CHARACTERIZATION OF REFLECTORS AND ABSORBER COATINGS FOR SOLAR CONCENTRATORS

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Abstract

Solar energy has great significance specifically for a country like India which is struggling to meet its energy demand. The project includes development of a test chamber for simulating different conditions of weathering and testing of ordinary glass mirrors and solar mirrors to identify the effect of weathering. This project will help in identifying the appropriate reflector and absorber coating for different locations and also in defining the maintenance schedule. This project is an attempt for testing of reflector and absorber coating which will help in material selection by identifying the merit and demerits of each material helpful in defining the replacement or maintenance cycle. New types of selective coatings and effect of different conditions on performance of reflectors and coatings have been discussed in this paper.

Key Words-*Solar Energy, Test chamber, Reflector, Absorber coating*

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1. INTRODUCTION

Solar energy is a very large, inexhaustible bit dilute source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 10^{11} MW which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on a counting basis. This makes it one of the most promising of the unconventional energy sources. Solar concentrator is a device that allows the collection of sunlight from a large area and focusing it on a smaller receiver or exit. A conceptual representation of a solar concentrator used in harnessing the power from the sun to generate electricity is shown in Figure 1.

The material used to fabricate the concentrator varies depending on the usage. For solar thermal, most of the concentrators are made from mirrors while for the BIPV system, the concentrator is either made of glass or transparent plastic. These materials are far cheaper than the PV material. The cost per unit area of a solar concentrator is therefore much cheaper than the cost per unit area of a PV material. By introducing this concentrator, not only the same amount of energy could be collected from the sun, the total cost of the solar cell could also be reduced.

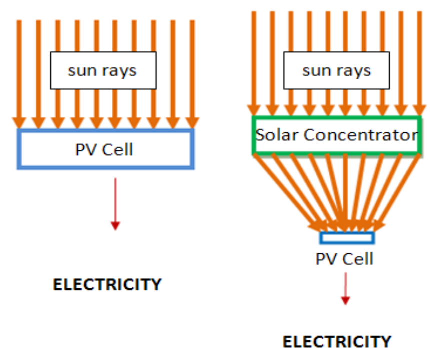


Fig -1: Generating electricity from the sun, with and without a solar concentrator.

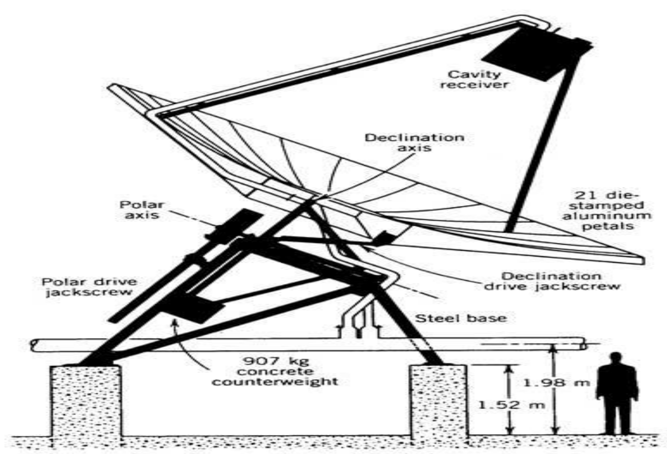


Fig -2: Solar Concentrator

1.1 Types of Solar Concentrator

1. Parabolic Concentrator
2. Hyperboloid Concentrator
3. Fresnel Lens Concentrator
4. Compound Parabolic Concentrator (CPC)
5. Dielectric Totally Internally Reflecting Concentrator (DTIRC)
6. Flat High Concentration Devices
7. Quantum Dot Concentrator (QDC)

2. DESIGN OF ACCELERATED WEATHERING CHAMBER.

2.1 Design of Chamber

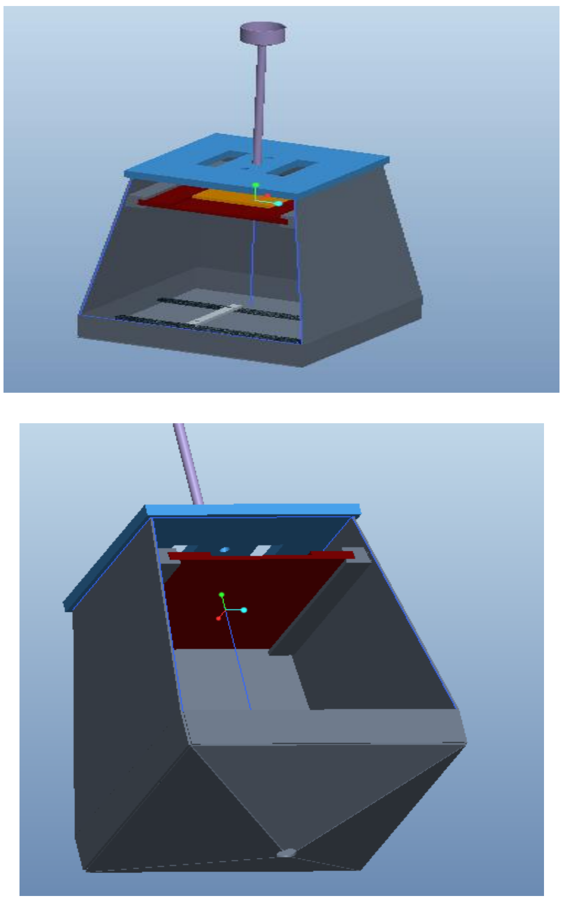


Fig -3: Pro-E Design of accelerated weathering chamber

2.1.1 Features

2.1.1.1 Cover plate

1) The cover plate consists of the heating and spraying arrangement with two heaters and water spray nozzles and one sand spray nozzle.
2) The cover plate is made up of insulating material with slots for the heating and spraying elements.

2.1.1.2 Heating Element and Sprays

1) The heating element is a finned air heater as it provides required heating.
2) The temperature of the heater can be controlled by using a thermostat.
3) The size of the finned heater: 160x60 mm.
4) Diameter of the holes provided: 20 mm and length greater than the heater thickness.
5) Metal nozzles (usually mild steel) are provided for both the sprays. The length of the nozzles is more than the thickness of the heating element.

2.1.1.3 Chamber

1) The walls of the chamber are insulated from the inside for creating ambient conditions.
2) The chamber is given slope such that the bottom square portion is larger than the upper portion.
3) A glass cover is provided as the opening for the chamber.

2.1.1.4 Drain

1) Drain hole for the exit of water and also contains a concentric pipe entering through it for the cooling of the rear side of the plate.

Advantages:

1) The nozzles are arranged such that the central portion of the plate is affected which is usually favoured while further testing of the test plate.
2) The top cover plate is made up of insulating material for safety.
3) The length of the nozzle is longer such that the water or the sand is not sprayed on the heating element.
4) A thermostat is provided for regulating the temperature of the heating element.

2.2 Specifications

2.2.1 Heater:

Type: Air Heater (Coil wire in Ceramic)
Voltage: 230V
Power: 500W
Temperature Range: Up to 200^{o} C

Fig -4: Heater images

2.2.2 Nozzles: Water Nozzle (Brass)

Fig -5: Water nozzle

2.3 Fabrication

2.3.1 Required Raw Material

Mild Steel Sheet-6ft x 4ft
Thickness-3mm

2.3.2 Fabrication of the Chamber

The setup for the weathering chamber was manufactured at SKNCOE workshop. The workshop staff helped in some of the complex operations.

Fig -6: Student performing welding operation

Fig -7: Fabricating the chamber

3. REFLECTIVITY MEASUREMENT METHODS

3.1 Pyranometer

A **Pyranometer** is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square) from a field of view of 180 degrees. The solar radiation spectrum extends approximately from 300 to 2,800 nm. Pyranometer usually cover that spectrum with a spectral sensitivity that is as “flat” as possible.

Advantages:

1) Portable and inexpensive.
2) Applies equally well curved surfaces.
3) Low temperature response, which is an advantage when working under extreme climate conditions.
4) Low non-linearity.

Restrictions in measurement:

1) The sky must be clear, particularly around the sun.
2) The spectral distribution of incident solar irradiance (Ii) and the incidence angle (θ) of the solar beam both vary with hour of day and day of year.

Fig -8: A Pyranometer

4. ABSORBER COATINGS

4.1 Sparc Coating

1) SPARC is an anti-reflective coating especially developed for solar applications.
2) SPARC is a single-side coating deposited on extra clear patterned glasses Solite and Solatex during the tempering process.
3) Being single-sided, SPARC minimizes the reflection at the glass/air interface without affecting the excellent adhesion between the glass and the interlayer used in laminating photovoltaic modules.
1) Transmission increase (%): Up to 2.4% At normal Incidence
2) Energy output increase (%): Up to 5% In actual Conditions (kWh)

4) Tests Cleared: i) Damped Heat ii) Thermal Cycle iii) Climatic SO2 iv) Salt Spray

4.2 Sun Mirox T

1) SUN MIROXTM THIN is an extra clear extra thin high reflectivity mirror perfectly suited for lamination purposes and use in parabolic dish, parabolic trough collectors, CSP or CPV.
2) Once laminated with an appropriate adhesive onto a support material the mirror is perfectly well protected and shows a very high chemical and mechanical durability.
3) In order to minimize its environmental impact before, during and after service, SUN MIROXTM THIN is copper-free and lead-free.

4.2.1 Thermal Characteristics

1) Hemispherical emissivity: 0.84(Between -18°C and 66°C)
2) Expansion coefficient: 9 (EN572between 20°C and 300°C)
3) Specific heat (J/kg/K): 720
4) Thermal conductivity (W/m/K):1
5) Softening point (°C): 722
6) Annealing point (°C): 552
7) Strain point (°C) : 500

4.3 Organic Coatings

1) Pencil hardness: 3H to 5H
2) Solvent resistance: 100+ acetone rubs w/o effect
3) Tape adhesion: no loss after 30 minutes boiling water

4.3.1 Advantages:

1) New Technology
2) Low Temperature
3) Heavy Metal Free

4.4 Almeco Tinox Solar Coatings

1) TiNOX is an energy trap.
2) Highly selective blue TiNOX energy absorber coatings take up a lot of energy -- some **95% of incident solar radiation** -- and convert it into heat energy.
3) Conventional absorbers lose a large part of that energy as heat radiation. In contrast, TiNOX energy coatings have an extremely low thermal emissivity of less than 4% in the infrared range to prevent such heat losses.
4) Once the energy has been converted into heat, it stays trapped within the TiNOX absorber.
5) The high performance of the absorber layer therefore requires the greatest possible degree of absorption within the solar radiation range and the lowest possible degree of emissivity in the heat radiation range.
6) TiNOX energy fulfils this requirement ideally:

Solar absorption α= 95%
Thermal emissivity ε < 4%

5. ACCELERATED CHAMBER TESTING

5.1 Sand Abrasion Testing

1) In this test sand is sprayed in ppm on the surface of the plate with the help of pump.
2) Different types of sand were used since plate can be used at any location in the world.
3) In our case the sand is made to fall vertically downwards from a particular height of 1.5-2m.

5.1.1 Results

1) Damage caused by windblown sand is proportional to the particle momentum.
2) Cumulative damage to surfaces is proportional to the sum of damage caused at certain wind velocities multiplied by the infliction time.
3) Properties influenced by sand damage:
   i) Absorptivity α, Reflection ρ, transmission τ
   ii) Roughness R_a, R_z, diffusion d
   iii) Wetting/contact angle α, dirt-repellent
   iv) Pitting has a strong influence on the wettability of the surface and thus on dirt accumulation and washing processes.

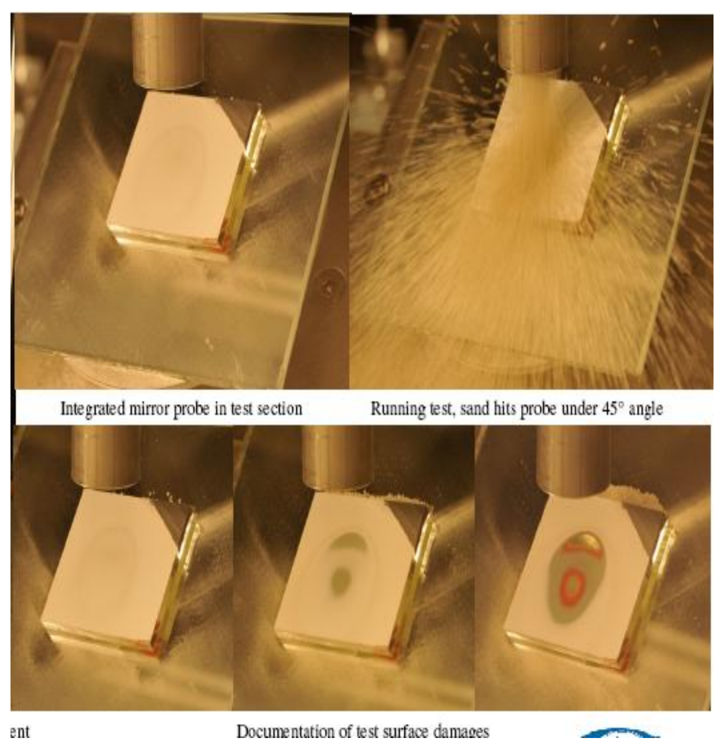


Fig -9: Sand Abrasion Test

5.1.2 Sand Abrasion Test on Front Side of the Mirror

Table -1: Sand Abrasion Mirror Reading before test

Time	Altitude Angle	Azimuth angle	Global radiation	Diffused radiation	Reflected radiation
1.22	77.57	273.23	748	158	324
1.23	77.27	273.25	749	159	322
1.24	76.96	273.31	752	162	315
1.25	76.65	273.28	753	161	323
1.26	76.35	273.30	753	162	321
1.27	75.81	273.35	753	161	322
1.28	75.63	273.37	746	162	315
1.29	75.24	273.42	747	165	323

Table -2: Sand Abrasion Mirror Reading after test

Time	**Altitude Angle**	**Azimuth angle**	**Global radiation**	**Diffused radiation**	**Reflected radiation**
2.02	68.79	274.35	716	162	4
2.03	68.72	274.38	715	160	4
2.04	68.15	274.40	712	159	4
2.05	67.98	274.42	710	157	5
2.06	67.71	274.41	709	158	5
2.07	67.47	274.40	708	156	5
2.08	67.28	274.47	705	155	5
2.09	66.89	274.53	699	152	5

5.2 Salt Water Spray

1) This test is similar to the sand abrasion test only difference is mixture of salt and water is used instead of sand.
2) The procedure is same for this test.

5.2.1 Salt Spray Test on the Mirror

5.2.1.1 Test on Front Side of the Mirror

Table -3: Salt Spray Mirror Reading before test (Front side)

Time	**Altitude Angle**	**Azimuth angle**	**Global radiation**	**Diffused radiation**	**Reflected radiation**
2.21	63.39	274.5	689	105	351
2.22	62.90	274.61	691	101	358
2.23	62.75	274.63	690	102	345
2.24	62.52	274.67	689	103	350
2.45	57.56	275.57	643	102	320
2.46	57.17	275.64	646	100	320
2.47	57.03	275.67	646	102	316
2.48	56.85	275.70	644	99	307

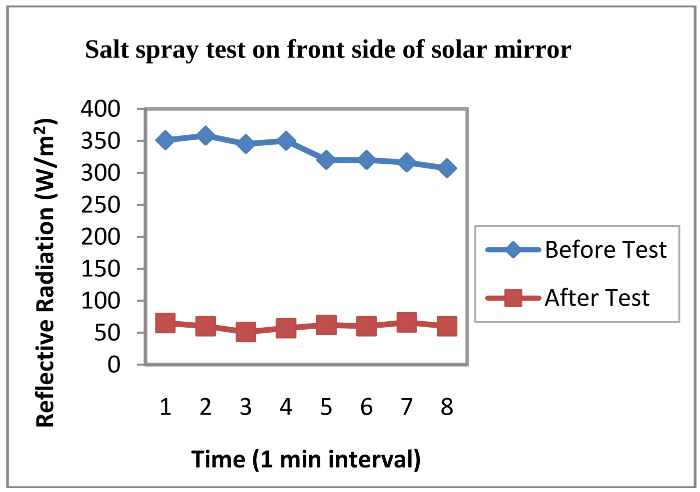
Table -4: Salt Spray Mirror Reading after test (Front side)

Time	Altitude Angle	Azimuth angle	Global radiation	Diffused radiation	Reflected radiation
11.56	82.64	86.91	761	154	65
11.57	82.77	86.90	762	154	60
11.58	82.93	86.89	765	154	51
11.59	83.26	86.85	760	154	57
12.00	83.38	86.83	757	155	62
12.01	83.58	86.80	759	154	60
12.09	85.51	86.21	780	157	66
12.10	85.74	85.08	784	161	60

Fig -10: Before Test

Fig -11: After Test

Graphical Representation:



5.2.1.1 Test on Rear Side of the Mirror

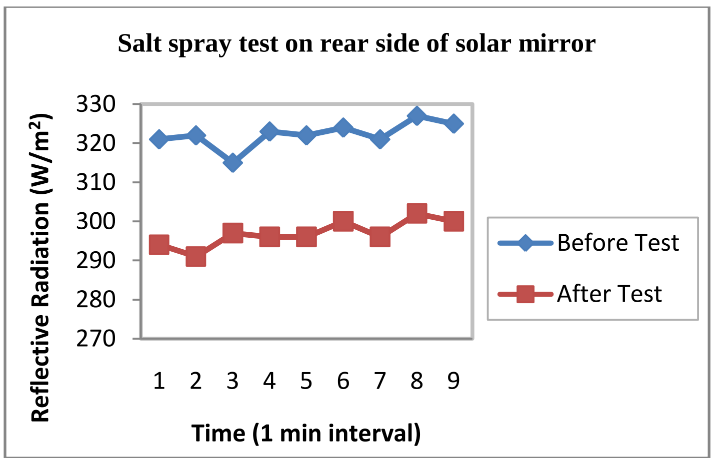
Table -5: Salt Spray Mirror Reading before test (Rear side)

Time	Altitude Angle	Azimuth angle	Global radiation	Diffused radiation	Reflected radiation
1.26	76.35	273.30	753	162	321
1.27	75.81	273.35	753	161	322
1.28	75.63	273.37	746	162	315
1.29	75.24	273.42	747	165	323
1.30	75.01	273.43	751	165	322
1.31	74.73	273.47	750	167	324
1.32	74.60	273.48	755	168	321
1.33	74.35	273.51	757	171	327
1.34	74.21	273.52	760	171	325

Table -6: Salt Spray Mirror Reading after test (Rear side)

Time	Altitude Angle	Azimuth angle	Global radiation	Diffused radiation	Reflected radiation
2.06	67.71	274.41	709	158	294
2.07	67.47	274.44	708	156	291
2.08	67.28	274.47	705	155	297
2.09	66.89	274.53	699	152	296
2.10	66.76	274.55	697	150	296
2.11	66.43	274.60	691	146	300
2.12	66.24	274.63	688	145	296
2.13	66.01	274.67	691	144	302
2.14	65.97	274.70	688	142	300

Graphical Representation:



6. RESULTS

1) Incident radiation = [$(I_g - I_d)/\cos(90-\alpha)$]
2) Reflected Radiation = (ρ^2)*(Incident Radiation) (Observed)

6.1 Salt Spray Test on Front Side

Table -7: Salt Spray Calculated Reading before test

Time	Global Radiation	Reflected Radiation	Altitude Angle	Incident Radiation	Reflectivity
2.21	689	105	63.39	653.18	0.7333
2.22	691	101	62.90	662.76	0.7350
2.23	690	102	62.75	661.40	0.7222
2.24	689	103	62.52	660.52	0.7279
2.45	643	102	57.56	641.03	0.7065
2.46	646	100	57.17	649.78	0.7017
2.47	646	102	57.03	648.42	0.6980
2.48	644	99	56.85	650.94	0.6860

Table -8: Salt Spray Calculated Reading after test

Time	Global Radiation	Reflected Radiation	Altitude Angle	Incident Radiation	Reflectivity
11.56	761	65	82.64	612.05	0.3258
11.57	762	60	82.77	612.87	0.3128
11.58	765	51	82.93	615.68	0.2878
11.59	760	57	83.26	610.21	0.3656
12.00	757	62	83.38	606.04	0.3196
12.01	759	60	83.58	608.82	0.3139
12.09	780	66	85.51	624.92	0.3249
12.10	784	60	85.74	624.72	0.3099

Percentage decrease in reflectivity on front side = 56.22%

6.2 Salt Spray Test on Rear Side

Table -9: Salt Spray Calculated Reading before test

Time	Global Radiation	Reflected Radiation	Altitude Angle	Incident Radiation	Reflectivity
1.26	753	321	76.35	608.17	0.7265
1.27	753	322	75.81	610.63	0.7261
1.28	746	315	75.63	602.86	0.7228
1.29	747	323	75.24	601.86	0.7325
1.30	751	322	75.01	606.64	0.7285
1.31	750	324	74.73	604.33	0.7322
1.32	755	321	74.60	608.86	0.7260
1.33	757	327	74.35	608.56	0.7330
1.34	760	325	74.21	612.10	0.7287

Table -10: Salt Spray Calculated Reading after test

Time	Global Radiation	Reflected Radiation	Altitude Angle	Incident Radiation	Reflectivity
2.06	709	294	67.71	595.49	0.7013
2.07	708	291	67.47	597.61	0.6986
2.08	705	297	67.28	596.26	0.7057
2.09	699	296	66.89	594.72	0.7054
2.10	697	296	66.76	595.30	0.7051
2.11	691	300	66.43	594.60	0.7103
2.12	688	296	66.24	593.28	0.7063
2.13	691	302	66.01	598.72	0.7102
2.14	688	300	65.97	597.81	0.7084

Percentage decrease in reflectivity on rear side = 1.9%

6.3 Sand Abrasion Test on Front Side

Table -11: Sand Abrasion Calculated Reading before test

Time	Global Radiation	Reflected Radiation	Altitude Angle	Incident Radiation	Reflectivity
1.22	748	324	77.57	604.16	0.7323
1.23	749	322	77.27	604.86	0.7296
1.24	752	315	76.96	605.61	0.7212
1.25	753	323	76.65	601.44	0.7286
1.26	753	321	76.35	608.17	0.7265
1.27	753	322	75.81	610.63	0.7261
1.28	746	315	75.63	602.86	0.7228
1.29	747	323	75.24	601.86	0.7325

Table -12: Sand Abrasion Calculated Reading after test

Time	Global Radiation	Reflected Radiation	Altitude Angle	Incident Radiation	Reflectivity
2.02	716	4	68.79	594.25	0.0820
2.03	715	4	68.72	597.86	0.0818
2.04	712	4	68.15	595.80	0.0819
2.05	710	5	67.98	596.51	0.0915
2.06	709	5	67.71	595.49	0.0916
2.07	708	5	67.47	593.61	0.0914
2.08	705	5	67.28	596.26	0.0915
2.09	699	5	66.89	594.72	0.0917

Percentage decrease in reflectivity on front side = 87.92 %

Fig -12: Mirror in Testing Process

7. CONCLUSIONS

The various test conditions required were water, salt, sand and temperature effects. When the chamber was manufactured, salt spray test was conducted on both the sides of the solar mirror. The reflectivity of the unused mirrors was first obtained from the reflectivity setup. Then the same mirrors were subjected to the salt spray and the readings were observed. From the observed readings it is clear that the amount of reflected radiation decreased by the test conducted on the solar mirror. The results obtained were far more different from the expected values. The reflected radiation was almost half of the initial value at some points. Hence the test showed the actual variation in the radiations which is helpful in designing the mirrors with specific properties that are resistant to such condition. Even if the upgrade to these special mirrors is not possible, one can prepare a maintenance schedule based on the results. This will ensure high reflectivity of the solar mirrors during their operation.

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