

Final Report
May, 1999

**INSTALLATION AND TESTING
OF A SOLAR STEAM SYSTEM
FOR COOKING IN INDIA**

Presented by Golo Pilz
on behalf of
the World Renewal Spiritual Trust (WRST) and
the Prajapita Brahma Kumaris Ishwariya Vishwa Vidyalaya

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1 Responsibilities

The body responsible for the project is the World Renewal Spiritual Trust (WRST)

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and others too numerous to mention who have tirelessly helped with setting up and maintaining the system, data collection and processing and the preparation of this final document.

3 Summary

Solar cooking is one of the most interesting applications in the field of renewable energies. During the last twenty years many designs and concepts have been developed and tested, especially in the field of family cooking: solar cooking boxes and small concentrators are available in most developing countries to help reduce the consumption of costly kerosene, gas or firewood. However, the problem of heat storage has not yet been satisfactorily solved and this is one of the reasons that solar cookers are not yet in everyday use.

In 1995, the World Renewal Spiritual Trust (WRST) and the Brahma Kumaris tested on behalf of GTZ, Germany, two parabolic concentrators for institutional cooking at the Academy for a Better World in Mt Abu, Rajasthan, India.

The concentrator is originally designed by Wolfgang Scheffler, a pioneer in solar cooking, and is already being manufactured in India by Deepak Ghadia at the ECU centre in Valsad. As a result of positive tests at the end of 1995, a proposal for a solar steam cooking system for 1000 people was forwarded to GTZ. The proposal was approved at the beginning of 1996 and successfully installed in 1997 at the Academy in Mt Abu.

The solar steam cooking system uses 24 concentrators to focus the sunlight on 12 receivers. The collected energy is transferred to a solar steam generator by means of a primary water circulation line. From there, steam is transferred by pipe to the kitchen, for cooking and preparation of tea.

In case of low solar radiation or extra demand, a highly efficient back-up steam generator, fuelled by kerosene, provides steam.

The system has been operating from the beginning without any major problem and has reached the theoretically calculated maximum steam output of 600 kg steam per day. The daily availability of the system is good. The whole solar cooking system is being operated and maintained by two local WRST staff members.

In view of the positive experiences with the steam cooking system in Mt. Abu, the Brahma Kumaris complex in Shantivan, Talheti, Abu Road considered introducing a similar but bigger system for its premises. In November 1997 the planning and design for a solar steam cooking system for 20000 meals per day started.

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The system in Shantivan consists of 84 parabolic concentrators and is designed to generate 3400 kg steam per day. The surface of the parabolas has been increased from 7.2 to 9.2m² and a new receiver has been designed and successfully tested. The steam is generated in a header pipe above the receivers and the whole system works without a pump by means of a thermosiphon.

The combination of the solar steam cooker with a conventional back-up system (generating steam with kerosene) provides 24 hours of steam on demand. This has created wide acceptance of the system by the kitchen staff.

As Talheti, Abu Road, has nearly 200000 visitors per year from all over India and abroad the demonstration and distribution of information is excellent. As the system is modular in size and application, several companies and institutions have already shown interest in the technology.

4 Goals

The main goal of the project *Solar Cooking for Institutions* is the transfer of technology, the demonstration of such a system in India and the evaluation of the efficiency of a solar cooking system of this size under practical conditions.

Another important aspect of the project is the adaptation of all the components like receivers, steam generators, control unit, tracking system and parabolic concentrators to local facilities and conditions, so that there are good chances for the distribution and acceptance of this modular technology in India.

It is estimated by the author that with its modular design of 14 mirrors the system can be replicated at moderate cost all over the country. In particular, institutions, companies and the media will be informed and should play a vital role in the dissemination of information concerning the system.

5 Project Progress

Between December 1997 and January 1998, several meetings and discussions were held with Ramesh Shah (WRST), Golo Pilz (BKWSU), Wolfgang Scheffler, Christoph Sutter, Deepak Gadhia (Eco Centre) and Mr Schmitt (HTT). The aim of these meetings was to gather information and to finalise the design of the new cooker and the back-up system.

After finalising all aspects of the project, work started in March 1998 with the construction of a workshop and the procurement of materials. Major components were ordered as follows:

J M Engineering	-	solar steam generator and 48 receivers
Termax	-	back-up system and chimney
Charitable Trust	-	water treatment plant, white glass, feed water pump

In April 1998, manufacturing of the parabolas, the rotating support and the stand started in the new solar workshop.

In May 1998, the layout of the master lines and of the 84 mirrors on the roof was carried out.

In July 1998, the feed water pump (Speck), the white glass (Flabeg) and the water softening plant were shipped to India.

Civil work for the platform started in August 1998.

Between October 1998 and January 1999 installation of the parabolic concentrators took place. Simultaneously, the white glass was cut into 20000 pieces of 165 x 200 mm.

From December to March 1999 the feed water pipeline/steam pipeline and reducer station were welded together by a certified welder and the back-up system and water treatment plant was installed.

In January 1999 the tracking system was fitted and tested. By the end of January 1999 all the electrical connections, the control unit and the insulation had been completed.

From February onwards, the flushing of all the pipes, pressure tests and electrical tests took place.

Finally the system was successfully tested at the end of February 1999.

6 Technical Description

Wolfgang Scheffler of Switzerland originally developed this type of parabolic concentrator in the '80s. Since then the parabolic dish has undergone several improvements.

For the Talheti solar cooker, the parabolic concentrators, the receivers and steam generator were further optimised with the help of Wolfgang Scheffler, Deepak Ghadia, the Brahma Kumaris Solar Department and Hochtemperatur Technik of Germany, a world leader in heat transfer technology.

The latest version of the parabolic concentrator is oval in shape and has a total reflective area of 9.2m². The parabola is fitted to a rotating support which itself rests on a stand. The whole construction is made out of mild steel. The parabolic disk reflects sunlight by means of 250 pieces of white glass (165 x 200 mm) with optical reflection close to 93%. The glass was imported from Germany. The sunlight is concentrated onto the round receivers of 45 cm in diameter, at a distance of 3 metres from the centre of the disk. A single disk has a maximum output of 4.0 kW at 1000 W/m² solar radiation and reaches temperatures up to 750° C in the focus.

In the solar cooking system in Talheti, a total number of 84 parabolic concentrators have been installed and are reflecting sunlight on a total of 42 receivers. The design is such that one parabola reflects from a higher position to the front side of the receiver and another mirror reflects from a lower position to the rear of the receiver. The mirrors are arranged in an accurate east-west alignment and tracking is done by a central system by means of 6 winches, 6 DC motors, an electronic regulator and a small PV system. In the evening, the system has to be reset manually to the morning position.

One of the most important parts in concentrator technology is the receiver. For the solar steam cooking system in Talheti, a shell type receiver out of MS, diameter 35 cm (schedule 40, boiler grade) was developed. The water in the receiver is heated by two concentrators (8 kW) focusing on both flat sides of the receiver. The hot water immediately shoots up as per the thermosyphon principle into the very well insulated header pipe and heats up the water there. Cool water immediately flows down into the receiver through an integrated ½" pipe. The steam is generated accordingly directly in the header pipe, diameter 12" (schedule 40, boiler grade), above the receivers. As the receivers work as per the thermosyphon principle there is no need for a separate steam

generator, a heat exchanger or any circulation pump. This increases efficiency and there is no interruption from power cuts.

Through its design and dimension, the header pipe works as a steam generator, temporary steam storage and feed water reservoir (see drawings in the Appendices). A total of 14 mirrors focus on 7 receivers in one module. A total of 6 of these modules are interconnected in a common steam drum. The system generates a maximum of 3500 kg steam per day (6.5 kWh/m²).

To avoid any scaling in the 42 solar receivers, water softening and filtration provides demineralised water to the system. Insulated pipes transfer the generated steam to the already existing steam cooking pots. Steam traps and a pressure reduction station ensure good steam. The steam is used for cooking, water sterilisation and the milk/tea kitchen.

In combination with highly insulated cooking pots, the system already provided enough steam for 33500 meals per day. The idea behind this new design is to minimise electrical loads like pumps, etc, to economise on piping and better overall design. In case of low solar insolation, two new and highly efficient kerosene-fuelled steam generators function automatically as a back-up system.

The system is protected against excess pressure by safety valves and an automatic shut down mechanism. The status of the whole plant is monitored by temperature and pressure meters and a computerised 6-channel data logger.

7 Results and Evaluation

For the evaluation and testing of the solar cooker a fully fledged measuring system was necessary. A system was designed and installed by Thorsten Ludwig (cand. Phys.) and Golo Pilz. Thorsten Ludwig also did the evaluation of output and efficiency.

The solar cooker came into full use during two big melas (gatherings). For each mela, between 12000 and 20000 visitors came to Shantivan. Each mela was monitored for a week. For the second mela, the data for solar radiation and pressure could also be monitored.

7.1 Technical

7.1.1 Abstract

A computer-based measuring program was carried out in March and April 1999 to analyse, evaluate and optimise the solar steam cooking system at Shantivan, Abu Road, Rajasthan. The pressure in the steam circuit, the temperature as well as solar radiation, total steam output and the number of meals served were recorded. It was found that the cooking included tea and milk for 18000 people and the boiling of 3000 litres water.

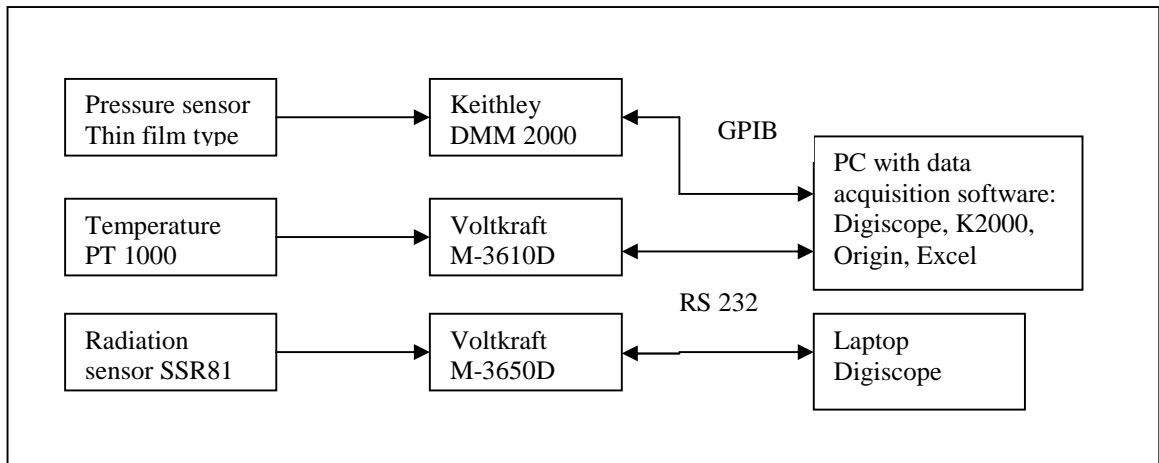
The cooker can be improved further through optimisation of the load management. It is expected that after fine tuning of the system the maximum number of meals cooked per day can be increased further.

7.1.2 Introduction

After the great success of the solar cooker in Gyan Sarovar, Mt Abu, it was decided to build a similar system in the Shantivan complex at Abu Road. The Shantivan system profited from the experience gained by the first system. Since the first system was a R & D project, a detailed measuring program was carried out. To learn more about the new system in Shantivan a similar measuring program was carried out. The following text should give the reader a detailed description of the agenda and the devices used. The long term data that were taken once a day were done by manual reading. To study the system's performance, a computerised measuring system was set up by the author.

7.1.3 The measuring system

Hardware set-up



For data acquisition, standard sensors for temperature, pressure and radiation were used. The sensors were read out with digital multimeters (DMM). For data-logging the DMM were connected via serial ports and via a GPIB bus with a Pentium-type PC and a Pentium laptop.

The Sensors:

Pressure Sensor GPE 81

A thin-film (DMS) pressure transducer from ECO-TRONIC with a maximum pressure of 16 bar was used. The sensor has a 4–20mA standard output. It is powered by a 12V-DC power supply. The error is less than 1%.

PT 1000 GFT 101

To measure the temperature, a platinum resistor-type sensor was used. Because of its higher accuracy the 1000 Ω type came into use. The temperature response of metal resistors is so well known, that for many decades the platinum resistor has been the international standard for temperature definition from the Kelvin range all the way up to 1000°C.

Standard Silicon Radiometer SSR 81

To measure the intensity of the sunlight we used a standard silicon radiometer SSR 81 from Zenit. The standard silicon radiometer has a temperature compensation with a built-in temperature sensor KTY 81/120. The calibrated output is 67mV at 1000 W/m².

The Digital Multimeters (DMM):

Keithley DMM 2000

The Keithley is a 6½ digit high-performance digital-multimeter. It has 0.002% 90-day basic DC voltage accuracy. At 6½ digits, the multimeter delivers 50 triggered readings/sec over the IEEE-488 bus. The Model has broad measuring ranges, is fully programmable and has internal memory and buffers. The DC current accuracy is 10nA. This high resolution DMM was connected to the PC via the GPIB bus. To read out the data we used the plug and play software that came along with the instrument. The program creates ASCII files of the data reading. These files were then further processed with Origin.

Voltkraft M-3610D and 3650D

These are quality multi-purpose 3½ digit DMMs, with a serial interface. They were connected to the PC or Laptop via the RS 232 serial port. One was used to measure the voltage of the standard silicon radiometer, the other to measure the resistance of the platinum temperature sensor. The accuracy of the measurements was ±0.5%. For the voltage measurement the accuracy was ±0.3%. See also specifications in the appendices.

Interfaces:

GPIB

The general purpose interface bus (GPIB) was developed by Hewlett Packard in the late '70s. It has become a widespread standard bus for test and measurement (T&M) instruments. It now runs under many names like IEEE-488, IEC or HP-IB. It is a parallel bus which has a much higher data throughput than a serial bus. Additionally the user will greatly appreciate the 8 data controlling wires which give great stability and reliability. The bus is organised by a controller, usually the computer-card. The instruments are listeners, speakers or both. Each instrument has an address from 1 to 32. The Model 2000 DMM had the address 16.

RS 232

The RS 232 is a standard PC serial port. The advantage is that only two wires are necessary and the disadvantage is a high error rate when run without handshaking or data control. The settings for the Conrad DMM are 1200 baud, 7-bit-ASCII, 3 stop bit no parity and no hardware handshaking.

Software:

We used the software supplied by the manufacturer to log the data. For data processing and analysis we used standard programs Excel and Origin (product of Microcal).

Digiscope

The Digiscope is a 16 bit DOS program that allows us to read out the data of the DMM at the desired rate. The data is then displayed in a similar way to an oscilloscope. We read out the DMM every 10 seconds. The data is recorded in pages. Every page holds 40 minutes of data. The setting of the DMM and the time are recorded at the beginning and the end of each page. The data is saved as ASCII files which are then further processed with Origin.

K2000 plug and play software

The plug and play software for the Model 2000 is basically a Testpoint program. Testpoint is the virtual instrumentation software from Keithley. It allows us to access the instrument via the RS232 or via the GPIB bus. All basic functions can be set by the software. The user can take either single or continuous readings. The continuous readings are displayed in a graph and can be stored in a file. The file then consists of ASCII code. The rate of the readings can be set from 0.01 sec to 10 sec. Again we took readings every 10 sec. The starting time was recorded manually and time stamps were added later on with Excel. Every 10 seconds a reading was taken. For security reasons we saved the data files every 2 hours. The data is stored in a data file in ASCII format, to make exportation easy.

Origin

Origin is a program used for data analysis and technical graphics. It allows you to read in ASCII files into worksheets and to create graphs from the data. Additionally the data can be integrated, averaged and much more. A wide selection of fit functions and analysing tools allows the user to do a detailed analysis of his data. All graphs in this report were created with Origin.

Excel

For some simple worksheet calculations we used this Microsoft Office standard worksheet program.

7.1.4 Data acquisition

The software programs were run continuously for 3 days during the gathering of the 30.3.99. Only during the gathering was the system used fully. The data was then further processed and the

data streams were put together with Excel. The data was then analysed in Origin. Also all graphics were done with this program.

Manual data collection:

Steam output

To estimate the steam output, the feed water intake was manually recorded at fixed times by an analogue water meter.

Diesel consumption

A local mechanical meter was used to measure the diesel consumption of the back-up system. The diesel meter was recorded manually before and after each meal. The diesel consumption per kg steam of the old system was estimated on the basis of the monthly diesel purchased before the solar cooking system was in operation, and the boiler manual.

7.1.5 Results

Output:

As a measure of the productivity of the system we are using the number of cooked meals (Graphs 1 and 4) and the steam production (Graphs 2 and 5) during the gathering of the 15th and 30th March 1999. The peak production of steam occurs on the 30th March (Graph 4) with 3050 kg steam. Similarly, on the same date, the greatest number of meals (33500) were prepared with the help of the solar system.

Performance of the system:

Graphs 7 to 9 show the diurnal variation of pressure. These graphs indicate the direct relation between the load management and energy input through the sun. Each day shows a significant difference. Still there is a certain pattern to each day which shows the pattern of usage. First we have the initial build up of pressure. From around 09:30 the valves are opened and the steam is used. Then, depending on demand and solar radiation, the pressure varies only a little around the working pressure during lunchtime cooking. The time between lunch and tea is used for the feed water injection and to boil water for drinking purposes. Then the pressure rises as load is less till tea preparation starts at around 13:00. After 14:00 the kitchen staff starts to prepare dinner and the pressure drops accordingly. The pressure was recorded every 10 seconds very accurately so we can see even minute changes in the demand and input relation.

Solar radiation:

Graphs 10 to 12 show the diurnal variation of direct solar radiation. The total direct radiation varies from 6.9 to 7.9 kWh. On 1st April the sky was hazy, without clouds, and so the radiation recorded was only 6.88kWh. We can see that on 1.4 the peak did not even reach 800w/m² and that it varies more than on the other days with full sunlight.

Average Power of the System:

Number of mirrors:	84
Aperture per mirror:	6.7 m ²
Solar radiation per day:	7.4 kWh/m ² (880 W/m ² peak)

The system has an energy input of 4.1 MWh per day at an average sunshine of 7.4 kWh/m² and has a peak power 500 kW.

System efficiency:

To accurately assess the system efficiency we evaluated one separate module of 14 mirrors for one day. After the pressure had reached 3 bar the valve was opened and the steam was used at this pressure for the whole day. This was done because we expected a higher efficiency at this pressure. Graph 13 indicates that the efficiency goes down as the operating pressure rises. The efficiency at higher pressures was calculated out of the pressure curves and the solar radiation and steam production for that day.

Calculation for one module:

The energy input for one module was

Number of mirrors:	14
Aperture per mirror:	6.7 m ²
Solar input per day:	7.4 kWh/m ²
Steam production per day:	577kg = 395 kWh
System efficiency:	$395 / (14 \times 6.7 \times 7.4) = 0.57$

The steam production of 577 kg at 3 bar has an energy equivalent of 395 kWh. The solar radiation input is equivalent to 694 kWh. The ratio of energy input to the energy content of the steam output is the system efficiency. For this test with an operating pressure of 3 bar we calculated a system efficiency of 57%.

Efficiency during standard load conditions:

To assess the efficiency we averaged the operating steam pressure. We excluded the initial rise period. The average was between 5.1

and 6.9 bar for the different days. The 6.9 bar average occurred on the most sunny day, the 30th March, which was also the day with most load. We then calculated the energy stored in the steam at the average pressure and set this in relation to the total of the direct sunlight. We got efficiencies between 41% and 49% with an average of 45%.

This indicates clearly that higher efficiency can be obtained the moment proper load management is applied. It is the conclusion of the author that the system efficiency could be optimised by keeping the operating pressure below a maximum of 5 bar. Another key factor for efficiency is the cooking time per meal. It could be observed that by opening the valves fully and cooking at a high speed, efficiency also dropped. In addition thermal losses through wind and leakage at the cooking pot also play a major role.

Diesel savings:

As shown in Graphs 3 and 6 the diesel savings average around 300 to 400 litres per day. That saving is equivalent to 950 kgs of CO₂ per day.

7.1.6. Discussion

The accuracy and stability of the sensors and the measuring system was good. The solar cooking system also works very reliably. On a sunny day the solar cooker is ready for use at around 10:00. The daily pressure graph shows clearly that up to the point where the steam is used the pressure builds up first exponentially and then linear with time and ultimately shows signs of saturation close to the maximum operating pressure of 12 bar. It is interesting to note the response of the system to load. In this case the rise in pressure is slower or the pressure drops with a speed relative to the load. Even with maximum load the pressure does not drop below 3 bar. So in comparison to the solar cooker in Gyan Sarovar this system matches full load with ease. So it seems that 33500 meals is still not the maximum capability of the system. It is advisable to add additional loads, especially for times with lower food cooking requirement in the complex. This statement is backed by the efficiency of 45% under normal running conditions at present times in comparison to the optimum efficiency of one module of 57%. Additional loads like a small steam turbine for power production and a drinking water boiling system are already under consideration.

7.1.7 Conclusion

Such types of solar steam cooking systems are suitable for institutional cooking and industrial steam requirements. Here it can be a cheap way to produce low pressure steam.

In between the gatherings the output and storing capability of the system was excellent so that even at 04:00 sufficient steam for tea preparation was available. During such periods the back-up system could be switched off completely.

The solar cooker has been in operation for 3 months. In the monsoon season, usually a period of 10 weeks, it is not practical to run the solar steam cooking system because of continuously cloudy conditions. In this period the steam is totally provided by the back-up system. The rest of the year is excellent and Abu Road reaches a maximum of 2000 kWh/m² per year because of its desertlike climatic condition.

The system has already passed through heavy winds without any damage. Presently the parabolic concentrators are getting equipped with hail storm protection made of polyester net. The mechanical stability of the foundation and the parabolic concentrators is excellent. The lifespan of the white glass is expected to be close to 8-10 years.

The electrical DC timer operated tracking system is running satisfactorily at present. The overall handling of the system is easy and operation and maintenance is already in the hands of three trained staff members of WRST.

7.2 Demonstration and Distribution

The Brahma Kumaris Shantivan Complex has an excellent infrastructure including two conference halls one with a capacity for 20000 people and accommodation capacity for 15000 people. The complex attracts around 300000 visitors per year from India and abroad. Regular conferences and workshops are held on its premises.

The complex is an ideal place for the dissemination of the renewable energy philosophy. Many people with different backgrounds, like industrialists and administrators, have already shown interest in the system. There are regular guided tours to the solar cooker and information material is available on site. There have been radio interviews (All India Radio) and press articles (see Appendices).

In addition the WRST and the BKWSU are distributing the information about solar cooking technology through seminars and lectures (see Appendices)

Mt. Abu 15.5.99

Golo Pilz
Project Manager

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8 Appendices

- I Data
- II Drawings
- III Photos