures as the giver of all life and energy. It has been estimated that the earth is receiving energy from the sun at a rate of $1.73 \times 10^{11}$ megawatts. Taking the land area into consideration, this may roughly work out to be about 7 million KWH per acre per year. Even a 15-minute solar insolation can equal the total electric power consumption. This energy offers to many tropical countries new opportunities for developing their agriculture and also to utilize various natural resources efficiently and economically. Economic application of solar energy are limited to localities in which there is a high proportion of clear sunshine during the winter as well as during the summer. The most favourable areas are mainly situated between latitudes 40° and 20° north and south of the equator; excessive humidity in the tropical equatorial zone is a handicap. As India is situated ideally, the scope for exploiting this natural resource is tremendous.

## 2. SOLAR RADIATION

### 2.1 Solar radiation outside the earth's atmosphere :

Before making any attempt to harness solar energy as a source of power it is necessary to have an accurate knowledge of its availability at the place and its characteristics like intensity, spectral distribution, diurnal and seasonal variations. The amount of solar radiation incident on a surface normal to the solar rays at the outer boundary of the earth's atmosphere is termed as solar constant and its latest value is 1.94 cal per sq. cm. per minute or 1358 watts per sq.m. at the mean distance between the sun and the earth.

If I is the solar radiation intensity, incident upon a surface expressed in cal/cm$^2$ hr, than

$$I = I_{on}\ r \cos Q \text{ ---------------------------- } (1)$$

where $I_{on}$ is solar constant expressed in cal per sq. cm. per hour, r is the square of the ratio of the mean distance between earth and sun to the actual distance between earth and sun, a quantity varying with the time of the year and ranges from a maximum value of 1.034 in January to a minimum value of 0.967 in July and $Q$ is the angle of incidence, i.e. the angle between the sun's rays and the normal to the surface under consideration. When the surface is horizontal, the incident angle becomes the complement of the solar altitude, $\alpha$ , and then :

$$I_h = I_{on}\ r \sin\alpha \text{ ------------------(2)}$$

If a surface is tilted at an angle $\beta$ from the horizontal plane, the incident angle, $\theta t$, can be calculated from the equation,

$$\begin{aligned}\cos\theta t = {} & (\cos\beta \sin L - \sin\beta \cos L\cos\phi)\sin\delta \\ & + (\cos\beta \cos L + \sin\beta \sin L\cos\phi)\cos\delta \cos W \\ & + \sin\beta \sin\phi \cos\delta \sin w \text{ ----------(3)}\end{aligned}$$

Where L is the latitude of the place, $\delta$ is the solar declination, $\phi$ is the azimuth angle of sun with respect to south direction and w is the hour angle.

For a surface facing the equator as is the case with flat-plate collectors, the equation(3) is reduced to :

$$\cos\theta t = \cos(L-\beta)\cos\delta \cos w + \sin(L-\beta)\sin\delta \text{ ---------(4)}$$

If the surface is horizontal, then equation (4) is reduced to :

$$\cos\theta h = \cos L \cos\delta \cos W + \sin L \sin\delta \text{ ----------------(5)}$$

From the above equation the sunset hour angle, $W_s$, can be obtained as :

$$\cos W_s = -\tan L \tan\delta \text{ ------------------------------(6)}$$

It can be seen that possible sunshine hours is given as $S_p = 2\ W_s/15$ ---------------------------------------- (7)

Thus the daily extraterrestrial radiation on a horozontal surface $H_o$, is given as

$$H_o = \frac{24}{\pi} I_{on} \sin L \sin\delta (W_s - \tan W_s) \text{ ------------------ (8)}$$

The sunset hour angle, $W_{st}$, for the tilted surface is given as.

$$\cos W_{st} = -\tan(L-\beta)\tan\delta \text{ ------------------------------ (9)}$$

The daily extraterristrial radiation on the tilted surface, Hot, is given as :

$$H_{ot} = \frac{24}{\pi} I_{on} \left[\cos(L-\beta)\cos\delta \sin W_s + W_s \sin(L-\beta)\sin\delta\right] \text{ --------(10)}$$

When $W_s \leq W_{st}$ and $H_{ot} = \frac{24}{\pi} I_{on} \left[\cos(L-\beta) \text{ con } \delta \sin W_{st} + W_{st} \sin(L-\beta)\sin\delta\right.$ ------------ (11)

when $W_{st} \leq W_s$

Thus the conversion factor RD, for converting direct solar radiation from a horizontal surface to a tilted surface, useful for flat-plate collectors, outside the earth's atmosphere is given as :

$$RD = \frac{H_{ot}}{H_o} = \frac{\mathrm{Cos}\,(L-\beta)}{\mathrm{Cos}\;L}\left[\frac{\mathrm{Sin}\;W_s - W_s\cos W_{st}}{\mathrm{Sin}\;W_s - W_s\cos W_s}\right] \quad \text{When } W_s \leq W_{st} \qquad \text{-----------(12)}$$

$$\text{and } R_D = \frac{H_{ot}}{H_o} = \frac{H_{ot}}{H_o} = \frac{\mathrm{Cos}\,(L-\beta)}{\mathrm{Cos}\;L}\left[\frac{\mathrm{Sin}\;W_{st} - W_{st}\cos W_{st}}{\mathrm{Sin}\;W_{st} - w_s\cos W_s}\right] \quad \text{When } W_{st} \leq W_s \qquad \text{--------------- (13)}$$

By using the above equations, the values of daily extraterristrial radiation, Ho, the possible sunshine hours, Sp, and the daily conversion factors, $R_D$, for tilts which are generally used for flat-plate collectors for the Indian latitude stations are computed and are shown in tables 1, 2 and 3 respectively.

The knowledge of all the above factors are required for utilizing solar energy. For example the optimum tilt for the flat plate collector can be seen from table 3. A collector inclined at an angle of 45° from horizontal at 30° north latitude will have the ratio of Hot/Ho equal to 1.98 in december. This ratio increases to as much as 2.85 for a surface at 40° north latitude and tilted at 55° from the horizontal surface. Although these ratios are worked out for extraterristrial radiation only, the conclusion drawn will still hold good when the effect of the earth's atmosphere is taken into consideration. However, the actual quantitative values may be different.

The intensity of the beam radiation at the top of the atmosphere is known to a high degree of accuracy and remains sensibly uniform from sunrise to sunset throughout the year, the only variation being due to the slight ellipticity of the earth's orbit. The solar energy reaching the earth, however, varies progressively with latitude, season and time of day and may change rapidly and discontinuously with changes in local meteorological conditions. During the passage downwards through the atmosphere the solar beam is split up into four parts. One part is reflected back into space mainly by clouds, another is scattered in all directions by molecules of dry air, water vapour and dust particles, some

Table 1 : Mean values for calender months of extra terrestrial daily insolation (langlay/day) on a horizontal surface outside the earth's atmosphere for various latitudes.
(Solar constant = 1.94 langlay/minute)

| Month | LATITUDE<br>8°N | 10°N | 12°N | 14°N | 16°N | 18°N | 20°N | 22°N | 24°N | 26°N | 28°N | 30°N | 32°N | 34°N | 36°N | 38°N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 751 | 729 | 707 | 685 | 661 | 537 | 612 | 587 | 562 | 535 | 509 | 482 | 454 | 427 | 399 | 371 |
| February | 814 | 799 | 783 | 766 | 748 | 729 | 709 | 689 | 667 | 645 | 623 | 599 | 575 | 551 | 526 | 500 |
| March | 871 | 864 | 856 | 847 | 837 | 825 | 813 | 800 | 786 | 771 | 755 | 738 | 721 | 702 | 682 | 662 |
| April | 900 | 903 | 906 | 907 | 907 | 906 | 903 | 900 | 896 | 890 | 884 | 877 | 868 | 859 | 848 | 837 |
| May | 897 | 908 | 919 | 928 | 936 | 943 | 950 | 955 | 959 | 962 | 965 | 966 | 966 | 965 | 964 | 961 |
| June | 887 | 902 | 917 | 930 | 943 | 954 | 965 | 975 | 984 | 992 | 999 | 1005 | 1010 | 1014 | 1017 | 1019 |
| July | 891 | 905 | 918 | 930 | 941 | 951 | 961 | 969 | 976 | 982 | 988 | 992 | 995 | 998 | 999 | 1000 |
| August | 901 | 909 | 915 | 921 | 925 | 928 | 931 | 932 | 932 | 931 | 929 | 926 | 922 | 917 | 911 | 904 |
| September | 890 | 888 | 885 | 881 | 876 | 870 | 862 | 854 | 844 | 834 | 823 | 810 | 797 | 782 | 767 | 751 |
| October | 844 | 833 | 820 | 807 | 792 | 777 | 761 | 743 | 725 | 706 | 687 | 666 | 645 | 623 | 600 | 576 |
| November | 776 | 757 | 737 | 716 | 695 | 673 | 650 | 626 | 602 | 577 | 552 | 526 | 500 | 473 | 446 | 419 |
| December | 734 | 711 | 688 | 664 | 639 | 614 | 589 | 563 | 536 | 509 | 482 | 454 | 426 | 398 | 370 | 341 |

Table 2 : Mean values for calender months of possiblesunshine hours on a horizontal surface for various latitudes.

| | LATITUDES (DEGREES) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | 8°N | 10°N | 12°N | 14°N | 16°N | 18°N | 20°N | 22°N | 24°N | 26°N | 28°N | 30°N | 32°N | 34°N | 36°N | 38°N |
| Jan. | 11.58 | 11.47 | 11.36 | 11.25 | 11.14 | 11.03 | 10.91 | 10.79 | 10.66 | 10.54 | 10.40 | 10.26 | 10.12 | 9.96 | 9.80 | 9. |
| Feb. | 11.75 | 11.69 | 11.62 | 11.56 | 11.49 | 11.42 | 11.35 | 11.28 | 11.21 | 11.13 | 11.06 | 11.98 | 10.89 | 10.80 | 10.71 | 10. |
| Mar. | 11.95 | 11.94 | 11.93 | 11.91 | 11.90 | 11.89 | 11.87 | 11.86 | 11.85 | 11.84 | 11.82 | 11.80 | 11.79 | 11.77 | 11.75 | 11. |
| Apr. | 12.17 | 12.22 | 12.26 | 12.31 | 12.35 | 12.40 | 12.45 | 12.50 | 12.86 | 12.61 | 12.66 | 12.72 | 12.78 | 12.85 | 12.91 | 12. |
| May | 12.35 | 12.45 | 12.54 | 12.63 | 12.73 | 12.83 | 12.93 | 13.04 | 13.14 | 13.25 | 13.37 | 13.49 | 13.61 | 13.74 | 13.88 | 14. |
| June | 12.45 | 12.57 | 12.69 | 12.81 | 12.94 | 13.06 | 13.19 | 13.33 | 13.46 | 13.61 | 13.75 | 13.91 | 14.07 | 14.24 | 14.42 | 14. |
| July | 12.42 | 12.53 | 12.64 | 12.75 | 12.87 | 12.98 | 13.10 | 13.22 | 13.35 | 13.48 | 13.62 | 13.76 | 13.91 | 14.07 | 14.23 | 14. |
| Aug. | 12.27 | 12.34 | 12.41 | 12.48 | 12.55 | 12.63 | 12.70 | 12.78 | 12.86 | 12.94 | 13.03 | 13.12 | 13.21 | 13.31 | 13.41 | 13. |
| Sept. | 12.06 | 12.07 | 12.09 | 12.11 | 12.12 | 12.14 | 12.16 | 12.18 | 12.20 | 12.21 | 12.23 | 12.26 | 12.28 | 12.30 | 12.32 | 12. |
| Oct. | | | | | | | | | | | | | | | | |
| Oct. | 11.84 | 11.81 | 11.77 | 11.73 | 11.69 | 11.64 | 11.60 | 11.56 | 11.51 | 11.47 | 11.42 | 11.37 | 11.32 | 11.26 | 11.21 | 11. |
| Nov. | 11.64 | 11.55 | 11.46 | 11.37 | 11.28 | 11.18 | 11.08 | 10.98 | 10.87 | 10.77 | 10.65 | 10.54 | 10.42 | 10.29 | 10.15 | 10. |
| Dec. | 11.54 | 11.42 | 11.30 | 11.18 | 11.06 | 10.93 | 10.80 | 10.67 | 10.53 | 10.39 | 10.24 | 10.09 | 9.93 | 9.76 | 9.58 | 9. |

Table 3 : Conversion factors for direct solar radiation for various tilts at outside the earth's atmosphere.

| Months | 10°North latitude | | | 20°North latitude | | | 30°North latitude | | | 40°North latitude | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B=L+15 | B=L-15 | B=0.9L | B=L+15 | B=L-15 | B=0.9L | B=L+15 | B=L-15 | B=0.9L | B-L+15 | B+L-15 | B=0.9L |
| Jan. | 1.26 | 1.00 | 1.12 | 1.49 | 1.10 | 1.32 | 1.88 | 1.41 | 1.66 | 2.62 | 2.01 | 2.32 |
| Feb. | 1.14 | 1.00 | 1.07 | 1.28 | 1.06 | 1.20 | 1.51 | 1.26 | 1.41 | 1.91 | 1.61 | 1.78 |
| March | 1.01 | 1.00 | 1.02 | 1.07 | 1.03 | 1.08 | 1.18 | 1.14 | 1.19 | 1.36 | 1.31 | 1.37 |
| April | 0.87 | 1.00 | 0.97 | 0.87 | 1.00 | 0.97 | 0.89 | 1.03 | 1.01 | 0.95 | 1.09 | 1.08 |
| May | 0.77 | 1.00 | 0.93 | 0.73 | 0.98 | 0.90 | 0.72 | 0.96 | 0.89 | 0.73 | 0.97 | 0.91 |
| June | 0.72 | 1.00 | 0.91 | 0.67 | 0.97 | 0.86 | 0.64 | 0.93 | 0.84 | 0.63 | 0.91 | 0.83 |
| July | 0.73 | 1.00 | 0.92 | 0.69 | 0.97 | 0.87 | 0.67 | 0.94 | 0.85 | 0.66 | 0.93 | 0.86 |
| August | 0.81 | 1.00 | 0.95 | 0.80 | 0.99 | 0.93 | 0.80 | 0.99 | 0.94 | 0.83 | 1.02 | 0.98 |
| Sept. | 0.94 | 1.00 | 1.00 | 0.96 | 1.01 | 1.03 | 1.05 | 1.08 | 1.09 | 1.13 | 1.19 | 1.21 |
| Oct. | 1.08 | 1.00 | 1.05 | 1.18 | 1.05 | 1.14 | 1.34 | 1.20 | 1.30 | 1.60 | 1.45 | 1.56 |
| Nov. | 1.21 | 1.00 | 1.10 | 1.41 | 1.08 | 1.27 | 1.73 | 1.35 | 1.56 | 2.31 | 1.83 | 2.08 |
| Dec. | 1.29 | 1.00 | 1.13 | 1.54 | 1.11 | 1.35 | 1.98 | 1.46 | 1.74 | 2.85 | 2.15 | 2.50 |

is absorbed by carbon dioxide, ozone, water vapour, while the remainder is transmitted through the atmosphere being received at the ground as beam or direct radiation. Some of the reflected and scattered radiation also reaches the earth as diffuse or sky radiation, Id, with its intensity peak at 0.45 microns in the blue portion of the spectrum (hence the blue colour of the sky). The total radiation reaching a earth surface, $I_T$, is the sum of the direct, $I_{DN}$ and diffuse component:

$$I_T = I_{DN} \cos \theta + I_d \text{ --------------------------- } (14)$$

When the surface is horizontal, the incident angle, $\theta$, becomes the complement of the solar altitude, $\alpha$, and we have :

$$I_{Th} = I_{DN} \sin \alpha + I_{dh} \text{ ------------------------ } (15)$$

Usually total and diffuse components of solar radiation on horizontal surfaces are measured with an unshaded and shaded pyranometers, then the direct intensity can be found as :

$$I_{DN} = (I_{Th} - I_{dh})/\sin\alpha \text{ ---------------------- } (16)$$

## 2.2 Solar radiation measurement :

Sunshine is an important element of climate and has been receiving considerable attention in recent years all over the world, and specially in the arid and semi-arid regions, since this climatic parameter is responsible for the photosynthesis of plants and is also important for solar energy applications. The simplest and the most robust recorder for hours of sunshine is the campbell-stokes sunshine recorder. This consists of a glass sphere which focusses and burns the track of sun movement on a strip of paper. The strip clearly shows intervals of cloud cover where the paper remains unburnt. Sunshine data are being collected by about 100 stations in India by India Meteorological Department.

Central Arid Zone Research Institute, Jodhpur is maintaining a number of sunshine recording stations in western Rajasthan and these observations are being taken regularly at Jodhpur, Pali, Bikaner, Chandan and Jaisalmer. The Institute has also collected sunshine data for a few years at Churu, Jhunjhunu and Gadra Road. In order to compute more accurately the solar insolation, statistical relationships between the total solar radiation at horizontal surface and sunshine hours have been worked out at the Institute and these are being applied to sunshine data of the above mentioned stations in order to compute detailed radiation statistics for the arid zone of western Rajasthan.

The principal standard instruments for solar energy recording in the observational programme of most of the countries are :

The Angstrom Pyrheliometer

This instrument invented by K.J. Angstrom is the first, accurate and primary instrument used for the measurement of direct radiation at normal incidence. Angstrom pyrheliometer uses two thin blackened strips of manganin connected electrically so that either could be heated by a carefully measured electric current while the thermocouple junctions connected in opposition through a galvanometer. This instrument has been used as a standard for calibrating other instruments.

The Abbot silver Disc Pyrheliometer

This portable instrument was developed by smithsonian Institute, Washington. In this instrument the solar rays heat the blackened silver disc located at the bottom of the long tube. The silver disc, contains a sensitive thermometer. The solar intensity is obtained from the rate of rise of temperature.

The secondary pyrheliometers (used for measuring direct radiation at normal incidence) and pyranometers (used for measuring total or diffuse radiation) recommended by the world meteorological organisation are of thermopile detector type and the most commonly are Eppley, Linke-Feussner and Moll - Gorczynski pyranometer. They have flat thermopiles either made of silver-bismuth junctions or manganin-constantion junctions which are connected to recording milli-voltmeters. Generally Linke-Feussner pyrheliometers and Moll-Gorczynski pyronometers are used for measuring direct radiation at normal incidence and total radiation on horizontal surfaces respectively. The pyranometers can be used for the measurement of diffuse radiation also by using shade ring or shade disc.

India has at present a net work of 30 radiation stations of which 15 are recording total solar radiation with Moll-Gorczynski pyranometer, two with Eppley pyranometer and 7 with bimetallic pyranographs. Diffuse sky radiation is being recorded at 13 stations with Moll-Gorczynski pyranometer with the addition of a shading ring.

The Central Arid Zone Research Institute, Jodhpur is also recording continuously total solar radiation with the help of Moll-Gorczynski pyranometer alongwith the Honeywell potentiometeric recorder. Hourly as well as daily total solar radiation values available on horizontal surface for Jodhpur is available at this Institute since 1972. Direct radiation values at normal incidence without and with red, green and yellow filters are also recorded with Linke-Feussner pyrheliometer along with the millivolt meter.

## 2.3 Potential of Solar Energy Utilisation in India :

India because of its favourable geographical location, 7 to 37 degrees north latitude, has large potential for solar energy utilization. The measured total solar radiation (cal/cm$^2$ day) on horizontal surface for 20 Indian stations is shown in Table 4. It is seen from this table that for most of the stations except few hilly stations total solar radiation more than 550 cal/sq.cm. day are received in the month of May. In January typical of winter season values more than 350 cal/sq.cm. day are received for all the stations,

From this data it has been estimated that on an annual average India receives about 5.6 kw of solar energy daily on one square metre horizontal surface (Garg, 19) which is a tremendous amount of energy. Rajasthan State alone receives, on an average about 511 cal/sq.cm. day of solar energy. This, when computed for the whole area of Rajasthan state over a period of one year comes to around 31191 x $10^{12}$ Kcal and in terms of coal equivalent, approaches 91131 million tonnes which is more than the total energy consumption of the world in a year (Garg and Krishnan, 12). This is an indication of the sun's bounty received in just one of the many deserts of the world. These figures clearly indicate the possibilities of large scale use of solar energy utilization appliances in our country. In order to find out the effectiveness of various solar energy appliances, percentage number of days for each month when mean daily radiation exceeded 300 cal/sq. cm.day on horizontal surface were calculated and seasonal means were worked out for different stations. It was observed that the mean percentage of occasions exceeds 90 for all seasons except monsoon in North Indian stations and monsoon and post monsoon seasons in the peninsular stations. The later can be explained by the fact that the peninsula is affected both by the south west and north east monsoons. However, it is interesting to note that in no season the mean value goes below 80 percent. In special hill stations like shillong in Assam, the values are lower in view of frequent cloud occurrences during various seasons of the year.

Table 4 : Daily total solar radiation on a horizontal surface(Cal/cm$^2$/day)

| | Jan | Feb | March | Apr | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Mean | No.of year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Ahmedabad | 410 | 493 | 563 | 623 | 650 | 565 | 413 | 405 | 480 | 496 | 420 | 387 | 492 | 7 |
| 2. Bangalore | 472 | 493 | 596 | 587 | 556 | 443 | 354 | 366 | 405 | 412 | 388 | 417 | 466 | 3 |
| 3. Bhavnagar | 431 | 502 | 588 | 614 | 655 | 547 | 389 | 369 | 505 | 515 | 446 | 394 | 496 | 2 |
| 4. Calcutta | 357 | 417 | 480 | 528 | 542 | 413 | 394 | 392 | 367 | 381 | 386 | 350 | 417 | 12 |
| 5. Goa | 484 | 541 | 579 | 599 | 588 | 434 | 329 | 436 | 467 | 490 | 467 | 453 | 430 | 6 |
| 6. Gulmarg | 265 | 303 | 346 | 425 | 411 | 491 | 406 | 337 | 365 | 293 | 291 | 223 | 346 | 3 |
| 7. Hyderabad | 403 | 505 | 521 | 533 | 579 | 461 | 334 | 352 | 339 | 392 | 342 | 394 | 431 | 3 |
| 8. Jodhpur | 399 | 469 | 557 | 627 | 651 | 619 | 513 | 485 | 520 | 497 | 421 | 375 | 511 | 9 |
| 9. Kodaikanal | 508 | 562 | 555 | 535 | 510 | 445 | 374 | 397 | 421 | 383 | 405 | 453 | 462 | 7 |
| 10. Madras | 441 | 539 | 584 | 581 | 559 | 498 | 449 | 474 | 482 | 425 | 367 | 376 | 481 | 12 |
| 11. Mangalore | 455 | 518 | 551 | 541 | 503 | 359 | 293 | 353 | 413 | 421 | 411 | 431 | 427 | 5 |
| 12. Minkoy | 470 | 488 | 508 | 499 | 423 | 376 | 378 | 412 | 431 | 412 | 420 | 402 | 435 | 5 |
| 13. Nagpur | 420 | 500 | 543 | 583 | 598 | 505 | 379 | 367 | 433 | 488 | 442 | 390 | 471 | 9 |
| 14. New Delhi | 341 | 430 | 518 | 584 | 627 | 569 | 443 | 432 | 474 | 454 | 386 | 323 | 465 | 12 |
| 15. Poona | 445 | 524 | 578 | 611 | 620 | 517 | 388 | 392 | 448 | 487 | 435 | 403 | 437 | 12 |
| 16. Port Blair | 403 | 436 | 515 | 592 | 302 | 306 | 300 | 247 | 361 | 346 | 342 | 374 | 373 | 6 |
| 17. Shillong | 316 | 449 | 437 | 467 | 493 | 363 | 327 | 351 | 293 | 351 | 343 | 333 | 377 | 2 |
| 18. Srinagar | 175 | 247 | 386 | 493 | 593 | 628 | 583 | 506 | 427 | 322 | 278 | 172 | 401 | 3 |
| 19. Trivandrum | 503 | 538 | 563 | 530 | 470 | 449 | 416 | 458 | 499 | 448 | 425 | 442 | 478 | 10 |
| 20. Vishakhapatam | 455 | 521 | 553 | 567 | 576 | 425 | 395 | 444 | 438 | 445 | 441 | 427 | 473 | 8 |

Solar radiation is generally measured on horizontal surfaces. However, from the point of view of utilization, the knowledge of solar radiation on the inclined surface is more important since the flat-plate collectors are generally kept at optimum tilt so as to receive maximum solar radiation during the desired season of use. Hence it is necessary to convert the measured radiation values on horizontal surface on to the tilted surface so as to be used for predicting collector performance.

Based on the measured data, isopleths of total solar radiation (cal/sq.cm.day) on horizontal surface and computed total solar radiation on inclined surface (kept at optimum tilt i.e., latitude of the place plus 15 degrees) facing south for winter use was determined at C.A.Z.R.I., Jodhpur by Garg (14) for January month, typical of winter season and are drawn in Fig.1. It is seen from this figure that total solar radiation on horizontal surface in the month of January increases from 200 at Gulmarg, to 341 at New Delhi, 357 at Calcutta, 399 at Jodhpur, 420 at Nagpur, 445 at Poona, 441 at Madras and 508 at Kodaikanal. The values at optimum tilts (Garg,16) increase from 484 at Calcutta to 502 at Delhi, 580 at Nagpur and 510 at Madras. From this it can be concluded that flat-plate collectors kept at optimum tilts collect nearly ~~plate collectors kept at optimum tilts collect nearly~~ 50 percent more radiation than what a horizontal surface receives at northern stations like Jodhpur and Delhi and 35 percent more radiation in the interior peninsular stations like Nagpur and Poona, even for other stations this increase varies from 20 to 25 percent. This important finding is very much useful as shown by Garg (7) for using flat-plate plate collectors for water heating, crop drying, space heating, airconditioning etc.

Distribution of total solar radiation(cal/cm$^2$ day) on horizontal surface in the month of May, typical of summer season, in the country is shown in fig.2. It is seen here that the radiation in the month of May decreases from 655 at Bhavnagar and 651 at Jodhpur to 627 at New Delhi and 620 at Poona, 579 at Hyderabad and 559 at Madras, 542 at Calcutta and 510 at Kodaikanal to 493 at Shillong and 470 at Trivandrum.

Annual distribution of total solar radiation (cal/cm$^2$ day) on horizontal surface in the country is shown in fig.3. It is seen here that total solar radiation ranges from 377 in Srinagar area to 511 in Jodhpur. In the latitudinal belt of 18° to 28° N the daily total solar radiation ranges from 470 to 500 cal/cm$^2$ or 5.46 kw to 5.81 kw per sq. metre.

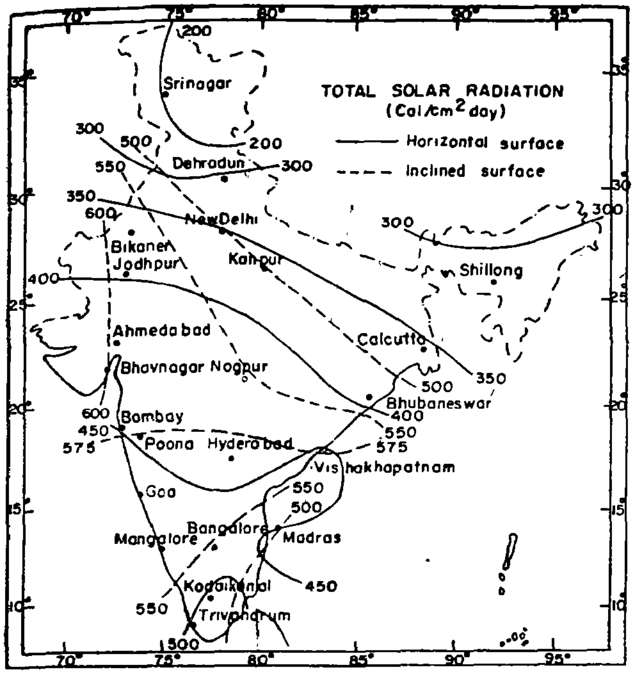

Fig. 1. Total solar radiation on horizontal surface and on optimum tilt over India during the month of January.

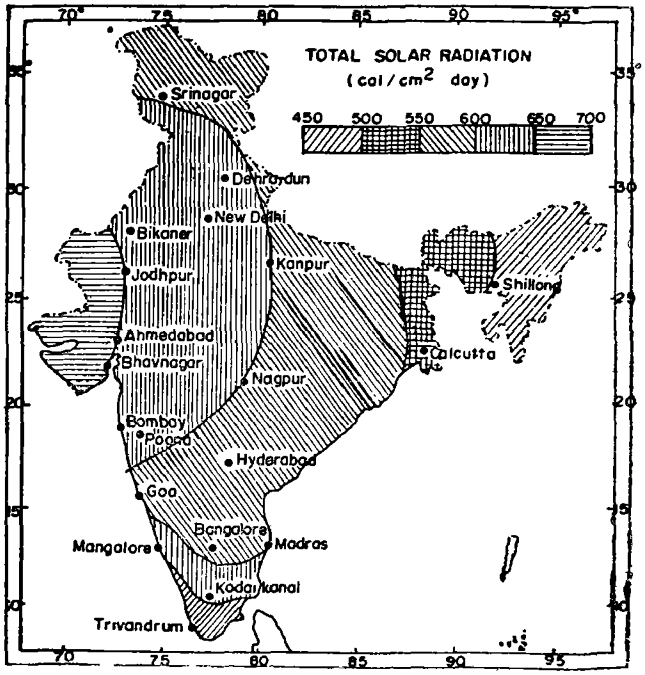

Fig. 2. Total solar radiation on horizontal surface over India during the month of May.

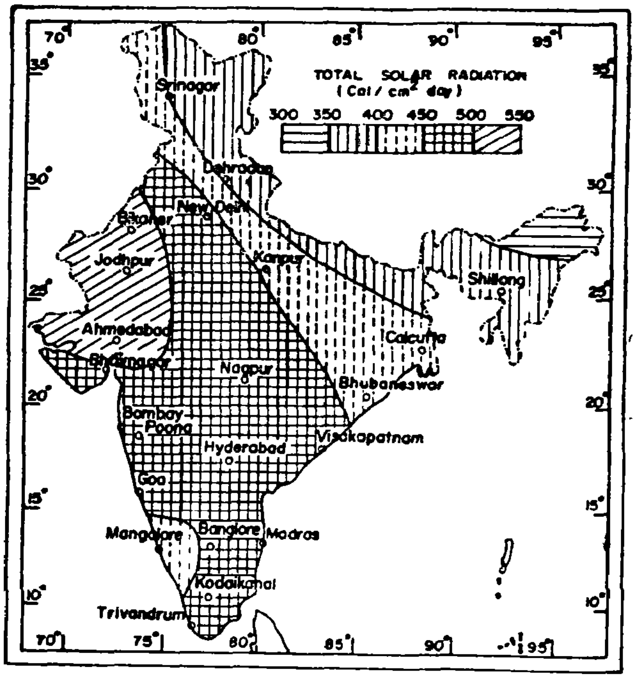

Fig 3. Annual total solar radiation on horizontal surface over India.

Because of the intermittent nature of the radiation and high day to day variation due to cloudiness the solar radiation values which are exceeded on 10 percent, 50 percent and 90 percent have been computed for Jodhpur and New Delhi, (Garg and Krishnan, 1 & 2). Table 5 below shows the average, 90 percent, 50 percent and 10 percent exceedance values of total solar radiation on horizontal surface (H) as well as on inclined at optimum tilt ($H_{*}$) (at an elevation of latitude + 15°) in respect of Jodhpur and New Delhi for the typical winter month of January.

Table 5 : Table showing the average and various exceedance values of total solar radiation (cal/sq.cm.day) on horizontal (H) and inclined surface ($H_{*}$ ) in the month of January.

| Place | Average | | 90 percent | | 50 percent | | 10 percent | |
|---|---|---|---|---|---|---|---|---|
| | H | Ht | H | Ht | H | Ht | H | Ht |
| New Delhi | 341 | 540 | 233 | 349 | 364 | 550 | 455 | 700 |
| Jodhpur | 399 | 639 | 337 | 496 | 390 | 635 | 501 | 740 |

It is interesting to note from the above table that in case of Jodhpur the 90 percent exceedance value in respect of inclined surface is almost the same as the 10 percent exceedance value for radiation over the horizontal surface. It is also seen that though the average radiation on horizontal surface over Jodhpur and New Delhi in the month of January are only 341 and 399 cal/sq.cm.day, the actual utilizable energy on inclined surface at optimum tilt are 540 and 639 cal/sq.cm. day respectively.

Detailed analysis of total solar radiation on various inclined planes (0°, 5°, 10°, 15°, 20°, 30° and 40° from horizontal) facing the equator are carried out in respect of Jodhpur and Madras a high latitude (26.3°) and low latitude (13.06°) station respectively. This data in respect of Jodhpur and Madras is shown in tables 6 and 7 respectively. From table 6 it is clear that in case of Jodhpur maximum radiation can be collected during winter season (January, February, November and December) if the surface is inclined at an angle of 40° from horizontal. For the best year round performance the surface may be inclined at an angle of 20° or 30° from the horizontal.

Table 6 : Total solar radiation(Cal/$cm^2$day) on horizontal and various inclined planes facing equator for various months at Jodhpur.

| Months/Tilt | 0° | 5° | 10° | 15° | 20° | 30° | 40° |
|---|---|---|---|---|---|---|---|
| January | 399 | 422 | 470 | 503 | 529 | 575 | 604 |
| February | 469 | 487 | 513 | 534 | 557 | 582 | 596 |
| March | 552 | 576 | 592 | 609 | 619 | 627 | 621 |
| April | 627 | 630 | 635 | 635 | 632 | 615 | 585 |
| May | 651 | 643 | 638 | 630 | 619 | 585 | 538 |
| June | 619 | 598 | 592 | 582 | 568 | 535 | 490 |
| July | 513 | 523 | 508 | 500 | 491 | 465 | 434 |
| August | 485 | 486 | 485 | 480 | 475 | 456 | 420 |
| September | 520 | 518 | 525 | 530 | 535 | 536 | 507 |
| October | 497 | 512 | 530 | 546 | 559 | 568 | 573 |
| November | 421 | 460 | 497 | 525 | 550 | 588 | 612 |
| December | 375 | 411 | 444 | 476 | 505 | 516 | 586 |
| Average | 511 | 522 | 536 | 546 | 553 | 554 | 547 |

Table 7 : Total solar radiation(Cal/$cm^2$day) on horizontal and various inclined planes facing equator for various months at Madras.

| Months/Tilt | 0° | 5° | 10° | 15° | 20° | 30° | 40° |
|---|---|---|---|---|---|---|---|
| January | 441 | 461 | 479 | 495 | 516 | 522 | 526 |
| February | 539 | 556 | 572 | 584 | 595 | 601 | 594 |
| March | 584 | 590 | 596 | 599 | 597 | 585 | 560 |
| April | 581 | 575 | 572 | 563 | 553 | 522 | 479 |
| May | 559 | 549 | 538 | 524 | 508 | 463 | 420 |
| June | 498 | 487 | 478 | 465 | 450 | 415 | 372 |
| July | 449 | 495 | 481 | 473 | 460 | 421 | 382 |
| August | 474 | 469 | 463 | 456 | 446 | 420 | 387 |
| September | 482 | 475 | 475 | 478 | 471 | 453 | 426 |
| October | 425 | 431 | 436 | 437 | 438 | 434 | 420 |
| November | 367 | 378 | 388 | 395 | 402 | 419 | 404 |
| December | 376 | 370 | 413 | 417 | 426 | 437 | 432 |
| Average | 481 | 486 | 491 | 499 | 489 | 474 | 450 |

While in case of Madras for best winter performance the angle should be 30° and for best year round performance it should be about 15° from the horizontal. This important finding is very much useful for using flat-plate collectors for water heating and airconditioning etc. and solar stills for getting distilled water.

## 3. Utilisation of Solar Energy at CAZRI, Jodhpur

When solar radiation falls on a surface, its temperature rises until an equilibrium is established when the heat loss from the body equals its heat gain. The heat loss takes place by radiation as it is a heated body, by convection which is because of air movement and by conduction if this heated body is in contact with any other material. The amount of heat gained by the body depends on the intensity of solar radiation as well as on the absorptivity of the surface. Solar energy can be collected either through flat-plate collector or by focussing collectors. Flat-plate collectors are of low cost, simple in design, absorbs direct and diffuse radiation, need not to follow the sun but can supply low grade heat i.e., below 100° c. Focussing collectors which require sun tracking arrangement can work with direct radiation only and can produce temperatures upto 4000° C.

Some of the applications of solar energy which are tried at Central Arid Zone Research Institute, Jodhpur are as follows :

1. Solar water heating,
2. Solar distillation,
3. Solar drying and
4. Solar cooking

The design details and the studies carried out on the above mentioned solar energy appliances are dicussed below :

## 4. SOLAR WATER HEATING

One of the most successful and widely used application of solar energy is solar water heating. In this application the interruptions due to bad weather may be tolerated. Solar water heaters are in use for more than a decade in countries like Japan, Israel, Australia and some parts of U.S.A. like california and Florida. In Israel almost every house has got solar water heater and in Japan more than 2.6 million solar water heaters are in use at present. Because of the energy crisis and the high cost of fuel, the Mironit firm of Israel has received an order of 100000 units of solar water heater from abroad which will be used in factories, hospitals, hotels and private homes. The increased use of solar water heating in India will help in saving fuel like cowdung, wood, kerosine oil and electric power which are generally used for water heating.

The domestic solar water heater (140 litres capacity) employing natural circulation of water and large size solar water heater (600 litres capacity) employing forced circulation of water as developed by Garg in India are comparable in efficiency with any of the solar water heaters developed abroad but these are of high cost and unsuitable in rural areas where there are no mains supply of water. Keeping this in mind a simple, efficient and of low cost solar water heater is designed, fabricated and tested at Central Arid Zone Research Institute, Jodhpur. The heater plate of built in storage type solar water heater performs the dual function of absorbing the heat and storing the heated water. The design details of this solar water heater as developed by Garg (9) is as follows :

## 4.1. Design of built-in-storage type solar water heater

The solar water heater consists of a G.I. rectangular tank of 20 gauge and of dimensions 112x80x10 cm ~~of~~ with a capacity of 90 litres in a M.S. box with 5 cm layer of fibre glass insulation below it and one glass cover (3 mm) on the top. Bulging of tank under water pressure is reduced by using angle iron flats which are bolted on the sides of the box. The front face of the tank is blackened by lamp black paint. The hot water is taken out from the heater's outlet pipe at the top by opening the gate valve from the inlet pipe side of the heater fixed at the bottom. The heater is inclined at 43 degrees from horizontal and is oriented due south to collect maximum solar radiation during winter season at Jodhpur. A photograph of two solar water heaters installed side by side in the solar energy yard of the Institute for studying the effectiveness of night insulation cover and of insulated drum is shown in fig. 4. For rural use, where there is no mains water supply, a big funnel of the size of the bucket can be fixed at the top of the heater and then connected to the inlet tube as shown in fig. 5 (Garg and Krishnan, 3). Hot water can be taken out immediately by putting the same amount of cold water in the funnel. A number of such solar water heaters are installed in and around Jodhpur and all are rendering good service.

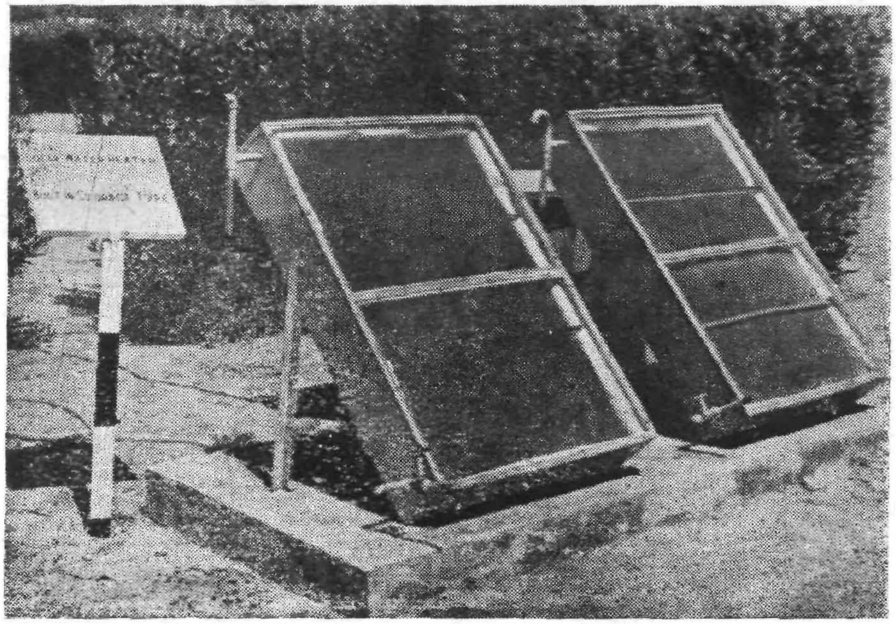

Fig. 4. Two built in storage type solar water heaters suitable for urban use developed at C. A. Z. R. I., Jodhpur

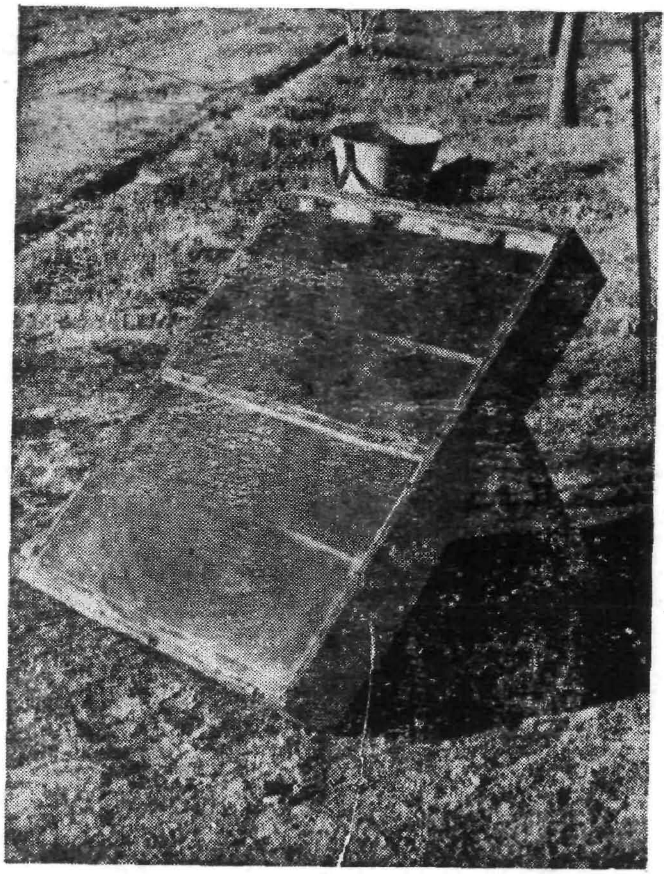

Fig. 5. Rural model of built in storage type solar water heater developed at C. A. Z. R. I., Jodhpur

## 4.2 Performance of the heater :

This solar water heater is tested extensively for complete two years (1973-74) at Jodhpur by Garg (10, 13, 20). The data of fortnighty means of maximum water temperatures (i.e. recorded at 4.p.m.) along with the total solar radiation on horizontal surface is shown in table 8. It shows that in winter months (i.e. December, January and February) hot water at 50°C to 60°C and in other summer and monsoon months at 60°C to 75°C can be obtained.

Table 8 : Fortnightly means of maximum water temperature reached in the built in storage type solar water heater and total solar radiation on horizontal surface at Jodhpur.

(A) Performance during the year 1973.

| Month | Ist Fortnight | | IInd Fortnight | |
|---|---|---|---|---|
| | Temperature ($0_c$) | Total solar radiation (cal/cm$^2$ day) | Temperature ($0_c$) | Total solar radiation (cal/cm$^2$ day) |
| January | 51.9 | 356 | 55.6 | 383 |
| February | 59.7 | 422 | 60.5 | 436 |
| March | 62.2 | 465 | 65.7 | 501 |
| April | 65.9 | 506 | 66.7 | 594 |
| May | 67.5 | 490 | 65.3 | 551 |
| June | 56.1 | 467 | 56.3 | 327 |
| July | 61.6 | 437 | 48.0 | 413 |
| August | 55.7 | 299 | 52.4 | 351 |
| September | 57.5 | 379 | 68.6 | 440 |
| October | 69.7 | 459 | 72.0 | 459 |
| November | 68.4 | 375 | 68.4 | 358 |
| December | 58.4 | 321 | 60.2 | 365 |

## (B) Performance during the year 1974.

| Month | Ist fortnight | | IInd fortnight | |
|---|---|---|---|---|
| | Temperature (°C) | Total solar radiation (cal/cm² day) | Temperature (°C) | Total so radiati (cal/c |
| January | 61.6 | 394 | 56.3 | 396 * |
| February | 60.3 | 439 | 62.7 | 478 |
| March | 64.5 | 486 | 64.6 | 513 |
| April | 64.4 | 523 | 62.1 | 512 |
| May | 65.0 | 644 | 64.2 | 622 |
| June | 61.9 | 567 | 57.0 | 550 |
| July | 62.3 | 510 | 55.6 | 310 |
| August | 60.3 | 463 | 68.1 | 474 |
| September | 72.8 | 512 | 77.2 | 441 |
| October | 75.3 | 466 | 73.1 | 438 |
| November | 76.4 | 427 | 68.7 | 380 |
| December | 62.2 | 312 | 60.9 | 371 |

For getting the hot water for morning use, this heater is either to be covered with 5.0 cm thick insulation layer for overnight period or the hot water should be stored in a seperate double walled storage tank. These two possibilities were studied in detail on two identical solar water heaters for the four winter months of 1974 at Jodhpur. The fortnightly and monthly means of average water temperature obtained for 90 litres of water at 8.0 A.M. are given in table 9. It is seen from this table that by using the insulation cover or double walled storage drum, hot water at about 46°C and 40°C respectively can be obtained in early morning. For comparison purposes the tap water temperature has also been shown in the same table.

Table 9 : Effect of night insulation and storage tank on the mean water temperature (°C) at 8.0 AM in built in storage type solar water heater during the year 1974.

| Month | Ist fortnight | | IInd fortnight | | Monthly Mean | | Monthly mean tap water temp. |
|---|---|---|---|---|---|---|---|
| | Storage tank | Insulation cover. | Storage tank | Insulation cover | Storage tank | Insulation cover | |
| January | 41.1 | 36.5 | 36.8 | 31.3 | 39.0 | 33.9 | 17.0 |
| February | 38.4 | 32.4 | 37.8 | 32.2 | 38.1 | 32.3 | 17.5 |
| November | * | * | 43.2 | 41.8 | 43.2 | 41.8 | 24.2 |
| December | 40.1 | 36.1 | 39.3 | 34.9 | 39.7 | 35.5 | 16.8 |
| Average | 39.9 | 35.0 | 39.3 | 35.1 | 40.0 | 35.9 | 18.9 |

* Data could not be taken.

## 4.3 Development of performance prediction equation for solar water heater.

The mathematical model for predicting the performance of built in storage type solar water heater under various climatic and operating conditions was developed (Garg 13) and is discussed here in short.

The instantaneous heat balance equation for built in storage type solar water heater may be written as :

(Insolation absorbed by the absorber) = (Heat absorbed by water) +
(Heat absorbed by container) +
(Heat loss from the absorber)

This can be written as :

$$I_{Tt}(\tau\alpha)_e A_e = W_w \left(\frac{dt_w}{d\theta}\right) + W_c\left(\frac{dt_c}{d\theta}\right) + (U_L+U_B)A_c\left[(t_c-t_a)+\frac{\frac{dt_c}{d\theta}-\frac{dt_a}{d\theta}}{2}\right] \quad \text{------ (1)}$$

where

$L_{Tt}$ = total radiation on the glass (Kcal/m$^2$ hr),

$(\tau\alpha)_e$ = effective transmittance absorptance product,

$A_c$ = exposed area of storage tank (m$^2$) = 0.9 m$^2$,

$W_w$ = Weight of water in storage tank (kgm) = 90 Kgms.

$W_c$ = Water equivalent of tank (kgms) 2.28 Kgms.

$U_L$ = overall heat loss coefficient from the absorber to outside air,

= 6.0 Kcal/m$^2$ hr $^\circ$c

$\frac{dt_w}{d\theta}$ = rate of rise of average water temperature($^\circ$c/hr.)

$\frac{dt_c}{d\theta}$ = rate of rise of average absorber temperature($^\circ$c/hr)

and $\frac{dt_a}{d\theta}$ = rate of rise of ambient temperature ($^\circ$c/hr)

For practical purposes it can be assumed (under steady state conditions) that the water temperature is equal to absorber temperature i.e. $t_w = t_c$ and $\frac{dtw}{d\theta} = \frac{dtc}{d\theta}$

Thus equation (1) becomes :

$$I_{Tt}(\tau\alpha)_e\ A_c = \left[W_w + W_c (U_L+U_B)\frac{A_c}{2}\right]\frac{dt_w}{d\theta} + (U_L+U_B)A_c\ t_w$$

$$- \ (U_L+U_B)\ \frac{A_c}{2}\left[\frac{dt_a}{d\theta} + 2t_a\right] \quad \text{-----------(2)}$$

This may be rewritten as

$$X\ \frac{dt_w}{d\theta} + Y\ tw = Z \quad \text{----------------------------------- (3)}$$

$$\text{where } x = W_w + W_c + (U_L+U_B)\ \frac{A_c}{2} \quad \text{------------------ (4)}$$

$$Y = (U_L + U_B)\,A_c \quad \text{------------------------------------}(5)$$

$$Z = I_{Tt}(\tau\alpha)_e\,A_c + (U_L + U_B)\frac{A_c}{2}\left[\left(\frac{dt_a}{d\theta}+2t_a\right)\right] \quad \text{---}(6)$$

The solution of equation (3) can be written as

$$t_w = \frac{Z}{Y} + \left(t_{w1} - \frac{Z}{Y}\right)e^{-\frac{Y}{Z}(\theta-\theta_1)} \quad \text{-----------------------------}\ (7)$$

where the boundary condition is that at time $\theta_1$, the water temperature is $t_{w1}$.

The total solar radiation ($I_{Tt}$) in the plane of heater and the ambient temperature ($t_a$) are hourly recorded and used in the above model.

The equation (7) now can be used for predicting the average storage temperature at any time of the day under given climatic conditions.

Efficiency of collector :

The collection efficiency of the heater is defined as :

Daily collection efficiency = $\dfrac{\text{Daily total heat collected}}{\text{Daily total radiation incident}}$

$$\eta = \frac{\sum_0^{\theta} q_u\,d\theta}{A_c \sum_0^{\theta} I_{Tt}\,d\theta}$$

where $q_u$ = rate of heat collection (Kcal/hr),

and $\theta$ = Period of test.

The above equations are used for predicting the hourly storage water temperatures. A close agreement between the measured and predicted temperatures are observed.

Design optimization :

The mathematical model developed above can be now used for design optimization of this type of solar water heater.

For the same absorbing area (0.9 $m^2$), if the depth (i.e. distance between upper and lower plate of storage tank) increases the water capacity also increases and hence the maximum storage water temperature reached decreases and vice versa. It was observed that as the depth of storage tank increases from 2.5 cms to 20 cms the maximum storage water temperature decreases first at a faster rate say up to a depth of 10.0 cm and then at a slower rate.

From the above temperature curve, the collection efficiency as defined in equation (8) is also calculated for all depths. It is interesting to see that as the depth increases, the collection efficiency increases since the thermal losses to the outside air decreases.

From the efficiency figures it can be said that upto a depth of 10.0 cms, the rise in efficiency is very fast but after 10.0 cms depth, the rise in efficiency is very small. Thus it can be concluded that 10 cms depth gives the optimum performance.

## 5. SOLAR DISTILLATION

In the arid zone of India there are many villages in which underground water from wells is highly saline with the result the villagers are experiencing considerable hardships for getting pottable water for drinking. They have to go to miles together for obtaining sweet water. In many families at least one or two members are kept entirely busy in bringing water in this manner. Moreover, distilled water is required in health centres, laboratories and automobile workshops. Although, considerable amount of work has been done in India and in other countries like Australia, U.S.A., Chile etc. on large solar stills for community use, no sincere efforts are made to optimize the size of solar still in order to get maximum distilled water output for individual families in isolated villages. Keeping all these in mind and the high intensity and suitability of solar radiation for water distillation, studies on small family size solar stills, single sloped and double sloped, have been undertaken at C.A.Z.R.I., Jodhpur. The performance of the solar still depends on a number of design parameters such as material of construction and their thermophysical properties, base insulation, water depth, absorptance-transmittance properties of the glass and basin, glass angle, orientation etc., climatic parameters such as solar insolation, ambient air temperature, wind speed atmospheric humidity, sky conditions etc., and on the operational parameters. The effect of some of the parameters and the design details of the solar stills developed at CAZRI, Jodhpur are discussed below :

## 5.1 Optimum Orientation for conventional solar stills

In solar stills, saline water is heated in a blackened flat basin covered with a sealed glass canopy. The glass surface can be in a single slope, a tent like structure as in conventional stills or in V-form. The temperature difference between the water and the glass surface, because of the absorption of solar energy, results in evaporated vapour condensing on the underside of the glass. This vapour is collected as the distillate.

After surverying the literature it is found that no theoretical or experimental study has been made for orienting the solar stills to get maximum solar radiation. Some experimental studies were carried out at NPL, New Delhi for optimizing the orientation but no definite conclusion could be drawn. The orientation is usually with the long side along the north-south axis. It is therefore, necessary to compute total solar radiation on a surface oriented differently and inclined by 20 degrees from horizontal. The measured total and diffuse radiation on horizontal surface for Jodhpur and Madras, a high latitude and low latitude station, has been used for the above computation. This computation was made by Garg and Krishnan (6).

Seasonal means of total solar radiation (cal/cm$^2$ day) incident on the glass of conventional double sloped solar stills placed with long axis in East-West and South-North direction for Jodhpur and Madras are given in Table 10. It is seen from this table that taking year as a whole, the East-West orientation receives more radiation than the south-north orientation in case of Jodhpur and almost equal radiation for both the orientation in case of Madras. It may therefore be concluded that for the conventional double sloped solar stills, the East-West orientation receives more radiation than the South-North oriented still in case of higher latitude stations like Jodhpur.

## 5.2 Design of experimental solar stills

Four experimental solar stills each having basin dimensions 245 x 125 x 15 cm i.e. with a basin area of 3.0 sq.m. were developed and the same are shown in fig.6. The floor of the solar still No.1 i.e., in the extreme right in fig.6 does not contain any insulation while the floor of still Nos. 2,3 and 4 contains 2.5 cm layer of saw dust insulation. This layer of insulation is obtained by mixing 4 parts by volume of saw dust and 1 part of cement and than mixed with water. A concrete layer of about 2.5 cm thick is made over the insulation layer by mixing 3 parts of sand by volume to 1 part of cement. After making a well levelled floor with the help of rectangular wooden frame, the walls of the basin, 5,0 cm thick and 15 cm height are poured using retaining frames of wood. The top of each long walls are V-grooved and sloped for collecting the fresh water. Two alluminium tube, 9 mm diameter, one on either side of the collecting channels are fixed. These stills are made on a raised platform made of stones and cement.

Two G.I. pipes, 19 mm diameter one at a height of 12.5 cm in the basin for inlet of saline water and another near the bottom in the basin for outlet of the saline water are fitted. All the four basins were painted black with black board paint.

The glass angles for still No. 1, 2, 3 and 4 starting from extreme right (fig.6) from horizontal are 20°, 20°, 30° and 10° respectively. Thus the difference in outputs of distilled water between still nos. 1 and 2 will show the effect of base insulation, while the differences in outputs of distilled water between still Nos. 2, 3 and 4 will show the effect of glass inclination from horizontal. The glasses of the still were sealed with tar plastic.

### 5.3 Design studies on solar stills :

Each of the four stills was filled with about 5 cm layer of water daily in the morning and hourly values of distillate was collected in bottles and then measured from each channels of the four stills with the help of measuring flask. From the hourly means of distillate the daily distillate and then the mean monthly distillate (ml/sq.m.day) was determined for all the twelve months for the year 1974 (1st January to 31st December, 1974) for both the channels i.e. glass facing south as well as of facing north for all the above mentioned four solar stills and the results are shown in table 11.

Table 10 : Seasonal means of total solar radiation($cal/cm^2 day$) incident on the glass of conventional double sloped solar stills placed with long axis in East-West and South-North directions.

| Place | Direction of long axis | Winter Dec.-Feb. | Hot weather March-May. | Monsoon June-Sept. | Post Monsoon Oct.-Nov | Annual Jan.-Dec. |
|---|---|---|---|---|---|---|
| Jodhpur | East-West | 334 | 514 | 448 | 376 | 418 |
| | South-North | 340 | 489 | 414 | 377 | 405 |
| Madras | East-West | 357 | 458 | 397 | 318 | 382 |
| | South-North | 354 | 460 | 399 | 320 | 382 |

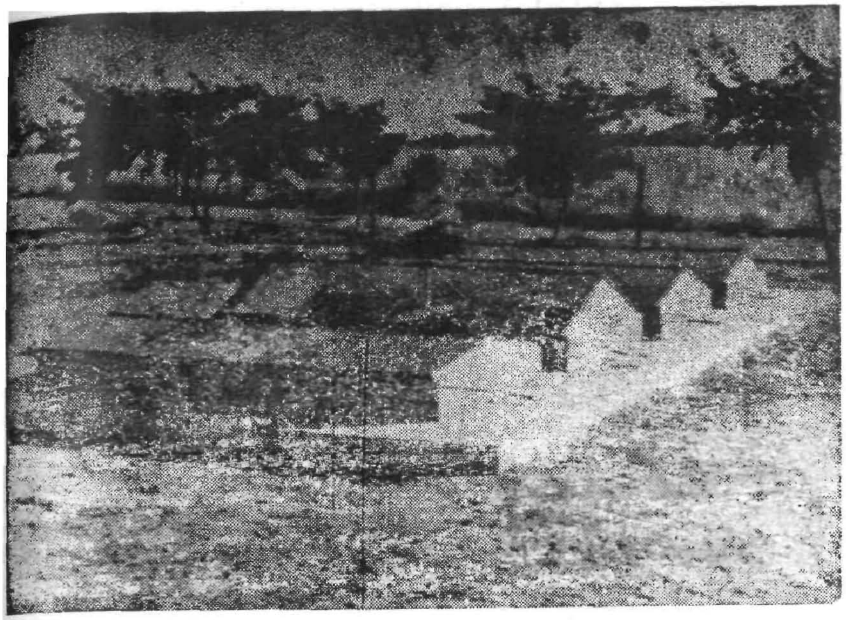

Fig. 6. Experimental solar stills at C. A Z. R. I., Jodhpur

Fig. 8. Simple solar hot box type cooker developed at C. A. Z. R. I., Jodhpur

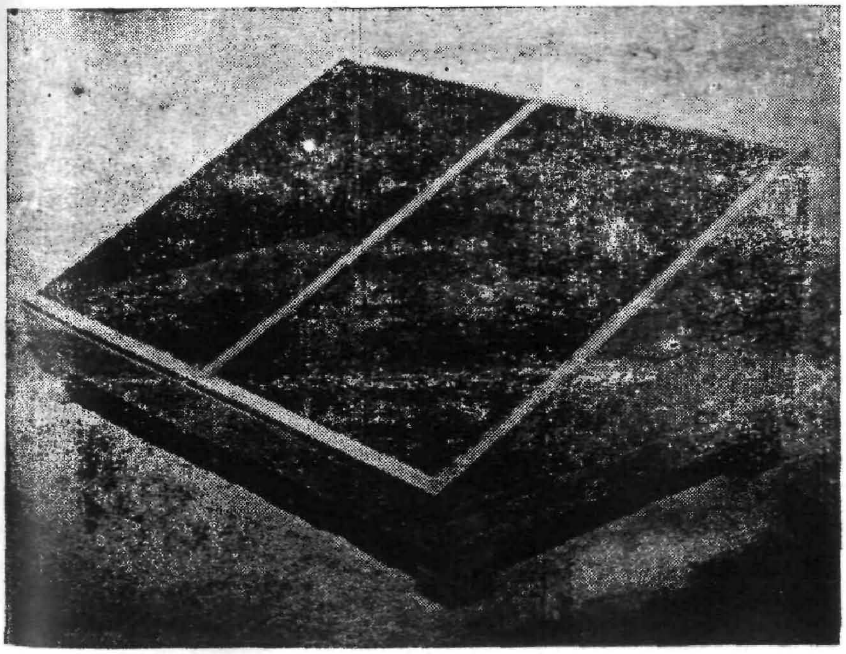

Fig. 7. Solar cabniet dryer developed at C. A. Z. R. I., Jodhpur

After comparing the distillate output of still No.1 and 2 in table 11, it is seen that the still having base insulation i.e. still No.2 gives higher output. The average increase in distillate output in case of insulated still is seven percent over the uninsulated solar still. By comparing the distillate output of still Nos.2, 3 and 4, it is clearly seen that still having lower glass angle gives higher output. This may be because of low air capacity and lower diffusion space. The still having 10 degrees glass angle and with base insulation i.e. still No.4 gives highest output i.e. 2447 ml/sq.m.day. By comparing the distillate output of still No.1 and 3, it is observed that still No.1 with 20 degrees glass inclination and without base insulation performs better than still No.3 with 30 degrees glass inclination and with base insulation. By comparing the distillate output of each of the two channels i.e. glass facing south and north for each of the solar stills, it is observed that each channels collect almost equal amounts (Garg, 18). This is true for all the four solar stills. It means that the usual assumption made that in case of double sloped solar still, one of the glass side remains at lower temperature and thus collects more distillate may not be correct.

### 5.4 Effect of climatic parameters

The object of this study is to study the behaviour of the single sloped solar still in various seasons in the arid zone of India and to find out the contribution made by the various climatic parameters on the distillation output.

For this purpose two small single sloped solar stills each having basin area equal to 0.58 sq.m. were built and their performances studied (Garg, 15) for one complete year in the solar energy yard of Central Arid Zone Research Institute, Jodhpur. Each of the still consists of a blackened galvanized iron tray of dimension 92 x 63 x 7 cms placed inside a wooden box of 25 mm thick having a glass cover (3 mm) at the top with an inclination of 20 degree from the horizontal. For collecting the distillate, an aluminium channel of 12 x 12 mm is fitted. A known amount of saline water can be filled inside the tray with the help of small aluminium pipe fitted at the top of the tray. The solar still has been made vapour proof by means of tar plastic. One still was with base insulation(2.5 cm saw dust) and the another was without base insulation.

The two stills were installed side by side at a site with good exposure and were facing south. Hourly distillate of each still was collected in bottles and measured by means of measuring glass. Thus daily values of distillate was determined from the hourly values and analysed for one complete year. Total solar radiation on horizontal surface for the above period was recorded by means of Kipp pyranometer alongwith a Honey-well potentiometric recorder. Daily mean ambient temperatures for the above period were obtained by averaging the daily maximum and minimum temperatures measured inside the Stevenson screen. The daily daytime wind speeds were recorded at 7.30 A.M. and 2.30 P.M. by a cup counter anemometer and were averaged for seven hours. The vapour pressure values were computed by the values of wet and dry bulb thermometers. Daily means of the same were obtained by averaging the values corresponding to the apochs of maximum and minimum temperatures.

The daily distilled water output (litres/m$^2$ day) total solar insolation (Cal/cm$^2$day), daytime ambient temperature ( °C), day time wind speed (km/hr) and daytime vapour pressure of air (mm of Hg) were determined and means of 52 standard weeks were found out. It is seen that in case of uninsulated still the maximum (5.27 litres/m$^2$ day) and minimum (0.89 litres/m$^2$ day) distilled water is obtained in the 19th and 49th week falling in the month of May and December having solar insolation of 658 and 337 cal/cm$^2$ day in these weeks respectively. Table 12 shows the month wise variation of distilled water output in case of insulated and uninsulated solar still alongwith the total solar insolation. It is seen from this table that on an average by providing cheap saw dust insulation (2.5 cm thick layer) at negligible cost in the base, an improvement of about 8 percent in the yield over the uninsulated still can be obtained. Here also the maximum and minimum distilled water output is obtained in the month of May and December respectively.

The efficiency of the solar still which is defined as the ratio of the heat utilized in evaporation to solar insolation was also worked out for all the twelve months for both the stills. It is found that the efficiency varies from 15.6 percent in December to 51.2 percent in the month of July. By providing saw dust insulation an increase of about two to five percent efficiency has been observed.

A scatter diagram of the distillate collected (in litres/day sq.m.) for 52 standard weeks for various solar insolation values for uninsulated solar still was drawn. A regression line was fitted to these scatter points by means of the least square method (Garg & Mann, 17) The linear regression equation between still output, Y, in litres/day sq.m. and the total solar radiation, $X_I$, in Cal/day sq.cm. is

$$Y = 0.0134 \quad X_I - 3.5969 \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

The correlation coefficient worked out to be 0.84 indicating that the bulk of the differences in the distillate values viz. 70 percent of the same can be explained by means of differences in total radiation received at horizontal surface on individual days. The value of the distillate increased from 1.76 litres/day sq.m. at the radiation intensity of 400 cal/day sq.cm. to 5.11 litres/day sq.m. at the radiation intensity of 650 Cal/day sq.cm.

A scatter diagram of the distillate collected (in litres/day sq.m.) for 52 standard weeks for various values of air temperatures for uninsulated solar still was also drawn. A regression line was fitted by least square method. It is seen here that the productivity of the solar still increases as the ambient air temperature increases. The increase in productivity is about 0.87 litres/day sq.m. for each 5°C rise in ambient temperature. The linear multiple regression equation between still output, Y, total solar radiation, $X_1$ and mean ambient temperature, $X_2$, in °C is

$$Y = 0.0103 \quad X_I + 0.0852\ X_2 - 4.3882 \quad \ldots\ldots\ldots \quad (2)$$

The multiple correlation coefficient works out to be 0.89 thereby indicating that 79 percent of the variance of the dependent variable has been explained by these two variables.

Table 12 : Mean monthly daily water distillate obtained with an insulated and uninsulated solar still.

| Months | Distillate ($ml/m^2$ day) | | Total solar insolation $Kcal/m^2$ day |
|---|---|---|---|
| | Insulated | Uninsulated | |
| January | 1578 | 1392 | 3967 |
| February | 2020 | 1758 | 4604 |
| March | 3488 | 3163 | 5095 |
| April | 4369 | 4124 | 5067 |
| May | 5217 | 4981 | 6468 |
| June | 4838 | 4645 | 5630 |
| July | 4184 | 4059 | 4466 |
| August | 1956 | 1871 | 3643 |
| September | 2005 | 1655 | 4207 |
| October | 1777 | 1323 | 4432 |
| November | 1125 | 1109 | 3600 |
| December | 1049 | 986 | 3545 |
| Average | 2800 | 2588 | 4560 |

A scatter diagram of still output values for 52 standard weeks for various values of average day time wind speeds for uninsulated solar still was also drawn. Here also it is seen that as the wind speed increases, the productivity of the still increases particularly in the summer months. This may be because of the fact that increase in wind speed over glass cover increases the rate of condensation inside the still. But if there is a small hole or crack in the still then the increased wind speed will decrease the productivity. For uninsulated solar still the linear multiple regression equation between still output, Y, total solar radiation, $X_1$, mean ambient temperature, $X_2$, and the mean day time wind speed, $X_3$, in KMPH is given as

$$Y = 0.009\,X_1 + 0.0636\,X_2 + 0.0633\,X_3 - 3.9246 \ldots (3)$$

The multiple correlation coefficient works out to be 0.90, thereby indicating that 81 per cent of the variance of the dependent variable has been explained by these three variables.

It was also found out that vapour pressure of air has got no relation with the productivity of the solar still.

After comparing the computed and observed values. It is seen that the values computed by the above prediction equation agree closely with the observed still output values.

### 5.5. Determination of various heat fluxes in the solar still by energy balance technique.

Heat transfer analysis of single sloped still was carried out at CAZRI, Jodhpur by Garg (21). The heat and mass transfer relationships used in our method are similar to those given by Dunkle and Morse and Read. The heat balance equation on water in the solar still can be written as :

$$q_a = q_w + q_t + q_b + q_c + q_r + q_e \ldots (1)$$

where $q_a$ is the radiation absorbed by the water in the tray, $q_w$ and $q_t$ are the hourly enthalpy rise of water and tray respectively, $q_b$ is the heat less from the base of the still to the xxx outside air $q_c$, $q_r$ and $q_e$ are the convection, radiation and evaporation losses within the still respectively.

The heat balance equation on the glass cover of the still can be written as

$$q_g = q_{ro} + Q_{co} \dots\dots (2)$$

where $Q_g$ is the total heat loss from the glass cover to the outside, $Q_{co}$ and $q_{r0}$ are the convection and ratiation components of this heat loss to the outside.

The mathematical expressions by which various heat flow components were computed are given below :

$$q_a = H \tau_w A_w \dots\dots (3)$$

$$q_w = (M-m)\, C_p \frac{d\,tw}{dQ} \dots\dots (4)$$

$$q_t = m_T A_w \frac{d\,tw}{DQ} \dots\dots (5)$$

$$q_b = \frac{K_o Aw}{d} (tw - ta) \dots\dots (6)$$

$$q_c = 0.7684\ Aw \left[ tw-tg + \frac{(p_w-p_{wg})}{(2690-P_w)} (tw+273) \right]^{\frac{1}{3}} (tw-tg) \dots (7)$$

$$q_e = 2.216 \times 10^{-3}\ Aw \left[ tw-tg+ \frac{(P_w - P_{wg})}{(2690-P_w)} (tw-273) \right]^{\frac{1}{3}} (p_w-p_g) \dots (8)$$

$$q_r = 0.9 \sigma A_w \left[ (tw + 273)^4-(t_g+273)^4 \right] \dots\dots (9)$$

$$q_{co} = h_c A_g (t_g-t_a) \dots\dots (10)$$

$$q_{r0} = t_g \sigma A_g \left(0.10+0.90 \frac{n}{N}\right) \left[ (t_g+273)^4-(t_a+273)^4 (0.534+0.063\sqrt{e}) \right] \dots (11)$$

Where

H = total solar radiation on the glass, Kcal/m$^2$ hr.

$\tau \alpha w$ = Product of transmissivity of glass and absorptivity of water (0.80).

$A_w$ = evaporation area (0.58m$^2$)

$A_g$ = glass condensing area (0.62m$^2$)

M = mass of water in the tray (6.0 Kgm)

m = cumulative mass of distillate (Kgm)

Cp = specific heat water (Kcal/Kgm °C)

K = Coefficient of thermal conductivity of wood (0.12 Kcal/Mhr °C)

d = thickness of base (0.025 m)

$t_w, t_g, t_a$ = water, glass and ambient temperatures respective (°C)

$p_w, p_g$ = partial pressure of water vapour at $t_w$ and $t_g$ respectively (mb)

$\sigma$ = Stefan - Boltzman constant ($4.9 \times 10^{-8}$ Kcal/$m^2$hr $K^4$)

$\epsilon_g$ = emissivity of glass (0.95),

n = actual sunshine hours,

N = Possible sunshine hours,

e = water vapour pressure of the ambient air at the level of still (mm of Hg)

$h_c$ = Convective heat transfer coefficient in Kcal/$M^2$ hr °C computed by the following expression as suggested by McAdams

$$h_c = 5.370 + 0.908\, V \qquad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where V is the wind velocity in Km/hr.

The expression for $q_{rO}$, the net energy lost by radiation from the glass surface to the actual sky taking into account the long wave radiation exchange between the two was computed by equation 11. Though this equation is similar to the form suggested by Brunt which was modified by Holden on inclined surfaces, our equation takes into account the cloudiness in the sky also as suggested by Penman.

With the help of the above equations, various absorption and loss coefficients were computed for 3rd September and from them the hourly distillate values that can be obtained were worked out from theoretical consideration (Garg and Krishnan).

The hourly values of distillation rate actually measured as well as those predicted from the above equations are compared. The day selected for this study was an intermittently cloudy day with a maximum intensity of 840 K cal/m2 hr at 1300 hrs IST. The distillation in solar still commences from 9 a.m. when the temperature differences between water and glass cover is about 5°C and is maximum at 2 p.m. when the temperature difference is 10°C. At 2 p.m. the water temperature is also the highest. The total measured distillate for the day was 2.90 litres/day while the predicted amount of stillate was 2.92 litres/day showing very good agreement. However, the comparison of measured and predicted hourly distillation values indicates a lot of flucations.

Table 13 shows hourly values of various heat transfer coefficients pertaining to the solar still. The percentage losses of the total radiation received on the inclined glass surface of the still are as follows :

The loss due to reflection from glass surface and absorption within the glass and the loss due to imperfect absorption of raidation by the water and tray is about 20 per cent. The convection loss with the still accounts for 3.5 per cent while the radiation loss from water to glass amounts to 11 per cent. The heat loss through the base of the solar still is about 26 per cent of the total incident radiation. As seen from the table, the heat absorbed by the water and tray is 9.5 per cent, while the heat used in actual evaporation of saline water in the still works out to be 33 per cent. However, the sum of these two components by substraction of other losses should have been 29.5 per cent. The difference may be due to some overlapping between these 2 components.

As regards the heat losses occurring from glass surface of the solar still to the ambient air, the convection accounts for 63 per cent while the radiation accounts for 37 per cent ~~while the radiation accounts~~ illustrating importance of aerodynamical factors in heat dissipation under arid zone conditions.

It would be seen from the above mentioned energy balance considerations that the efficiency of solar still which is defined as the ratio of the heat utilised in evaporation to solar radiation works out as follows :

$$= \frac{\text{Heat lost in evaporation}}{\text{total incident energy}} = \frac{1642}{5006}$$

$$= 33 \text{ per cent}$$

Table 13 : Various heat transfer coefficients (Kcal/m$^2$ hr) for the day of test.

| Time (hours) | H | $q_a$ | $q_w$ | $q_t$ | $q_r$ | $q_c$ | $q_e$ | $q_b$ | $q_{co}$ | $q_{ro}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0700 | 126 | 101 | 0 | 0 | 10 | 2 | 5 | 20 | 30 | 51 |
| 0800 | 321 | 257 | 22 | 2 | 15 | 3 | 9 | 20 | 19 | 45 |
| 0900 | 447 | 357 | 112 | 5 | 27 | 8 | 37 | 67 | 116 | 75 |
| 1000 | 630 | 504 | 84 | 5 | 34 | 10 | 63 | 98 | 193 | 93 |
| 1100 | 546 | 437 | 74 | 3 | 38 | 12 | 10 | 125 | 264 | 125 |
| 1200 | 675 | 540 | 21 | 2 | 38 | 12 | 157 | 131 | 280 | 133 |
| 1300 | 239 | 671 | 34 | 2 | 45 | 14 | 182 | 143 | 298 | 143 |
| 1400 | 767 | 614 | 105 | 5 | 70 | 22 | 300 | 186 | 387 | 177 |
| 1500 | 505 | 404 | - | - | 76 | 26 | 280 | 169 | 325 | 158 |
| 1600 | 140 | 112 | - | - | 39 | 12 | 170 | 133 | 280 | 148 |
| 1700 | 10 | 8 | - | - | 62 | 19 | 160 | 112 | 182 | 114 |
| 1800 | 0 | 0 | - | - | 67 | 24 | 138 | 70 | 38 | 71 |
| 1900 | 0 | 0 | - | - | 31 | 10 | 40 | 34 | 13 | 67 |
| 2000 | 0 | 0 | - | - | - | - | - | - | - | - |
| Total: | 5006 | 4005 | 452 | 24 | 552 | 174 | 1642 | 1308 | 2425 | 1400 |

Hence in order to improve upon the thermal efficiency of the still, efforts should be made to reduce the losses as much as possible. In this connection, the following remarks are relevant :

(1) The maximum heat loss of 26 per cent occurs through the base of the solar still. This is a very serious heat loss serving no useful purpose. This heat loss can be reduced by using suitable insulating materials such as fibre glass, vermiculite, thermocole, saw dust etc. By providing some insulating material this heat loss can probably be reduced to 5 to 10 per cent. Loss of 20 per cent of incident radiation occurs due to reflection from the glass surface and absorption within the glass and due to imperfect blackening of the evaporator. This heat loss can be reduced by using either thin glass (of low iron content) coated with low reflective coating or by using wettable and durable plastic film. The absorption of heat by black evaporator pan can be increased by using various dyes mixed in water.

(2) The convection and radiation losses occurring within the solar still amount to 14.5 per cent. These are unavoidable heat losses which are inherent in the operation of the solar still.

In the actual experiment, the thermal efficiency of the still can also be defined as the ratio of actual water produced to the theoretically possible water yield. This ratio in our experiment works out to be 32 per cent indicating good agreement with the theoretically computed efficiency.

## 6. SOLAR DRYING

The traditional and widespread techniques for drying agricultural products like paddy, corn, copra, groundnuts, chillies, fruits and vegetables, timber, tea leaves, hay, fish etc. for preservation and dehyration in India and in other developing countries are by spreading the produce in thin layers on the ground ~~water~~ under direct sunshine. This method of drying farm produce and vegetables etc. is unhyganic, time consuming and is generally of poor quality. In west Bengal and Tamil Nadu in India, considerable amount of paddy is grown and is just thrown on the platforms for drying, with the result more than 25 percent of the paddy is spoiled because of excessive humidity. Thus there appears to be much loss and spoilage of agricultural crops which might be saved by the use of effective and economical solar drying fascilities. Estimates of these losses would be of interest and value in an appraisal of the magnitude of the problem. There is no doubt, however, that the cycles of abundance and starvation could be ameliorated by application of adequate solar drying methods in the under-developed countries. In fact, an improved, dependable and cheap solar drying methods is long overdue. Solar drying systems ranging from cottage produced small capacity cabinet defices to very large capacity, drying plants can be developed. Solar dryers can be broadly classified into two groups (1) radiation type dryers, and (2) convective type of dryers.

### 6.1. Radiation type Cabinet dryer :

Radiation type of cabinet dryers having common space for storage and collecting solar energy can be manufactured on a cottage scale and have been used for drying copra in Fugi, grapes in USSR and France, corn and Yarn in United States and west Indies and various other products in Turkey and the middle east. A simple solar cabinet dryer suitable for drying small farm produce has been designed, fabricated and tested for drying chillies at Central Arid Zone Research Institute, Jodhpur (Garg and Krishnan 11). The design details and the tests conducted are described below :

The principle of hot box has been used in designing the solar cabinet dryer which is made of wooden planks (25 mm. thick) having a base area of 1.37 sq.m. and a volume of 0.324 cu.m. The dryer is provided with a glass roof made of clear window glass (5 mm thick) at a fixed inclination of 23° from the horizontal so as to receive maximum solar radiation year round at Jodhpur. The bottom of the dryer is insulated with 5 cm. thick saw dust insulation. A number of holes are drilled in the base as well as on the sides of the dryer so that the humid warm air can escape through the upper side holes thereby creating a partial vacuum and inducing fresh air from the holes in the base. The inside walls as well as base of the dryer is painted with matt black paint for absorbing solar heat. The drying material can be placed on the perforated removable screen made of wire mesh which can be kept in the dryer through an openable door provided on the rear side of the dryer. The dryer was installed in the solar energy yard of the Central Arid Zone Research Institute on a cement plateform. The dryer was kept facing due south at a clear site. The photograph of the dryer is presented in Fig. 7.

Two field trials of drying chillies in the solar cabinet dryer one in the month of January, 1974 and another in the month of February, 1974 were conducted. Equal quantities of chillies were kept inside as well as outside the dryer keeping the area of exposure constant. The albedo of the freshly picked up red chillies was measured by means of albedometer. Total bulk weights of the chillies were measured daily in the morning at 8 AM and in the evening at 6 PM. Moisture contents of chillies during each day were computed from the differences in these weights. Obviously, moisture contents obtained from bulk differences of weights would be more accurate than by estimating the same by sampling technique. The air temperatures inside the cabinet dryer were measured hourly by means of a calibrated bead type of thermistor.

The ambient air temperatures were recorded in a thermo-hygrograph kept in Stevenson screen of the agromet observatory near the solar energy yard. Total solar radiation on horizontal surface was automatically recorded with a Kipp & Zonen Pyranometer alongwith a Honeywell potentiometric recorder. It was observed that the drying of chillies can be completed within 7 days in solar cabinet dryer where as the same will take 15 to 16 days in the open drying method. Thus solar cabinet dryer reduces the drying time to less than half. The pattern of drying was similar in both the tests. In the solar dryer, the drying curve becomes steeper after 3 to 4 days from commencement when moisture content falls to 60 per cent or so. Similar feature occur in respect of curve for open drying also roughly at the same moisture percentage.

Detailed climatic observations such as, total solar radiation on horizontal surface (Kcal/m$^2$ day) average day time temperatures (°C) as well as maximum and minimum temperatures (°C) of the day were recorded during the whole period of Test No. 2. Hourly values of the air temperatures inside the dryer and the moisture contents of chillies during morning and evening were also measured during each day. These data are presented in Table 14.

The fraction of the total radiation that was being reflected by the freshly picked chillies was measured on the first day of the experiment by means of an albedometer. This value comes out to be about 35 percent. This high value may be due to the shiny surface of the freshly picked chillies. It is seen from Table 14 that the average temperature of air in the solar dryer during 7th to 13th February, 1974 when chillies were kept in it is 40.2°C which is 22.8°C more than the day time average temperature. However, the average of the maximum temperature in the solar dryer works out to be 53.9°C compared to average maximum ambient temperature of 21.6°C.

Since during the period from 14th to 21st February, the mean ambient temperature rose to 24.2°C the recorded air temperatures inside the dryer also increased to 52.5°C. The corresponding values of average maximum temperatures are 29.0 and 69.5°C respectively.

The total solar radiation on horizontal surface exceeded 4350 Kcal/sq.m.day except on 15th February, 1974 when the lowest value of 3700 Kcal/sq. cm.day was recorded. The higher radiation value was 4810 Kcal/sq. m. day on 11th February, 1974. The initial moisture content of chillies in respect of the two tests were about 85 and 79 per cent respectively. It is seen that the moisture evaporated per day generally follows the pattern of solar radiation. The average efficiency of utilisation of solar energy i.e. ~~the~~ ratio of heat used in the evaporation of moisture from the chillies to the incident total

Table 14 : Results of Chillies Drying tests.

| Date Feb. 1974 | Total Solar radiation Kcal/m²day | Average day time (temp.°C) | Temperature of day (°C) |  | Air temperature in dryer (oC) |  | Average moisture content (precent) |  | Moisture evaporated (Kg.) |  | Efficiency |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Max. | Min. | Av. | Max. | Solar | Outside | Solar | Outside | Solar | Outside |
| 7 | 4760 | 16.4 | 19.6 | 0.0 | 44.6 | 54.0 | 77.9 | 79.6 | 2.50 | 0.90 | 22 | 8 |
| 8 | 4680 | 14.7 | 18.0 | 6.6 | 33.5 | 44.0 | 73.3 | 78.2 | 2.10 | 1.05 | 18 | 9 |
| 9 | 4400 | 16.1 | 20.5 | 6.1 | 29.1 | 39.5 | 67.6 | 76.4 | 1.60 | 0.85 | 15 | 8 |
| 10 | - | 18.1 | 23.5 | 8.6 | 38.3 | 54.0 | 61.4 | 74.7 | 1.90 | 1.05 | - | - |
| 11 | 4810 | 18.6 | 23.3 | 6.0 | 44.4 | 57.5 | 50.0 | 72.3 | 2.00 | 1.05 | 17 | 9 |
| 12 | 4360 | 19.0 | 23.0 | 10.4 | 43.1 | 61.5 | 27.3 | 69.4 | 1.10 | 0.80 | 10 | 8 |
| 13 | 4500 | 19.4 | 23.8 | 11.0 | 48.8 | 67.0 | 3.0 | 66.5 | 0.10 | 1.20 | - | 11 |
| 14 | 4670 | 20.0 | 24.4 | 11.4 | 46.8 | 58.5 | - | 61.5 | - | 1.00 | - | 9 |
| 15 | 3700 | 22.1 | 26.7 | 12.0 | 41.8 | 58.5 | - | 55.8 | - | 0.80 | - | 9 |
| 16 | - | 25.5 | 31.0 | 15.1 | 50.7 | 72.0 | - | 50.0 | - | 0.80 | - | - |
| 17 | 4450 | 25.0 | 29.8 | 12.5 | 57.6 | 77.0 | - | 42.3 | - | 0.80 | - | 7 |
| 18 | - | 23.6 | 28.2 | 15.2 | 48.2 | 63.0 | - | 31.8 | - | 0.50 | - | - |
| 19 | 4780 | 24.2 | 29.1 | 15.8 | 54.9 | 76.0 | - | 23.0 | - | 0.40 | - | 3 |
| 20 | - | 26.3 | 31.0 | 17.5 | 59.6 | 76.0 | - | 14.3 | - | 0.30 | - | - |
| 21 | 4780 | 26.7 | 32.2 | 14.4 | 60.3 | 75.0 | - | 6.2 | - | 0.20 | - | 2 |

radiation on the horizontal surface works out to be 14 per cent in case of solar cabinet dryer and 7 per cent in case of open drying method.

A number of design variables, such as length by width ratio, number and size of vent holes, type and thickness of insulation, number of glazings, tilt and orientation etc. and the climatic parameters, such as solar insolation, ambient air temperature, air humidity, wind speed, cloudiness of the atmosphere etc. and the operating parameters such as type of product to be dried, initial moisture values, optimum temperature for drying, amount of drying material to be dried etc., effect the performance of the solar radiation cabinet dryer. All these factors and its techno-economic feasibility are under detailed investigation at Central Arid Zone Research Institute, Jodhpur.

## 6.2. Convective type of Solar Dryers :

Convective type of solar dryers have separate areas for collection of solar energy and for drying the product. This type of dryers have large potential in Industries as well as in villages as these are very useful for drying large products like paddy, groundnuts, tea leaves, fruits, vegetables, grains etc. In this forced convection type of dryers, auxiliary heating arrangement can also be made and thus makes the system more versatile and can be used continously.

In this type of dryers, some kind of air heaters are used which furnish hot air to a separate drying unit. The air heater may consist of two flat metal plates with some spacing for air flow or one flat plate with one vee-grooved plate as in Australia or two corrugated sheets with some spacing in between or matrix type or glass plates type as in U.S.A. or pillow of steel chips encased in chicken mesh as in Canada etc. The idea in all these air heaters has been to improve the film heat transfer coefficient without effecting the pressure drop during the air flow.

At Central Arid Zone Research Institute, Jodhpur, a theoretical analysis for getting the temperature profile in a conventional solar air heater (parallel plate) for various design, operating and climatic conditions has been carried out by Garg (5). The performance prediction equation as developed here in terms of temperature of air t at a distance of x from the inlet end of the air heater is :

$$t = \frac{C2}{C1} + \left(t1 - \frac{C2}{C1}\right) \text{Exp.} (-C1x) \ldots\ldots\ldots\ldots (1)$$

where $C1 = WF_p\, UL/GC_p \ldots\ldots\ldots\ldots\ldots\ldots (2)$

$$C2 = \frac{WF_p}{GC_p} \left[ .H(\tau\alpha)e + UL\ ta \right\} \ldots\ldots\ldots\ldots (3)$$

and $F_p = \frac{hc}{(U_L + hc)} \ldots\ldots\ldots\ldots\ldots\ldots (4)$

where W = Width of air heater (m)

L = Length of air heater (m)

H = Solar insolation on collector (Kcal/m$^2$ hr)

$(\tau\alpha)_e$ = effective transmittance absorptance product,

$U_L$ = Overall heat loss coefficient from collector plate to outside air (Kcal/m$^2$ hr $^o$C).

$t_p$ & ta = Collector plate and ambient air temperature respective ($^o$C)

hc = film heat transfer coefficient from absorber plate to fluid inside (Kcal/m$^2$ hr $^o$C),

t = temperature of air in the collector at distance from inlet side ($^o$C),

G = mass flow rate through absorber (Kgm/hr),

and $C_p$ = specific heat of air (Kcal/Kgm $^o$C)

Using the above equations/temperature of air at any point in the solar air heaters under the given situations can be determined. As a design aid various design curves based on the above equations are drawn with the help of which solar air heater performance can be predicted. With the help of above equations the gap xxxxxxx depth between the two parallel plates of the air heaters responsible for the film heat transfer coefficient and the pressure drop of air has been optimized.

A number of solar air heaters with various design parameters such as single or double exposure type, flat-plate or v-grooved or matrix type, their material, spacing, tilt, orientation etc. are to be studied in greater depth at this Institute. The effect of air flow rate, duct size, auxiliary heating arrangement and the size of drying cum storage bin need more investigations and will be taken up at C.A.Z.R.I., Jodhpur. A full fledged room type solar dryer with integrated solar air heaters which will work as roof will also be developed soon at C.A.Z.R.I., Jodhpur.

## 7. SOLAR COOKING

In the developing countries, the fuels which are generally used for cooking purposes are wood, kerosine, charcoal, dried animal dung, agricultural refuge and other combustible material. The widespread use of solar cookers can serve two important purposes : reduction in family cooking costs by decreasing the need for purchase or collection of fuel, and conservation of fuels for other uses, such as fertilizer in the case of dung, forest protection and erosion reduction in the saving of wood and charcoal. Most cooking involving boiling stewing, frying and liquid heating in general is by means of direct heating from below which can be done by parabolic reflectors whereas baking, roasting and cooking can be performed in solar ovens. Solar cookers are mainly of two types, one involving focussing type concave mirror either spherical or paraboloidal, the other is of hot box type. At Central Arid Zone Research Institute, Jodhpur, we have a project on the development of suitable solar cooker for urban as well as for village use. As a result of our study we are able to develop five types of solar cookers which are under field test and are described below in short :

### 7.1. Solar hot box type cooker :

This solar cooker though not very efficient but is simple in design and operation and is of low cost. Such a solar cooker developed at C.A.Z.R.I., Jodhpur is shown in fig. 8. It is based on the principle of hot box. This cooker as developed by Garg (24) consists of a double walled box made of teak wood with fibreglass insulation in between. A metal black painted lining was provided on the inner side of the box. Two glass (3 mm thick) covers are provided at the top of the box at a spacing of 5 cm. The glasses are inclined at an angle of 26 degrees from the horizontal (latitude of Jodhpur). This type of mounting is known as equatorial mounting. A wooden cover containing a mirror lining on the inner side is also provided for reflecting the solar radiations into the hot box. This cover can be adjusted to any angle with the help of two Kamanis. Four castor wheels are fitted in the box for orienting the cooker towards the sun. Direct and diffuse radiation penetrates through the two glass covers which is further augmented by the radiation coming through the glass sheets after reflection from the mirror.

Temperature as high as 150°C has been observed in this simple cooker under clear sky conditions. Some of the dishes which are prepared in this cooker at Jodhpur are as follows :

One kilogram of potatoes can be boiled in about 2 hours time. One kilogram of rice can be cooked in about 2 hours time but one kilogram of arhar Dal takes about 4 hours for cooking. The cost of this cooker comes to be only Rs.150/-. Further modifications for making the cooker more efficient and faster in operation are required and are under consideration.

7.2. <u>Solar Oven</u> :

The Solar oven developed at Central Arid Zone Research Institute, Jodhpur (Garg, 23) consists of a well insulated semi-cylindrical form, made of sheet aluminium and wood. Two shells are made and the space between them (7.5 cm) is filled with fibreglass insulation. The interior shell is painted black. A door of the same insulating material is also made for keeping and taking out the food. The window of the oven consists of two transparent gl glass sheets (3 mm thick). Eight reflectors, made of silvered glass mirrors, four of square shape and four of triangular shape, have been used. The stand and the orienting device is made out of mild steel angle iron having rolling wheels to follow azimuthal movement of the sun. The altitude position of the sun is followed with the help of slotted "Kamani" fixed with the oven. A cradle like cooking platform is made in the oven which helps in keeping the vessel containing food horizontal irrespective of the inclination of the oven. Two or three vessels containing food materials like rice, dal etc. can be kept on this plateform. A photograph of the solar oven is shown in fig. 9.

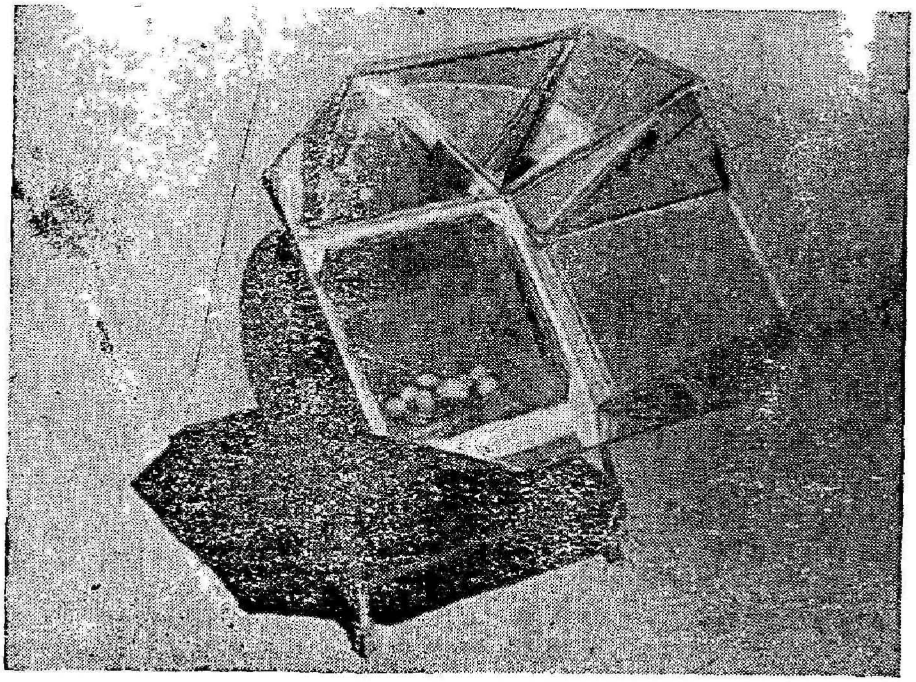

Fig 9. Solar oven developed at C. A. Z. R I., Jodhpur

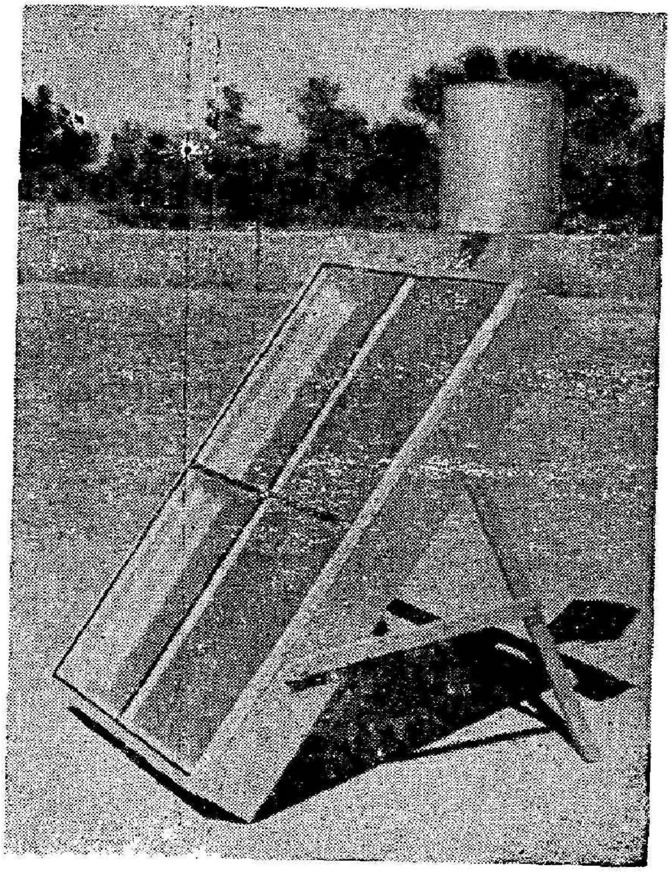

Fig. 10. Solar steam cooker developed at C. A. Z. R. I., Jodhpur

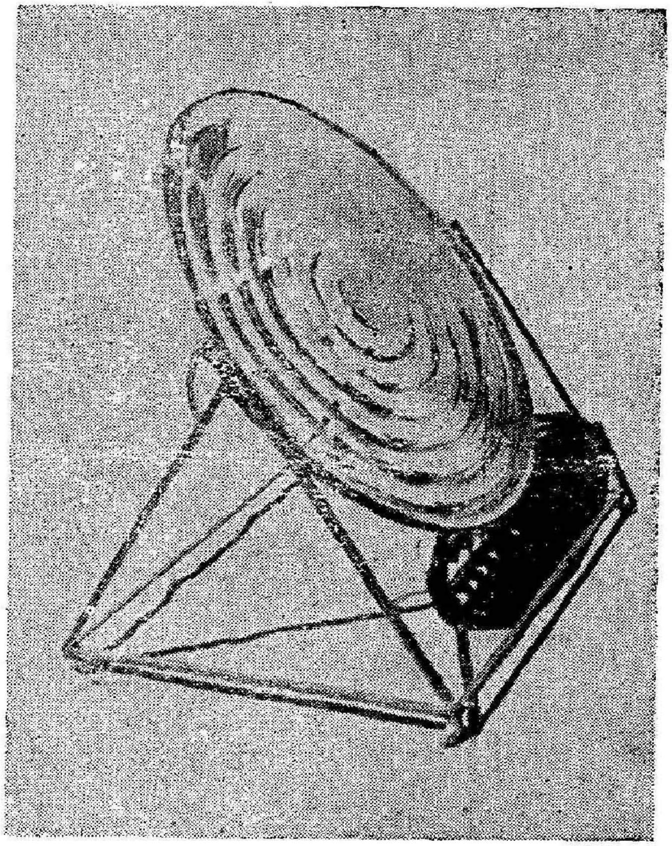

Fig 11. Step reflector for solar energy concentration developed at C. A. Z R. I., Jodhpur

When the oven is oreinted towards the sun, direct and diffuse solar energy is transmitted into the oven through the transparent double glass windows, and is further augmented by the eight flat-reflectors. The advantage of this solar oven is that it is of low cost, require less attention for following the sun, not influenced by wind cooling, heat storage devices can be used, food can remain warm for hours even after sun set.

The solar radiation enters directly through the window and also after reflection from the mirrors. The projected area of the mirrors is twice the window area.

On clear days if the radiation is assumed as 1.3 Cal/sq. cm min, then the total radiation absorbed by the oven comes out to be about 278 Kcal/hr. So this oven is equivalent to 0.32 KW of electric hot plate. The oven plate temperature reaches to 250°C and brings one litre of water to boiling point with in 45 to 60 minutes. This oven is just sufficient for meeting the daily cooking requirement for a family of five persons. Following cooking figures at Jodhpur are observed under clear sky conditions :

1. One kgm. of potatoes can be roasted in 45 minutes.
2. Two kgm. of chicken can be roasted in 60 minutes
3. One kgm. of rice can be cooked in 60 minutes
4. One kgm. of Arhar Dal (soaked in water for 12 hours, can be cooked in 75 minutes.
5. One kgm. of bread can be baked in 30 minutes.
6. One litre of water can bring to boiling point in 45 minutes.

It is approximately estimated that the cost of the oven on a single unit basis is not likely to exceed Rs.300/-.

7.3. Solar Steam Cooker :

A simple and efficient solar steam cooker involving the principle of flat-plate collector has been developed at C.A.Z.R.I., Jodhpur by Garg (25). It consists of two parts, one is the metal flat-plate collector having two glass cover (tube in plate type) heated by the sun causing water to boil and producing steam. The second is the insulated steam cooker, in which the tiffin containing food is placed. The Santosh cooker which is easily available and was popular in olden days is used in place of the steam cooker. The flat-plate collector having an area of 1.0 sq.m. consisting of a wire wound steel fin of 28 gauge with steel pipe of 19 mm diameter spaced at 25 cms centres has been used. The simplicity of the flat-plate design makes it possible to fabricate the collector even in a domestic workshop without any specialised tools. The entire cooker shown in photo 10 is pointed towards the point of sunrise all morning, and the point of sunset all afternoon. More frequent adjustment is not required.

The solar collector always contains water, about one cup of water can be added each morning to replace the water that has boiled away. Steam is produced within an hour of sunrise and will continue to be produced for the rest of the day as long as the sun shines i.e., on the collector. Thus it is possible to cook both the midday meal and the evening meal. Food left in the cooker will remain hot for several hours after sunset.

This solar cooker is very much suitable for cooking or boiling cereals, rice, potatoes, dal, vegetables etc. It takes about 2 hours for cooking such things. This cooker can be installed in the open lawn or right in the chajja of the house and when connected with a pipe to the steam cooker (Santosh cooker) placed inside the kitchen.

The cost of the solar steam cooker is about Rs.300/- and is estimated to be equivalent to 400 to 500 watts electric hot plate. The same solar cooker can also be used as solar water heater with slight modification.

### 7.4. Solar step reflector type of cooker

The reflector type of cooker was first made in India by N.P.L., New Delhi which consisted of anodised aluminium paraboloid of about 1.0 sq.m. area having all tilting, orienting arrangements. This type of cooker can be used even for frying purposes. Though this cooker is quite efficient but is of high cost and is very difficult to make in a domestic workshop. So it was thought to design a simple reflector which can give a point focus and can be made on a cottage scale with the help of local materials and sheet metal worker. The reflector designed at C.A.Z.R.I., Jodhpur by Garg (22) consists of a number of aluminium strips of

7.5 cm width arranged in such a fashion so as to give a shape of spheroid. The spacing R, of the aluminium strips acting as reflector is calculated with the help of the equation :

$$R = F \tan 2\alpha$$

where R = spacing between the two strips,
F = focal distance from the centre of the speroid
and $\alpha$ = angle of the strip from the plane of the spheroid.

The area of the spheroid reflector designed is 1.48 sq.m. and is made out of wooden strips frame and aluminium strips. The focal distance from the centre of the reflector was chosen at 60 cm and this gives an image of the sun of about 15 cm. diameter. A step reflector designed at C.A.Z.R.I., Jodhpur is shown in fig. 11. The cost of the reflector comes to be about Rs.80/- only. Preliminary observations made with this simple but novel reflector have given encouraging results and further tests are in progress.

## 8. FUTURE PLAN OF WORK

The rural model and urban model of built in storage type solar water heater, capacity 90 litres, developed at C.A.Z.R.I., Jodhpur will be further modified and a built-in [illegible] system will be developed so that the heater may give hot water for early morning use. Attempts will be made to reduce the cost of the heater by suitable modifications. A number of such solar water heaters will be installed in the country for demonstration cum test purposes.

A selective coating which will reduce the radiation loss from the absorber plate considerably suitable for galvanised iron sheets will be developed. By the use of this selective coating the efficiency of the flat-plate collector will be increased and will make the flat-plate collector suitable for a number of applications like, water heating, air heating, air conditioning etc.

After studying the long term effect of all the climatic, design and operational parameters on the distilled water output of solar stills a mathematic model will be developed for optimizing the size of domestic solar stills.

Few domestic solar stills will be installed in some of the villages of Western Rajasthan where there is a problem of getting sweet water. Actual users data will also be collected from these stills.

A number of parameters effecting the performance of radiation type of solar cabinet dryer will be experimentally studied and the dryer will be suitably modified. A number of drying trials with various vegetables, fruits etc. will be conducted with this cabinet dryer.

Solar air heaters suitable for drying large quantities of agricultural products may be crops like paddy or corn etc. for safe storage purposes∠be developed ∠will and performance data will be collected. Actual forced connection type of solar dryer will be developed and tested in various parts of the country for various crops. Environmental and solar dryer performance data will be analysed for making recommendations for drying of different crops in various regions of India.

A few more types of solar cookers will be developed and tested alongwith the existing cookers at C.A.Z.R.I., Jodhpur. All the cookers will be tested and their technoeconomic feasibility will be studied in great detail. A number of such cookers will be installed in villages for collecting the users views.

A suitable and efficient solar concentrator will be developed which can be used for generating steam and finally for the production of electricity using turbines.

Various solar pumps available in the world will be studied and a suitable, simple and economical solar pump which can be within the reach of a farmer will also be developed at C.A.Z.R.I., Jodhpur.

The suitability of silicone solar cell or cadmium sulphide solar cell lighting kit will be studied and actual field trials will be conducted.

## 9. ACKNOWLEDGEMENTS

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