IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Experimental Investigation on Solar Water Heater using Scheffler Reflector

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ABSTRACT

Energy storage is one of the key technologies for energy conservation and therefore is of great practical importance. One of its main advantages is that it is best suited for solar thermal applications. This study deals with a comprehensive discussion of the selection of materials and evaluation of the reading of a redesigned scheffler reflector. In addition, some criteria, techniques, checklists on the selection, implementation and operation of scheffler reflector are provided for the use of energy engineers.

***Keywords*: Scheffler Reflector, Reflector dish, Receiver, Dish stand, Piping and Insulation, Instrumentation and Safety Mechanism, Heat Storage System.**

I. INTRODUCTION

In the 1980s, Wolfgang Scheffler began developing a solar "parabolic fix focus reflector", an alternative cooking method which did not relay on open fires. The first prototype was built in North Kenya using methods appropriate for the developing nation and Scheffler further developed construction methods in India with local craftsmen. While other solar cookers had been developed previously, the Scheffler reflector offered a unique advantage. Since the reflective surface was not rigid, it allowed for the focal point of the reflector to remain constant, unlike many reflectors at the time. Using the axis of rotation of the Earth, the Scheffler reflector also only needed to track the sun across the sky on one axis. Other cookers were less effective, for some, the sunlight was not concentrated (e.g. Box cookers), while others required multiple axes for maximum efficiency (e.g. Photovoltaic). While many other solar cooking technologies had not been well adopted, the Scheffler reflector was well promoted and adopted. A reason could be the ease of construction, the easy access to materials, the co-construction with people in developing nations, and an open-source model. By 2004, there were approximately 750 reflectors in 21 countries.

However, since there is no central registration, the actual number of Schefflers is unknown, but most likely there are over 1000 Schefflers currently. In 2009, a number of students working with Peter Schwartz examined different solar cooking technologies appropriate for developing nations.

They rest explored a parabolic solar trough since it had relatively simple geometry and had single-axis tracking. However, upon testing, the lack of rigidity caused in torsion problems such that while one end was rotated, the other end remained stationary. The component that was easiest to reduce in cost and time investment was the frame. Using electrical metallic tubing (EMT), the cost of the materials for the frame was reduced to 700rs with a construction time of 2 hours. Investigating methods to re-create the reflective parabolic structure originally

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

made with a complex GI sheet matrix and polished mirror has been and continues to be much more challenging. The rest method was to create a male mold and pull of a reflective surface. Due to complications, the team decided to lay GI sheeting down as a reflective surface which proved sufficient. Heat from sun's rays can be harnessed to provide heat to a variety of applications. But in general, sun's rays are too diffuse to be of direct use in these applications. So solar concentrators are used to collect and concentrate sun's rays to heat up a working fluid to the required temperature.

II. LITERATURE REVIEW

Mangesh R Phate, et.al., [04] has done an experimental analysis of $2.7m^2$ scheffler reflector and formation of a model, this study is done in order to maximize its effectiveness, this system can be used only for household cooking.Rupesh. J. Patil, et.al., has done an comparison of performance analysis of scheffler reflector and model formation, this study concludes that these types of innovative solar concentrators can open new landmarks in decentralized solar based systems , this system finds its application in household cooking.

Yogesh R. Suple, et.al., [05] Design and fabrication of manually track parabolic solar disc for in-house cooking. In this fabrication work a primary reflecting parabolic surface concentrates the solar radiation on it and reelects them on to the secondary reflectors. This secondary reflectors then incident radiation at the point of interest, thus generated heat can be used for cooking purpose. This system mainly finds its application in household cooking.

S.K.Sharma, [01] has done an performance analysis of scheffler reflector using approximate generalized model. This system mainly finds its application in household cooking. Small systems use a well insulated solid iron-block which is heated to about 100^0 c at the focal-point which can be used for cooking for a family.

Robert L. Jeffcoat, et.al., [02] Andrew Jackson et.al., design and fabrication of solar cooking stove. The cooking unit contains the phase change material (PCM) that can store as well as transfer energy to the cooking surface. The reflector is a parabolic mirror that helps focus the sunlight onto the cooking unit. This system mainly finds its application in household cooking.

III. ABOUT SCHEFFLER DISH TECHNOLOGY

Scheffler dish is a small lateral section of a paraboloid, which concentrates sun's radiation over a fixed focus, with an automatic single axis tracking.

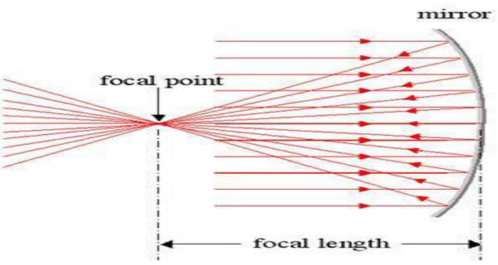

Fig.1 Focal point on concave mirror

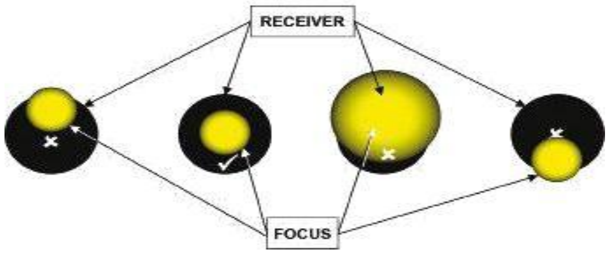

Fig.2 Focus point

3.1. Underlying principle

Scheffler dish is made of number of flat shaped mirrors or reflective films which are mounted on a structural frame. The dish rotates about north-south axis parallel to earth's axis to track the sun's movement. The axis of

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

rotation passes through the centre of gravity of the reflector and that's how the reflector al-ways maintains its gravitational equilibrium. The scheffler reflector also performs change in inclination angle while staying directed to sun, in order to obtain sharp focal point. Focus is fixed at distance of focal length of the parabolic along the axis of the paraboloid. Receiver at a fixed location captures the concentrated heat and transfers it to water/thermic fluid to generate hot water/hot thermic fluid or high pressure steam.

3.2. How is this Physics?

While it may be contested that this is not conventional physics, we assert that physics underlies every aspect of what we are doing, and is informed by this knowledge and its implementation. The science and engineering behind the Scheffler Reflector is not random. It requires understanding of how the sun moves throughout a day and year. Using an axis parabolic, axed focus is achieved. Also important to this project is the technology it might provide for people in developing nations. It enables me to use Physics for a directly humanitarian end. My physics background was used as a tool belt to manipulate technology and empower myself to create sustainable technology.

3.3. Frame Design

The Scheffler's reflector frame was originally designed out of aluminium and steel. Polycarbonate ribbing and aluminium was used for the intricate matrix upon which reflective aluminium strips were taped. This was the next aspect that was considered for redesign. By changing this aspect, we were hoping to greatly minimize costs through design. In order to conceptualize the re-design, an implicit understanding of the purpose of the frame and what it interacted with was important. The frame needed to incorporate something sturdy enough such that the dish would not blow away and be made of a material strong enough to withstand most environments (water, wind, rust, etc). We also made sure that any material used was something that could be easily found anywhere in the world. Since our dish was independently constructed and the focus of our re-design, our new frame needed to be able to accommodate this shape.

3.4. Dish Design

The original Scheffler's reflector construction manual uses a complex matrix to maintain a parabolic shape appropriate for the reflector and a hoop to provide additional support for the dish. One design required the GI sheets to be riveted to the gridding. Currently, the reflective surface is attached to the frame with double sided sticky tape. Instead of creating a parabolic shape within the frame, alternative methods were designed which might remove the complex gridding holding the reflective dish. The dish is the essential aspect of the concentrator, an o-axis parabolic shape that could focus the light coming from the sun onto a smaller focal point, the cooking surface. It also needs to interface well with the structure supporting the dish. It has to be lightweight enough to rotate with a small motor and sturdy enough to attach to the frame. It is planned to redesign the dish, so it could be made independently of the concentrator; while recognizing this was the most crucial aspect and the rest of the reflector would be designed around it. Research began on alternative materials for the reflective part of the dish that are easily available yet much less expensive. a thin iron strip welded which has aluminum

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

sputtered onto it. It is the same material found on the frame, freely found in trash worldwide. Moving towards a sun direction to tilted as a standard for the reflective material, alternative methods were sought for dish construction that did not require such a complex grid. Research led to the idea of pressing a dish composed of berglass, resin, polished mirror and GI sheet. A sheet of this composition is plated on upper surface of the frame made which is fitted by drilled screw.

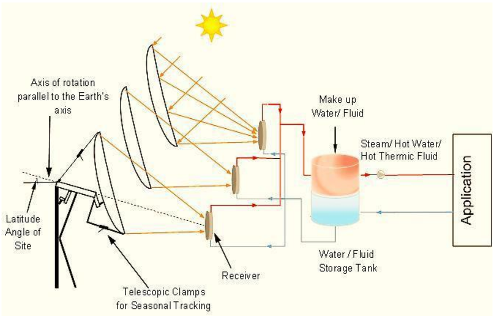

Fig.3 Scheffler Reflector

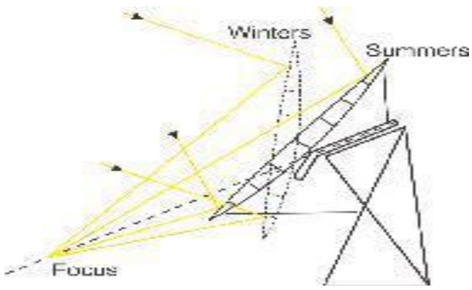

Fig.4 Scheffler reflector-Balance of System (North–South)

IV. SCHEFFLER'S REFLECTOR

In Scheffler Dish, with sun's movement from east to west, the dish continuously turns about an axis, tracking sun's radiation and maintaining the focus of collector on the receiver tube.

The axis of daily rotation is located exactly in north-south-direction, parallel to earth axis and runs through the center of gravity of the Scheffler reflector. Seasonal Tracking (North – South)(refer fig-5) is done to change position of Reflector in N-S direction depending on position of the sun. Mechanism providing lever and screws are mostly used, however new system incorporate linear actuators. Very slow Seasonal Movement, i.e. 23.5° in three months. Needs adjustment in 3-4 days in India, dishes are more vertical relative to ground during winters and flat in summers. Heat from sun's rays can be harnessed to provide heat to a variety of applications. But in general, sun's rays are too diffuse to be of direct use in these applications. So solar concentrators are used to collect and concentrate sun's rays to heat up a working fluid to the required temperature.

4.1. What is a Scheffler Dish ?

A Scheffler's reflector is a small lateral section of a paraboloid (Figure 3), which concentrates sun's radiation over a fixed focus.

4.2. Working Principle

The Scheffler dish system works on the following principles:

1) The Elliptic reflective dish turns about north-south axis parallel to earth's axis, tracking by manual moment of disc, the sun's movement from morning (East) to evening (West), and maintaining gravitational equilibrium of the dish.

2) The Elliptic reflector also performs change in inclination angle while staying directed to sun, in order to obtain sharp focal point.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

3) Focus lies at the axis of rotation. It remains at a fixed position, where concentrated heat is captured and transferred to water through the receiver to generate hot water

or high pres-sure steam

4) Water from header pipe passes to receiver. At the receiver, the hot water or steam generated water and collected in the header pipe flows to the end use application.

5) The receiving subsystem collects solar radiation in the solar field from parabola shaped reflecting collectors and transfers it to working fluid such as water or oil.

6) The circulation subsystem carries fluid and transfers the heat received by it to the end use application. Fluid has to circulate in the system at a certain rate to quickly and efficiently transfer the received heat from solar field to end use application.

V. INTERPRETING SYSTEM SPECIFICATIONS

A system to generate heat from Scheffler reflector consists of a number of subsystems and components. However, it is easy to see what the entire system does by specifying just a few basic parameters.

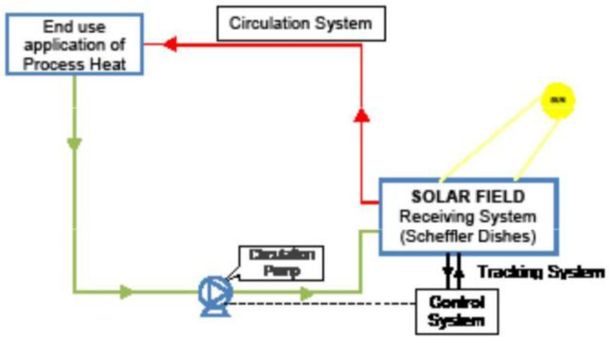

Fig.5 Interpreting Subsystem Specifications

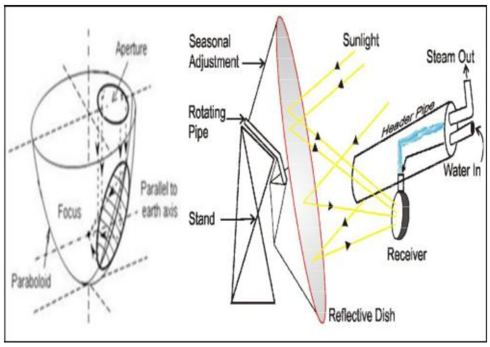

Fig.6 Scheffler reflector system working

As seen in Figure.5, the entire system can be thought of as made up of subsystems each performing a core functions.The receiving subsystem collects solar radiation in the solar field from parabola shaped reflecting collectors and transfers it to working fluid such as water or oil. It maximizes the solar energy captured by moving solar collectors towards the sun for complete day. By manual tilting of the dish towards sun as it changes its position during the seasons. The circulation subsystem carries fluid and transfers the heat received by it to the end use application. Fluid has to circulate in the system at a certain rate to quickly and efficiently transfer the received heat from solar field to end use application. Circulation subsystem has a number of components such as pipes, pumps and valves to control fluid flow and temperature. The thermal storage subsystem is a part of the circulation system. It extracts heat from the circulating fluid when the temperature becomes too high. When the temperature is too low, it supplies stored heat to the fluid. Finally, the control mechanism is the brain behind tracking and circulation system. It sends signals to these systems to control the tracking of the receiver and the pressure and flow rate of the circulating fluid (refer figure-6).

The table below shows a sample specification that describes each subsystem in more detail. The values provided are examples only. Please note that the format for technical specifications will vary by manufacturer.

International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 07, July 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

TABLE-1

DESCRIPTION

S.No	System Description	Description
1	Collector System	Collects and suns heat at a fixed focus point
2	Scheffler dish reflecting surface	Water from header pipe placed above the receiver, which enter the receiver and gets convert to steam due to high temperature.
3	Receiver System	Collects the heat and converts into hot water.

TABLE-2

MODULE RATING

S.no	System Module	Rating
1	Surface Area of Collector	16 m^2
2	Aperture Area of Collector	11.65 m^2(Average)
3	Dimension & Shape	Elliptical
4	Reflectivity	92 %
5	Thermal output Capacity	5.5 KW
6	Thermal Efficiency	42 % (approx.)
7	Single Dish Stand and Receiver	1m^2

VI. SCHEFFLER DISH

Arc glass of parabolic shaped reflector, made up of solar grade reflecting mirrors.

6.1. Receiver

1. It is placed at the focus of the Dish, which absorbs concentrated sunlight to heat up water to generate steam.
2. Receiver works on thermosyphon principle, in which cold water sinks down from header to receiver, and hot water/steam comes up (lower relative density) and is collected back in header pipe for storage.

6.2. Main parts

The main parts of the parabolic dish are listed below:

1. Dish frame assembly
2. Main rotating system
3. Reflector stand
4. G.I. Sheet covering
5. Mirror as Reflector
6. Receiver standing setup

6.3. Focus point

The focus point is corrected every time for getting an efficient output so maximum amount of heat is get. This is shown by figure [2].

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

6.4. Reflector

The reflector is the most important part of the solar cooker. If the reflector is not made exactly, the focus will not be correct and the cooker will not work properly, the food will take much longer to cook, and the cooker may even be unusable.

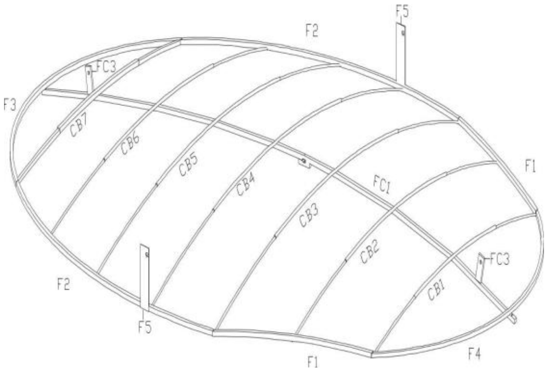

Fig.7 Frame

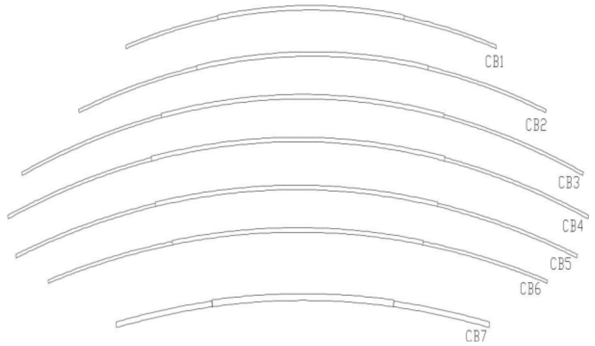

Fig.8 Crossbar

6.5. Design of Frame

The design thinking/ Design theory series seeks to develop vital conversations to help designers and researches serve business, industries and public sector for positive social and economic outcomes. This series explores strategic design as an opportunity to create value through innovative products and services. This design is done on the previous data's and done in the auto cad software.

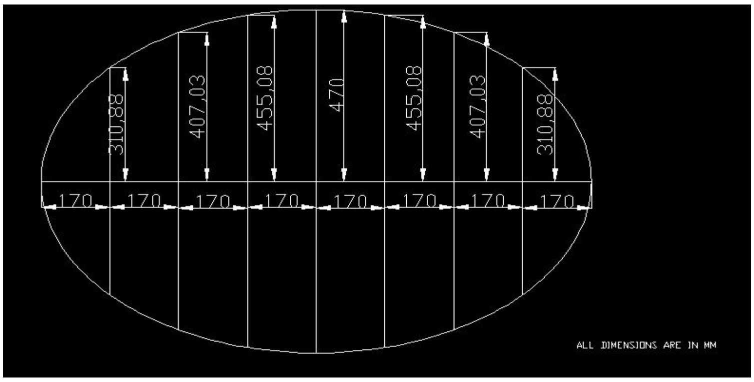

Fig.9 Design of frame

VII. SPECIFICATION OF MATERIAL

7.1. Dish

1) Size of the concentrators : $1m^2$

2) Reflective material : 2-3mm thick mirror

3) Reflectivity of the mirror : more than 90%

7.2. Receiver

1) Type : Tube Type Circular

2) Material : High Grade Copper Tube

3) Working pressure : $10kg/cm^2$

4) Design pressure : $15kg/cm^2$

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

7.3. Water inlet tube Capacity: 80 litre/day.

TABLE-3 SPECIFICATION

S.No	Components	Material
1	Glass	Mirror Glass
2	Receiver	Copper Tube
3	Metal	Tubular Steel, 3mm Flat Plate 36576mm Long.
4	Bolt	6mm Φ, 76.2mm Bolt & Nut
5	Glue	Ana bond Glue

VIII. READING

TABLE-4 MEAN TEMPERATURE AT TIRUCHIRAPALLI

S.No.	Month	Mean temperature of the month in (^{o}c)
1	January	25.09
2	February	26.01
3	March	28.53
4	April.	30.28
5	May	31.95
6	June	31.73
7	July	31.74
8	August	30.00
9	September	30.50
10	October	28.58
11	November	26.21
12	December	25.98

TABLE-5 SYSTEM READING OF WATER INLET

S.No	Time	Temperature (^{o}c)
1	9:00	31
2	10:00	31
3	11:00	32
4	12:00	35
5	13:00	35
6	14:00	36
7	15:00	34
8	16:00	34
9	17:00	33

International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 07, July 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

TABLE-6

DAILY OBSERVATION REPORT --- Log Book (Daily Monitoring)

S.no	Time	Temperature (^{o}c)	Temperature (^{o}c)	Temperature (^{o}c)	Temperature (^{o}c)
1	9:00	44	43	45	44
2	10:00	48	47	48	46
3	11:00	49	50	49	48
4	12:00	53	54	52	50
5	13:00	54	55	53	52
6	14:00	53	53	54	53
7	15:00	52	51	52	50
8	16:00	51	50	50	49
9	17:00	48	49	48	47

TABLE-7

MORNING SYSTEM READINGS-- Log Book (Weekly Monitoring)

S.no	Month	Temperature (^{o}c)
1	Feb 13	37
2	Feb 20	41
3	Feb 27	43
4	March 6	48
5	March 13	45
6	March 20	44

IX. WORKING PROCESS

9.1. Material Selection

Material selection is a step in the process of designing any physical object. In the context of product design, the main goal of material selection is to minimize cost while meeting product performance goals. Systematic selection of the best material for a given application begins with properties and costs of the materials. Systematic selection for applications requiring multiple criteria is more complex.

Fig.10 GI Sheet

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Fig.11 Cylinder and iron rod

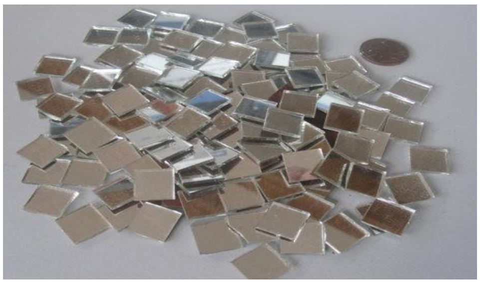

Fig.12 Pieces of mirror

Fig.13 Iron strips

9.2. Cutting Proce

Oxy-fuel welding (commonly called oxyacetylene welding, oxy welding, or gas welding in the U.S.) and oxy-fuel cutting are processes that use fuel gases and oxygen to weld and cut metals figure[14], respectively. According to the dimensions of Scheffler reflector the 3mm Flat plate material is cutted.figure[15

Fig.14 Gas Cutting Process

Fig.15 Metal cutting process

9.3. Shaping Process

In shaping, the tool is brought into position with the work piece. The tool then repeatedly moves in a straight line while the work piece is incrementally fed into the line of motion of the tool, this produces a flat, smooth, and sculpted surface. For shaped pieces the tool reciprocates across the stationary work piece. The tools are usually tilted or lifted after each stroke. This is done hydraulically or manually figure[16] in order to prevent the too surface from chipping when the work piece travels back across.

Fig.16 shaping strips

Fig.17 Bended material

9.4. Support Rod

After the bended flat plates are welded, the bended flat plates are holded by using support rod to attach the flat plate on the top side.

Fig.18 Support Rod (transverse& longitudinal)

Fig.19 Welding frame

9.5. Welding

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that is usually stronger than the base material. Pressure may also be used in conjunction with heat, or by itself, to produce a weld. Although less

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

common, there are also solid state welding processes such as friction welding or shielded active gas welding in which metal does not melt.(figure 19)

Fig.20 completed frame

Fig.21 GI sheet covered

9.6. Dish stand

The basic framework of the dish stand is a steel structure. The structure is designed to withstand wind speed in operating conditions as well as in parked stage as per the applicable structural design code. The overall system rests on a civil foundation. The rotary support, counter weight and other equipments like an electric motor for tracking are attached on the Dish stand.

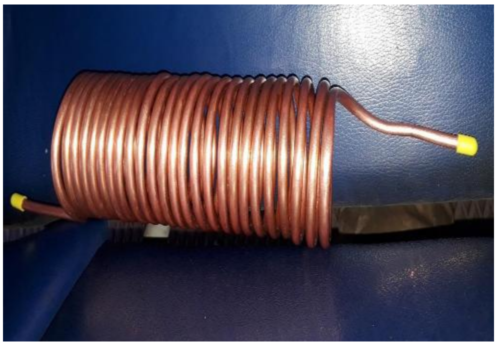

Fig.22 receiver

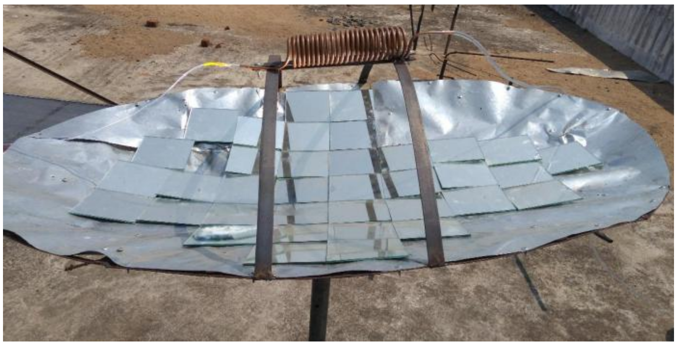

Fig.23 side view (finished setup)

X. INSTRUCTION FOR USE

10.1 . Positioning

1) Choose a place where no shadows disturb your heating over the day.
2) Position the Receiver North-South with the help of a compass. For the Northern Hemisphere: The Heating Place has to be in the North and the Reflector in the South. For the Southern Hemisphere: The Heating Place has to be in the South and the Reflector in the North.
3) Check that there are no shadows disturbing over the day.
4) Put the solar Receiver horizontally. If the ground isn’t horizontal, level the Receiver by adjusting the front adjustable support and the second foot.
5) If possible, fix the Receiver to the ground, so it can not be thrown over by strong wind.

10.2. Security

1) Check that your Receiver is standing firmly on the ground.
2) There shouldn’t be any inflammable material in a perimeter of about 1m around the Focusing Circle.
3) Do not look directly into concentrated light, e.g. the focus on the shutter; Use sunglasses!

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

4) Close the shutter always before putting a pot on the heating circle and before taking it away.

10.3. Setting a good focus

1. Spin the reflector around the rotation axis towards the direction of the sunlight.

2) Seasonal adjustment: loosen the two Seasonal Adjustments and change the inclination of the reflector around the lateral axis until the reflected light falls on the closed shutter. Now tighten one telescope pole to fix one end of the reflector.

3) keep on moving the loose end of the reflector easily up and down until you reach the smallest light spot possible. Now tighten the second bolt.

4) Then loosen the fixed bolt on the other side so you can move this side setup

10.4. Heating

1. It is best to use copper tube out of a material with high heat conductivity and with a thick base, to prevent burning the food in the centre, where the heat is strongest.

2. The base of the pan should be black on the outside to capture the maximum of heat. Use heat resistant black paint or blacken the bottom of the pot on fire.

3. Heat regulation while heating can be done by closing the focusing circle partially with the shutter.

11. ADVANTAGES OF SOLAR ENERGY

11.1. Renewable Energy Source

Among all the benefits of solar panels, the most important thing is that solar energy is a truly renewable energy source. It can be harnessed in all areas of the world and is available every day. We cannot run out of solar energy, unlike some of the other sources of energy. Solar energy will be accessible as long as we have the sun; therefore sunlight will be available to us for at least 5 billion years when according to scientists the sun is going to die.

11.2. Reduces Electricity Bills

Since you will be meeting some of your energy needs with the electricity your solar system has generated, your energy bills will drop. How much you save on your bill will be dependent on the size of the solar system and your electricity or heat usage. Moreover, not only will you be saving on the electricity bill, but if you generate more electricity than you use, the surplus will be exported back to the grid and you will receive bonus payments for that amount (considering that your solar panel system is connected to the grid). Savings can further grow if you sell excess electricity at high rates during the day and then buy electricity from the grid during the evening when the rates are lower.

11.3. Diverse Applications

Solar energy can be used for diverse purposes. You can generate electricity or heat (solar thermal). Solar energy can be used to produce electricity in areas without access to the energy grid, to distill water in regions with limited clean water supplies and to power satellites in space. Solar energy can also be integrated into the materials used for buildings. Not long ago Sharp introduced transparent solar energy windows.

11.4. Low Maintenance Costs

Solar energy systems generally don't require a lot of maintenance. You only need to keep them relatively clean, so cleaning them a couple of times per year will do the job. Most reliable solar panel manufacturers give 20-25 years warranty. Also, as there are no moving parts, there is no wear and tear. The inverter is usually the only part that needs to changed after 5-10 years because it is continuously working to convert solar energy into electricity and heat. So, after covering the initial cost of the solar system, you can expect very little spending on maintenance and repair work.

11.5. Technology Development

Technology in the solar power industry is constantly advancing and improvements will intensify in the future. Innovations in quantum physics and nanotechnology can potentially increase the effectiveness of solar panels and double, or even triple, the electrical input of the solar power systems.

XII. DISADVANTAGES

12.1. Cost

The initial cost of purchasing a solar system is fairly high. Although the UK government has introduced some schemes for encouraging the adoption of renewable energy sources, for example, the Feed-in Tariff, you still have to cover the upfront costs. This includes paying for solar panels, inverter, batteries, wiring and for the installation. Nevertheless, solar technologies are constantly developing, so it is safe to assume that prices will go down in the future.

12.2. Weather Dependent

Although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar system drops. Solar panels are dependent on sunlight to effectively gather solar energy. Therefore, a few cloudy, rainy days can have a noticeable effect on the energy system. You should also take into account that solar energy cannot be collected during the night.

12.3 Solar Energy Storage Is Expensive

Solar energy has to be used right away, or it can be stored in large batteries. These batteries, used in off-the-grid solar systems, can be charged during the day so that the energy is used at night. This is a good solution for using solar energy all day long but it is also quite expensive. In most cases, it is smarter to just use solar energy during the day and take energy from the grid during the night (you can only do this if your system is connected to the grid). Luckily our energy demand is usually higher during the day so we can meet most of it with solar energy.

12.4 Uses a Lot of Space

The more electricity you want to produce, the more solar panels you will need because you want to collect as much sunlight as possible. Solar panels require a lot of space and some roofs are not big enough to fit the number of solar panels that you would like to have. An alternative is to install some of the panels in your yard but they need to have access to sunlight. Anyways, If you don't have the space for all the panels that you wanted, you can just get a fewer and they will still be satisfying some of your energy needs.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

12.5 Associated with Pollution

Although pollution related to solar energy systems is far less compared to other sources of energy, solar energy can be associated with pollution. Transportation and installation of solar systems have been associated with the emission of greenhouse gases. There are also some toxic materials and hazardous products used during the manufacturing process of solar photovoltaic, which can indirectly affect the environment. Nevertheless, solar energy pollutes far less than the other alternative energy sources.

XIII. APPLICATIONS

Some of the common applications where Scheffler systems are used are:

1. Boiler feed water preheating
2. Washing in laundries
3. Oil heating for cooking or industrial applications
4. Milk pasteurization
5. Steam cooking

13.1. End-use application

Scheffler dish is used for the low-medium process heat applications. This dish can attain the temperature up to 50-100°C as per the specific requirements in industries, commercial & residential complexes, religious places, etc. A typical 16 m2Scheffler Dish has thermal capacity equivalent to 30,000 Kcal/ day to 35,000 Kcal/day depending on the clear sunny day.

XIV. CONCLUSION

Using the Scheffler Reflector as a model, we have been able to reduce the cost and manufacturing time of certain aspects significantly. Before our group had worked on it, the Scheffler was composed of a frame and reflective dish. Our group has constructed a manual tracking mechanism, which was used with our Scheffler to heat. Additionally, there has been an attempt at constructing a dish. The cost of the frame, and manual tracker, has been reduced to less than Rs 5000, while the time of building these elements has been shortened to approximately two days for our group.

Solar power is an immense source of directly useable energy and ultimately creates other energy resources: biomass, wind, and hydropower and wave energy.

Most of the Earth's surface receives sufficient solar energy to permit low-grade heating of water and buildings, although there are large variations with latitude and season. At low latitudes, simple mirror devices can concentrate solar energy sufficiently for cooking and even for driving steam turbines.

The energy of light shifts electrons in some semiconducting materials. This photovoltaic effect is capable of large-scale electricity generation. However, the present low efficiency of solar PV cells demands very large areas to supply electricity demands.

Direct use of solar energy is the only renewable means capable of ultimately supplanting current global energy supply from non-renewable sources, but at the expense of a land area of at least half a million km.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

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