Final Report
May, 2006

# Development and Testing of a 16 m² parabolic dish with Cavity Receiver for a Solar Steam System

**Presented by Golo Pilz**
**on behalf of**

**World Renewal Spiritual Trust (WRST)**

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# 1 Responsibilities

The body responsible for the project is the

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# 2 Acknowledgements

The World Renewal Spiritual Trust would like to express their sincere thanks to the following institutions and individuals:

The Ministry of Non-Conventional Energy Sources, New Delhi, for *financial assistance*.

The Charitable Trust IndiaCare, Berlin, Germany, for *assistance* and technical *support*.

Wolfgang Scheffler from Germany for his contribution *to system design* and *continuous support*.

B.K. Jayasimha and B.K Kartik and the tireless team *for manufacturing and construction work on site.*

and many 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 with the help of GTZ, Germany, two parabolic concentrators for institutional cooking at the Academy for a Better World in Mt Abu, Rajasthan, India.

The concentrator was originally designed by Wolfgang Scheffler, a pioneer in solar cooking, and is meanwhile manufactured in various places in India. Since then the parabolic dish has undergone several improvements.

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 steam cooking system in the Gyan Sarovar academy uses 24 concentrators of 7,2 $m^2$ size 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 staff members.

In view of the positive experiences with the steam cooking system in Mt. Abu, the Brahma Kumaris/ WRST 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 20,000 meals per day started.

The system in Shantivan consists of 84 parabolic concentrators and is designed to generate 3500 kg steam per day. The surface of the parabolas has been increased from 7.2 to 9.2$m^2$ 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 thermo siphon.

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 the Shantivan Complex has nearly 200,000 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.

Since then, the Brahma Kumaris and WRST Solar Department have continuously developed and improved the solar steam cooking system.

Meanwhile further Systems have been installed successfully in the Brahma Kumaris Yellapur Complex (10 dishes), the Brahma Kumaris Om Shanti Retreat Complex, in Maneswar near New Delhi (20 dishes), the global hospital and research centre ( 20 dishes ) and the BK Headquarters in Mt. Abu (6 dishes).

For the Global Hospital and Research Centre (GHRC) and BK Headquarters the dish size has been increased to 12.6 $m^2$. Furthermore the overall design has been modified. Instead of a Header pipe above all the receivers, a steam tank has been introduced in order to increase efficiency and reduce heat losses.

In both systems a new tracking system has been introduced and all the dishes are connected by means of stiff aluminium square tubes. The dishes are tracked by one DC motor and a gear system.

As per the positive results so far achieved with the 12.7m2 dish WRST / BK decided to build a prototype 16$m^2$dish and test the same.

# 4 Goals

The main goal of the project is to improve the technology, the demonstration of such a 16m2 dish with an improved design and the evaluation of the efficiency of a system of this size under practical conditions.

Another important aspect of the project is the adaptation of all the improved and redesigned components such as the increased dish of $16m^2$, receiver and tracking system.

## Areas of special interest in this project are:

- Increased dish size, flange system
- Improved receiver design
- Standardization of the overall design

It is necessary that all the experience of the previous projects will be used to further improve the manufacturing process and ensure that all improvements and positive results of the project will directly enter the manufacturing process.

The WRST/Brahma Kumaris have already established a vast expertise in the field of solar community cookers through the previous solar steam cooking projects in Mt. Abu, Taleti, Yellapur and Delhi and its collaboration with MNES, the IIT Delhi, the company HTT, the Institute für Solare Energie Versorgungs Technik (ISET) and the GTZ.

As Brahma Kumaris have networked extensively with various partners it will be easy to communicate the experience of this project to all the interested organizations.

By this, all future manufacturers and users of the solar dish cooking system will greatly benefit from the outcome of this project.

# 5 Project Description

## Title of the project:

## Development and Testing of a 16 m² parabolic dish with Cavity Receiver for a Solar Steam System

**The Project duration is one year**

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

The new 16m2 solar parabolic dish is partly based on an improved version of the 12 $m^2$ solar parabolic dish used already successfully at the Brahma Kumaris at its headquarters Pandav bhawan in Mt. Abu and other places in India .

After various discussions and meetings of solar department of WRST/ BK and BK Jayasimha and Wolfgang Scheffler a complete new 16$m^2$ dish and a prototype cavity receiver have been designed.

However, as a 16$m^2$ dish has a critical size, handling and transport gets a problem. Therefore the dish has been split into two half's and will be joint via flanges after assembly on the rotating support. This will enable for first time easy transportation and erection on the site.
It has also been found through tests that one of the mayor energy loses of solar steam systems still occur at the receiver. There fore one cavity cone type receiver will be tested against a standard flat Type receiver. Through its shape it is expected that the cone type receiver minimize reflection and emission of energy.

**Details of the System and improvements:**

For the new dish the total reflective surface of the mirrors has been increased to ~ 16 sqm. The aperture is around 11.4sqm. This enables us to concentrate more power on one point and hence avoid the previously used double dish (one upper and one lower dish) arrangement and reduce cost for platform and structure for receiver. The original Scheffler parabola has been completely redesigned and strengthened.
Furthermore the dish has been split in two half's and modified with flange system for easy transportation / installation.

The parabola is fitted to a strengthened rotating support which itself rests on a strengthened stand and the entire construction is made out of mild steel. The parabolic dish reflects the sunlight by means of rectangular pieces of mirror glass with an optical reflection close to 93%. The sunlight is concentrated onto the round receivers of 40 cm in diameter, at a distance of 5,2 meters from the end of rotating support. A single disk has a maximum output of ~8 kW at 1000 $W/m^2$ solar radiation and can reach temperatures up to 1000° C in the focus.

# 6 Project Progress

After finalizing all aspects of the project, work started in April 2005 with the procurement of materials and the construction of various gigs. All major components were ordered.

In June 2005, manufacturing of the parabola, the rotating support and the stand started in the workshop in Abu Road Taleti .

In October 2005, the layout of the master line and the installation of the dish on roof top were carried out.

Between October 2005 and January 2006, installation of the parabolic concentrators took place, while simultaneously the glass was cut into size and fitted onto the dishes.

From January – April 2006 onwards, various tests with the two different receivers in full sunshine condition took place. .

May 2006 evaluation of Data and preparation of report

# 7 Technology Transfer and Demonstration

WRST is a daughter organisation of Brahma Kumaris organisation and hence its campus in Taleti enjoys plenty of visitors throughout the year.

The Taleti Campus is an ideal place for the dissemination of the renewable energy philosophy. Many people with different backgrounds, such as industrialists and administrators, have already shown interest in the system. There are regular guided tours to the solar steam system and information material is available on site.

# 8 Results and Evaluation

For the evaluation and testing of the solar steam system, various digital metres have been procured. The monitoring system has designed and installed after discussion between Wolfgang Scheffler, B.K. Jayasimha and Golo Pilz

## 8.1 Technical Description

### 8.1.1 Abstract

A manual measuring program was carried out at various sunny days in spring 2006 in order to analyse, evaluate and optimise the solar dish and receivers. As key parameters the water temperature before and after focusing as well as solar radiation have been recorded at a fixed number of preset intervals.

### 8.1.2 Introduction

After the great success of all the previous solar cookers, it was decided to build a $16m^2$ prototype dish in Abu Road Taleti complex. The $16m^2$ Dish profited from the experience gained by all the previous dishes build by us. A measuring program was carried out. The following text should give the reader a detailed description of the agenda and the devices use.

**Procedure:** The Dish mirror surface has been thoroughly cleaned and its seasonal adjustments are optimized and accurate focus of the reflected sun rays onto the receiver (Black painted) is ensured. Direct as well as indirect Solar Radiation is measured by sensors.

Then the test starts with filling the receiver with cold water and focusing the reflector on the front surface of the receiver for a particular preset time span. Weight and Temperature of water before and after focus are noted down along with specific gravity of both water and iron.

These values have been noted down and interpreted in the formula which calculates the THERMIC POWER and EFFICIENCY of the Reflector.

### 8.1.3 The measuring system

The following Standard handheld sensors for temperature and radiation were used for data acquisition:

1. Digital Temperature Meter, Greisinger

2. Spring Balance

3. Solar Radiation Meter, Zenith

4. Stop Watch

5. Funnel

6. Volume Meter

7. Digital infrared distance temperatur Meter, Conrad

**Data acquisition, Manual data collection:**

Data collection of Water temperature, Surface temperature, and solar radiation was basically taken by hand at regular short intervals.

The total global radiation has been measured and by means off mathematical calculation the indirect sunlight has been determined and subsequently subtracted from the total radiation.

The amount of water input had been measured by standard volume meter and the weight of receiver been measured by standard scale.

The results have been noted down and accordingly through calculation the results have been established

**Variables Read.**

1. Solar Radiation (Direct)
2. Solar Radiation (Shaded)
3. Weight of Water
4. Weight of Iron
5. Temperature of water before focus
6. Temperature of water after focus
7. Time Span of Focus
8. Specific Gravity of Water
9. Specific Gravity of Iron (Receiver)

## 8.2 Results

Power = $\frac{\text{Temperature Diff. x Sp. Gravity x weight}}{\text{Time}}$

Efficiency = Actual Power / Theoretical Power

# Test-1: Cavity Receiver

**Thermic Power calculated taking the weight of the (medium) Water only.**

**Power (Water) =** $\mathbf{\frac{11.3 \times 4.186 \times 12}{120}}$

| | |
|---|---|
| Initial Temperature (before focus) | = 33.8 ºC |
| Final Temperature (after focus) | = 45.1 ºC |
| Sp.Gravity of water | = 4.186 |
| Weight of water | = 12 kg |
| Time Span | =120 sec. |
| | **= 4.73 KW** |

**Thermic Power calculated taking the weight of the Receiver only.**

**Power (Iron) =** $\mathbf{\frac{11.3 \times 0.5 \times 48.5}{120}}$

| | |
|---|---|
| Initial Temperature (before focus) | = 33.8 ºC |
| Final Temperature (after fous) | = 45.1 ºC |
| Sp.Gravity of Iron | = 0.5 |
| Weight of Receiver | = 48.5 kg |
| Time Span | = 120 sec. |
| | = **2.28 KW** |

Total Power = Power(water) + Power(Iron)
= **4.73 KW + 2.28 KW**

**Actual Power** = **7.01 KW**

| | | |
|---|---|---|
| Aperture of Reflector | = 16 cos (43.23 + δ/2) | ( δ – Sun Angle ) |
| | = 16 cos ( 43.23 +1.5 ) | |
| | = 11.36 | |

Theoretical Power = Aperture of the Reflector x Radiation
= 11.36 x 1050

Solar Radiation total – 1140 W/Sq mtr

Solar Radiation indirect – 90W/Sq mtr

Solar Radiation direct – 1050W/Sq mtr

**Theoretical Power = 11.93 KW**

**Efficiency = Actual Power / Theoretical Power**

**= 7.01 / 11.93**

**EFFICIENCY OF CAVITY RECEIVER = 58.7 %**

# Test-2: Flat Receiver

**Thermic Power calculated taking the weight of the (medium) Water only.**

$$\textbf{Power(Water)} = \frac{\underline{14.6 \times 4.186 \times 12}}{120}$$

| | |
|---|---|
| Initial Temperature (before focus) | = 37 ºC |
| Final Temperature (after focus) | = 51.6 ºC |
| Sp.Gravity of water | = 4.186 |
| Weight of water | = 12 kg |
| Time Span | = 120 sec. |
| | **= 6.11 KW** |

**Thermic  Power is calculated taking the weight of the Receiver only.**

**Power(Iron)** $= \dfrac{\mathbf{14.6 \times 0.5 \times 23.5}}{\mathbf{120}}$

| | |
|---|---|
| Initial Temperature (before focus) | = 37 ºC |
| Final Temperature (after focus) | = 51.6 ºC |
| Sp.Gravity of Iron | = 0.5 |
| Weight of Receiver | = 23.5 kg |
| Time Span | = 120 sec. |
| | = **1.43 KW** |

Total Power = Power(water) + Power(Iron)
= **6.11 KW +1.43 KW**

**Actual Power =7.54 KW**

Aperture of Reflector = 16 cos (43.23 + δ/2) ( δ – Sun Angle )
= 16 cos ( 43.23 +1.5 )
= 11.36

Theoretical Power = Aperture of the Reflector x Radiation
= 11.36 x 1065

Solar Radiation total – 1125 W/Sq mtr

Solar Radiation indirect – 60 W/Sq mtr

Solar Radiation direct – 1065 W/Sq mtr

**Theoretical Power = 12.09 KW**

**Efficiency = Actual Power / Theoretical Power**

**=7.54 / 12.09**

**EFFICIENCY OF FLAT RECEIVER = 62.3 %**

# 9 Discussion / Conclusion

It has been found that in overall the $16m^2$ Scheffler dish is a very viable and practical dish.
Despite its increased dish size, over all construction was similar easy to handle as in the previous $12m^2$ dish model.
All material is locally available and construction of jigs and platforms has also been similar easy to previous dishes.

In this connection we have to mention specially the split dish design. The 16m2 dish has been split in to two half's by means of flanges. We found this method easy and practically and it simplified transportation and erection to a great extend. This can be adapted for all future dishes of this size.
The mechanical stability and rigid ness of the $16m^2$ dish stand and rotating support dish is excellent and fulfils all promises.
The glass mirrors have been fitted/ glued for first time with non - acid silicon, directly on the aluminium bars (see photos). The experience is so far quite good and if a long terms bonding is achieved, this seems to be a good and easy method.

The overall output of the dish is per its expectations. The dish has an overall size of $16m^2$ and an aperture size of 11,36 $m^2$. The measured output at a direct solar radiation of 1050 W was as per the size of the aperture of the dish and can reach up to 8kw (thermal).
The efficiency of the dish varied around 58 % - 62 % as per the receiver tested. The focal point had a size of 45 centimetres.

This focal point can be improved by a more accurate construction and improved fitting of the glass mirrors. In the later development of the $16m^2$ dish by BK Jayasimha a focal point of 35 cm could be achieved. By this also the efficiency has been increased further and losses at focal point be minimised.

In the practical testing the cavity type of receiver has been tested aging the standard flat receiver and it was found that the efficiency in the flat type receiver at 62.3 % was higher than in the cavity type receiver at 58.7 %.

The reason maybe found in:

A: Higher metal volume

B: Bigger surface areas, more losses

In a later development Wolfgang Scheffler has developed an improved cavity receiver with smaller surface area / lesser water contents. (See photo page 12.) It seems further tests in the area of receiver have to bee carried out and there is quite some more potential for further improvement.

In general we can say that it seem that the $16m^2$ dish is a further valuable improvement of the SCHEFFLER dish series and definite fit for steam generating systems for institutional cooking and industrial steam requirements. Here the $16m^2$ dish can be a more cost efficient model than the previous dishes to produce low-pressure saturated steam.

Mt. Abu 12.5.2006

Golo Pilz
Project Coordinator

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# 11 Appendix

## I Photo