TÜV Rheinland PTL, LLC
2210 South Roosevelt Street
Tempe, AZ 85282

Test Report

**Solar Thermal Collector Testing
according to
SRCC 100-08
and
ISO 9806-1: 1994 and ISO 9806-2: 1995**

TÜV Report No. R1-TEC100817

**Tempe, AZ
February 2011**

ACCREDITED

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Report No: R1-TEC100817

on

Solar Thermal Collector Testing
according to
ISO 9806-1: 1994 and ISO 9806-2: 1995
and
SRCC 100-08

Client:	Tec-Solar Energy Industry Co. Ltd
TÜV PTL Quotation No:	TEC100817
TÜV Order No:	200374
Order of:	8/27/2010, TEC100817
TÜV Customer No:	798970
Responsible Engineer:	M. Witt, (tel: 480-966-1700, x167)
Examiner:	J. Castagna, (tel: 480-966-1700, x151)
Department:	Solar Thermal Testing
Date:	**2/22/2011**
No . of pages:	30
No. of Appendices:	5

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Summary of test results

Qualification of a Solar Collector in accordance with
ISO 9806-1: 1994 and ISO 9806-2: 1995
and
SRCC 100-08

Manufacturer : Tec-Solar Energy Industry Co. Ltd

Manufacturing Address : No. 120 ChangXing Road
ChangZhou, 213000 CHINA

Model Number : TS-10-70PA **Serial Number** : SC20091101

Collector Type : Evacuated Tube

Basis of testing : SRCC 100-08, ISO 9806-1: 1994, ISO 9806-2: 1995

Test		Date		Summary of main test results
		Start	End	
Incoming Inspection		10/06/10		No visual damage observed.
Static Pressure Test (pre-exposure)		10/08/10		Test pressure: 160 psi. No visual damage observed.
Static Pressure Test(post-exposure)		12/16/10		Test pressure: 160 psi. No visual damage observed.
Exposure		10/07/10	11/08/10	No visual damage observed.
External thermal shock	1st	10/19/10		G=924.91 W/m^2; No visual damage observed.
	2nd	11/09/10		G=995.90 W/m^2; No visual damage observed.
	3rd	11/30/10		G=1002.84 W/m^2; No visual damage observed.
Internal thermal shock		12/14/10		G=979.5 W/m^2; No visual damage observed.
Time constant		01/27/11		τ_c = 210 seconds
Thermal performance		01/20/11	01/21/11	$\eta_G = 0.3755 - 0.0151\ T_i^* - 0.0152\ G\ T_i^{*2}$
Incidence angle modifier		01/21/11	01/26/11	No visual damage observed.
Final inspection		2/16/11		No visual damage observed.

All above listed tests of the standard ISO 9806-1: 1994 and ISO 9806-2: 1995 as cited by standard SRCC 100-08 were performed and assessed as **passing successfully** in accordance with the criteria. It is therefore declared that the solar thermal collector of the aforementioned type fulfils the requirements of SRCC 100-08.

Responsible engineer

Mark Witt

Reviewing engineer

Jack Castagna

Summary of collector performance test results:

Manufacturer : Tec-Solar Energy Industry Co. Ltd
No. 120 ChangXing Road
ChangZhou, 213000 CHINA

Model Number : TS-10-70PA

Collector Type : Evacuated Tube

Year of Manufacture : 2009

Length	1.91 m	Absorber Area	0.96 m^2
Width	1.07 m	Aperture Area	1.16 m^2
Height	0.16 m	Gross Area	2.04 m^2
Weight (empty)	36.93 kg	Mass flow rate	0.041 kg/s
Heat transfer medium	Water (Tap)	Performance Test pressure	Approx. 20 psi

Thermal performance:

	Gross Area Basis (A_G)	Absorber Area Basis (A_A)
η_0	0.3755	0.7984
a_1	0.0151 W/(m^2K)	0.0321 W/(m^2K)
a_2	0.0152 W/(m^2K^2)	0.0324 W/(m^2K^2)

Output power* per collector unit area in W:

	Irradiation		
Tm-Ta [K]	400 W/m^2	700 W/m^2	1000 W/m^2
0	306.7	536.7	766.7
38	260.6	490.7	720.7
75	129.5	359.5	589.5

*****at near-normal incidence angle*

1 Setting of tasks

A complete collector test in accordance with standard SRCC 100-08 on the basis of ISO 9806-1: 1994 and ISO 9806-2: 1995 of the **Tec-Solar Energy Industry Co. Ltd** collector **TS-10-70PA** shall be performed with the aim of SRCC Certification.

2 Basis of testing

SRCC Standard 100-08 “Test Methods and Minimum Standards for Certifying Solar Collectors”

ISO 9806-1: 1994 “Test methods for solar collectors - Part 1: Thermal performance of glazed liquid heating collectors including pressure drop”

ISO 9806-2: 1995 “Test methods for solar collectors - Part 2: Qualification test procedures”

3 Sampling

Prototype samples	--
Samples from pilot production	--
Samples from serial production	✓
Selection of test samples according to SRCC OG-100	✓

4 Description of collector construction

Manufacturer	Tec-Solar Energy Industry Co. Ltd
Brand name	**Tec-Solar**
Model Number	**TS-10-70PA**
Collector Type and Optical Category	Evacuated Tube
Date of Manufacture	2009
Serial Number (or Selection Number if none provided)	SC20091101
Random Selection Number	00372

Collector & construction:

Gross dimensions, L x W [m]	1.91 x 1.07 (1)
Aperture dimension , L x W [m] x n tubes	1.67 x 0.07 x 10 (1)
Absorber dimensions, L x W [m] x n tubes	1.66 x 0.06 x 10 (1)

(1) Determined by test laboratory
(2) Reviewed manufacturer information
(3) Manufacturer specification

Gross / aperture / absorber area [m^2]	2.04 / 1.16 / 0.96
Weight empty [kg]	36.93 (1)
Volumetric fluid capacity [L]	1.2 L (1)

Figure 5-1 Photo of Tec-Solar Energy Industry Co. Ltd TS-10-70PA collector

Covers:

Number of tubes	10 (2)
Material(s)	*Not specified.* (3)
Thicknesses(es)	2.5 mm (1)
Transmittance(s)	*Not specified.* (3)

(1) Determined by test laboratory
(2) Reviewed manufacturer information
(3) Manufacturer specification

Absorber:

Construction type (e.g. sheet, fins, etc.)	Glass vacuum tube with heat pipe [2]	Number of Heat Pipes	10 [2]
Material(s)	Tube: copper [2] Plate: aluminium [2]	Flow Pattern	Manifold/Header [3]
Absorber fin thickness [mm]	0.8 mm [2]	Evacuated Tube O.D.	70 mm [2]
Absorber Plate to Fluid Passage Bonding Method	Segmented contact sheets to the inner glass tube, connect to the heat pipe [3]	Header O.D.	22 mm [2]

Absorber Coating:

Generic name	Sputtered aluminium nitride [3]	Substrate	*Not specified.* [3]
Material(s)	AL – N/AL [3]	Absorptivity	0.93 [3]
Method of application	Sputter [3]	Emissivity	0.06 [3]

Enclosure and Insulation:

Side Frame Materials	Stainless Steel [3]	Insulation material (back and sides)	Rock wool R7, vacuum [3]
Backing Materials	Stainless Steel [3]	Dimensions	850x150x140 mm [3]
Trim, retainers, mounting brackets	*Not specified* [3]	K-factor	*Not specified.* [3]
		Caulking, sealant gaskets material(s)	Silicon rubber [2]

Limit values (given by the manufacturer):

Maximum temperature [C]	*Not specified.* [3]
Operating temperature range [C]	*Not specified* [3]
Test pressure [psi]	160 psi [3]
Heat transfer medium	Water [3]

[1] Determined by test laboratory
[2] Reviewed manufacturer information
[3] Manufacturer specification

Collector label plate:

Label requirements do not apply for SRCC 100-08 testing by laboratories. This is for information purposes only.

Collector sample of model TS-10-70PA provided to laboratory for testing does not contain any informative label.

	Yes	No
Name of the manufacturer	✓	
Model number of collector	✓	
Type of collector		✓
Serial number	✓	
Year of manufacture	✓	
Gross collector area	✓	
Dimensions of the collector		✓
Maximum operating pressure	✓	
Stagnation temperature, at 1000 W/m^2 and 30°C	✓	
Fluid capacity	✓	
Empty weight of collector	✓	
Manufacturing location		✓

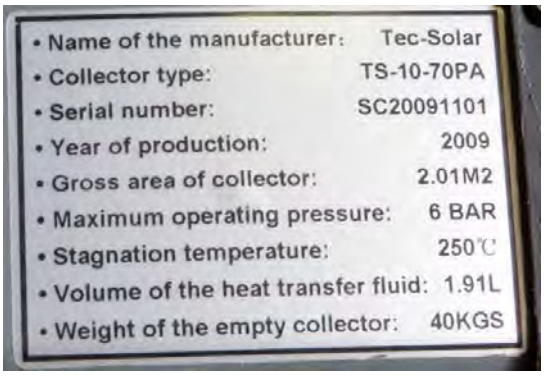


Figure 5-4 Photo of manufacturer label on Tec-Solar Energy Industry Co. Ltd TS-10-70PA collector

(1) Determined by test laboratory
(2) Reviewed manufacturer information
(3) Manufacturer specification

5 Test program execution and evaluation

5.1. Visual inspection

Date	10/06/10	Inspector	M. Witt

Serial No.	Description of defects
SC20091101	No visual damage observed.

5.2. Static pressure test

5.2.1. Collector type;

Cover		✓ **tubular**	
Test pressure specified by manufacturer [psi]	160		
Serial Number (or Selection Number if none provided)	SC20091101		

5.2.2. Test conditions;

	Pre-exposure	Post-exposure
Date	**10/08/10**	**12/16/10**
Inspector	M. Witt	M. Witt
Test temperature , ambient [°C]	30.3	17.8
Test temperature, fluid [°C]	23.6	19.3
Test pressure [psi]	160	160
Test duration [min]	15	15
Pressure loss [psi]	1.4	2.3
Permissible pressure loss [psi]	2.5	2.5

5.2.3. Test results;

Details of any observed or measured cracking, distortion, condensation, water penetration or loss of vacuum found and problems which according to §6.6 of SRCC 100-08 “may lead to abnormally short collector life”.
No visual damage observed.

5.3. Stagnation temperature

The stagnation temperature was calculated using Approach 1 from Annex B.1 of ISO 9806-2:1995, using the set of efficiency constants determined by Gross Area and Mean Reduced Temperature basis. The figures used are as follows:

Conversion factor η_0	0.3755
Heat loss coefficient a_1	0.0151
Temperature-dependent heat loss coefficient a_2	0.0152

To determine the stagnation temperature, the formula was extrapolated to an irradiance of 1000 W/m^2 and an ambient temperature of 30°C.

The calculation is as follows:

$$t_s = t_{as} + \frac{-a_1 + (a_1^2 + 4\eta_0 a_2 G_s)^{1/2}}{2a_2}$$

where,
t_s: Stagnation temperature
t_{as}: 30 °C
G_s: 1000 W/m^2

The resulting stagnation temperature is:

Stagnation temperature, t_s For ambient conditions of 1000 W/m^2 and 30°C (determination acc. to ISO 9806-2:1995, Annex B.1)	186.5°C

5.4. Exposure test

Serial Number (or Selection Number if none provided)	SC20091101	
Date begin/end	**10/07/10**	**11/08/10**
Inspector	M. Witt	

5.4.1. Test conditions;

Collector tilt angle [° from horizontal]	**33.5°**	
Total no. of test days and radiation energy [MJ/m^2]	31	695.83
No. of days with more than 18 MJ/m^2	30	
No. of rain days and total rainfall [inches]	2	0.22
Time period with G>950 W/m^2 and t_a>15°C [hrs]	32.08	
	Minimum value	Maximum value
Ambient temperature of test days, daily mean [°C]	14.66	30.38
Total daily rainfall [inches]	0	0.21

5.4.2. Test results;

Details of any observed or measured cracking, distortion, condensation, water penetration or loss of vacuum found and problems which according to §6.6 of SRCC 100-08 “may lead to abnormally short collector life”.
No visual damage observed.

For more details about Exposure testing, see Appendix 2: Exposure testing climate data.

5.5. External thermal shock test

5.5.1. Test conditions;

	1st Shock		2nd Shock		3rd Shock	
Test location	**Outdoors**		**Outdoors**		**Outdoors**	
Serial Number (or Selection Number if none provided)	SC20091101					
Date	10/19/10		11/09/10		11/30/10	
Inspector	M. Witt		M. Witt		M. Witt	
Collector tilt angle [° from horizontal]	**33.5°**					
Mean & min. irradiation [W/m^2]	924.91	308.4	995.90	984.7	1002.84	990.9
Ambient temperature [°C]	31.1		21.1		17.1	
Period during which steady-state conditions were maintained prior to shock [min]	60		60		60	
Water spray mass flow rate [L/(sm^2)]	0.05		0.05		0.05	
Water spray temperature [°C]	28.0		23.3		15.9	
Water spray duration [min]	15		15		15	
Absorber temperature before spraying [°C]	--		--		--	

5.5.2. Test results;

Details of any observed or measured cracking, distortion, condensation, water penetration or loss of vacuum found and problems which according to §6.6 of SRCC 100-08 “may lead to abnormally short collector life”.
No visual damage observed.

5.6. Internal thermal shock test

5.6.1. Test conditions;

	1st Shock	
Test location	**Outdoors**	
Serial Number (or Selection Number if none provided)	SC20091101	
Date	12/14/10	
Inspector	M. Witt	
Collector tilt angle [° from horizontal]	Tracking	
Min. & mean irradiation [W/m^2]	966.4	979.5
Min. & mean ambient temperature [°C]	22.32	23.12
Period during which steady-state conditions were maintained prior to shock [min]	60	
Shock-water mass flow rate [kg/(sm^2)]	0.0491	
Shock-water temperature [°C]	18.75	
Shock duration [min]	5	
Absorber temperature before shocking [°C]	--	

5.6.2. Test results;

Details of any observed or measured cracking, distortion, condensation, water penetration or loss of vacuum found and problems which according to §6.6 of SRCC 100-08 “may lead to abnormally short collector life”.
No visual damage observed.

5.7. Final inspection and disassembly

TEST NOTE: Data for Final inspection and disassembly will be released in a subsequent test report.

Serial Number (or Selection Number if none provided)	SC20091101
Date	2/16/11
Inspector	M. Witt

Evaluate each potential problem according to the following scale:

Key:
0: No problem
1: Minor problem
2: Severe problem
x: Inspection to establish the condition was not possible

Collector component	Potential problem	Evaluation
Collector box/ fasteners	Cracking/ warping/ corrosion/rain penetration	0
Mountings/ structure	Strength/ safety	0
Seals/ gaskets	Cracking/adhesion/ elasticity	0
Cover/ reflector	Cracking/ crazing/ buckling/ delamination/warping/ outgassing	0
Absorber coating	Cracking/ crazing/ blistering	0
Absorber tubes and headers	Deformation/ corrosion/ leakage/loss of bonding	0
Absorber mountings	Deformation/ corrosion	0
Insulation	Water retention/ outgassing/degradation	0

6 Collector time constant and effective thermal capacity

6.1. Collector time constant

The Collector Time Constant was determined out of the step response from time constant experimental data collected according to ISO 9806-1, §10.3. Figure 6-1 and Figure 6-2 show the two test runs of the collector time constant determination test.

Serial Number (or Selection Number if none provided)	SC20091101
Date	01/27/11
Run 1 time constant result [seconds]	159
Run 2 time constant result [seconds]	261
Collector time constant (mean) [seconds]	210

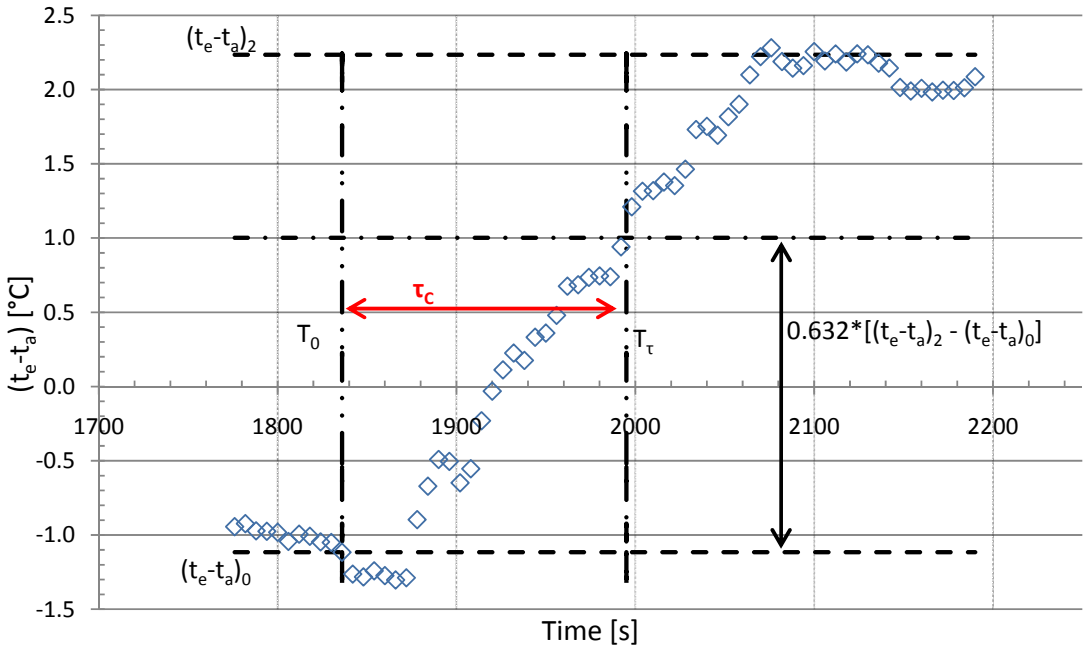


Figure 6-1 Time constant data for collector, Run 1

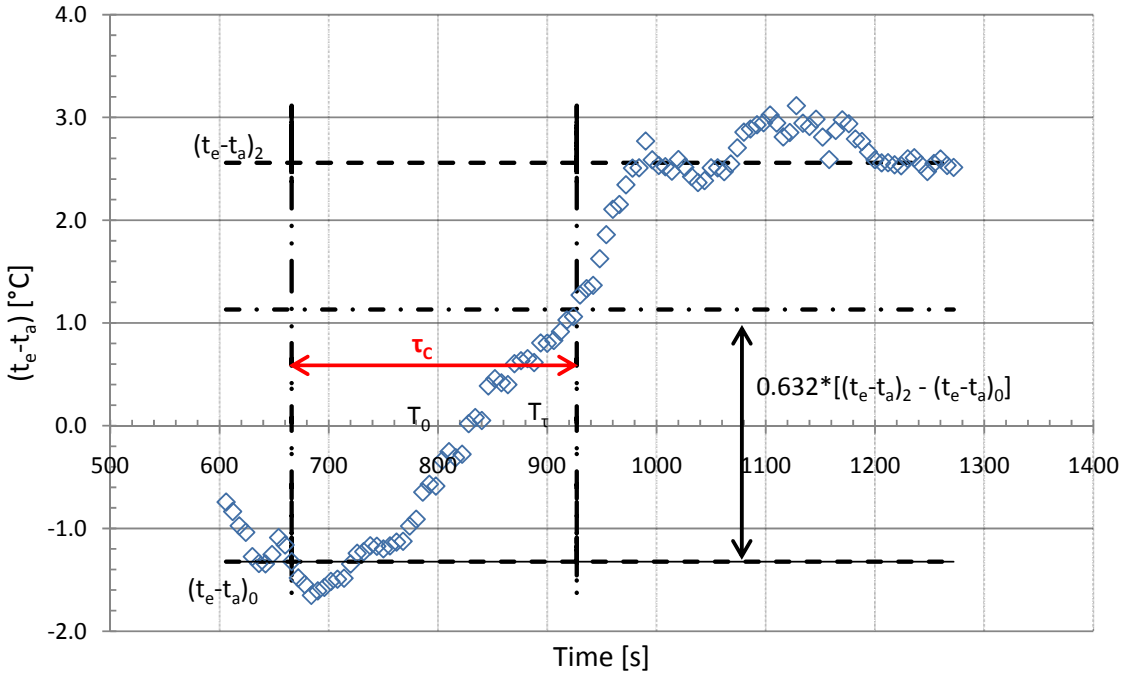


Figure 6-2 Time constant data for collector, Run 2

6.2. Effective thermal capacity

The effective thermal capacity was determined out of the step response from time constant experimental data.

This was accomplished by shading the collector and providing a stepwise change to the full sun by quickly removing the shade. The calculation was done according to ISO 9806-1, Annex E.

Gross area (area basis of calculation) [m^2]	2.04
Effective Thermal Capacity, Area-Related (calculated)	33.4 kJ/m^2K
Effective Thermal Capacity (calculated)	68.2 kJ/K

7 Thermal performance testing

Outdoor steady state procedure according to ISO 9806-1: 1994, §8.0 was used to determine the "instantaneous" efficiency curve of the collector. Each data point was obtained by averaging data from a six-second sampling rate into a 15-minute steady-state test period. Each 15-min steady-state test period was preceded by a 15-minute pre-conditioning period under which the same conditions are held within the stability requirements of ISO 9806-1: 1994.

7.1. Test method according to SRCC 100-08 & ISO 9806-1: 1994

Serial Number (or Selection Number if none provided)	SC20091101	
Date (Start/End)	01/20/11	01/21/11
Inspector	M. Witt	

7.2. Test conditions

Test Method	Outdoor, Steady-state
Latitude [°]	33.5
Longitude [°]	111.9
Collector tilt [° from horizontal]	Tracking (manual; 30-39°)
Collector azimuth [° from south]	Tracking (manual)
Heat transfer fluid	Utility tap water
Mean mass flow [kg/s]	0.041
Flow rate range [kg/hr]	1479.6 – 1515.6
Mean irradiance [W/m^2]	972.46
Mean windspeed [m/s]	2.07
Operating pressure during test [psi]	Approx. 20 psi

7.3. Test results

Second-order Fit to Data:

$$\eta_G = \eta_0 - a_1 \frac{t_{in} - t_a}{G} - a_2 G \left(\frac{t_{in} - t_a}{G}\right)^2$$

	Gross Area Basis (A_G)	Absorber Area Basis (A_A)
η_0	0.3755	0.7984
a_1	0.0151 W/(m^{2}K)	0.0321 W/(m^{2}K)
a_2	0.0152 W/(m^{2}K)	0.0324 W/(m^{2}K^2)

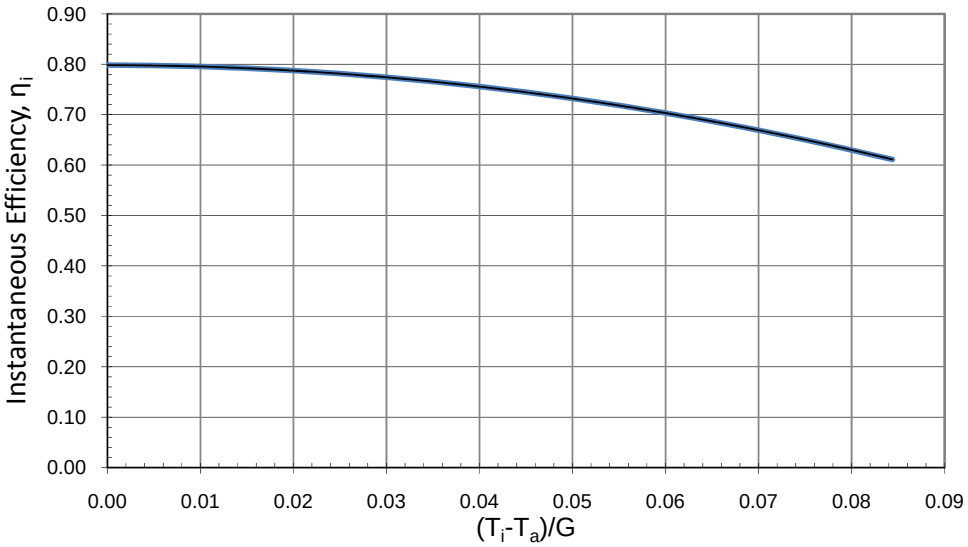


Figure 7-1 Regression curve of collector efficiency
for gross area basis of 2.04 m^2 and irradiance normalization of 800 W/m^2

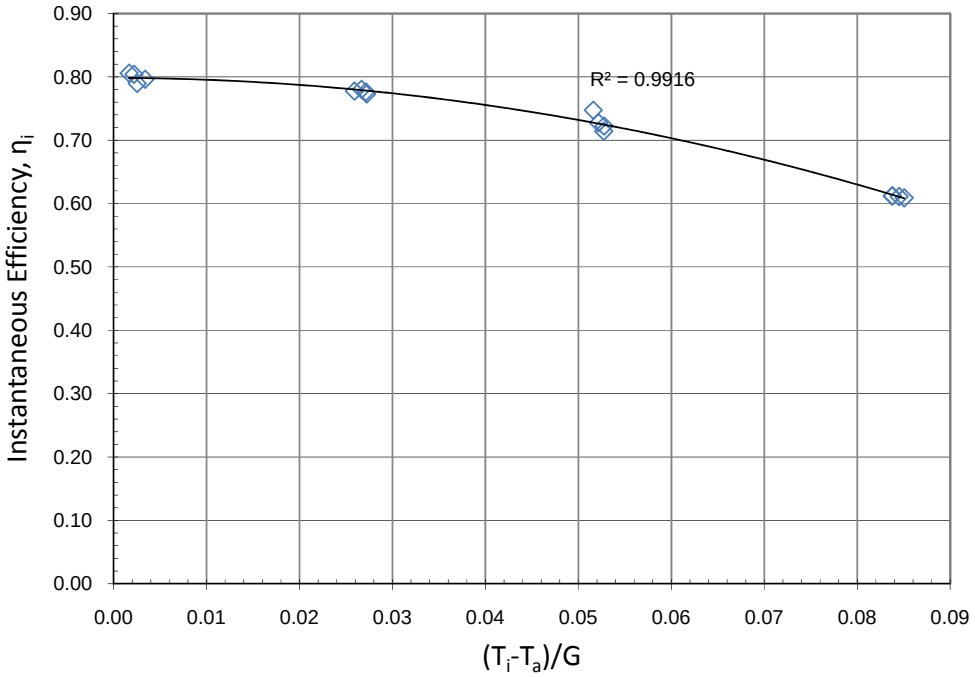


Figure 7-2 Data points for collector efficiency
on gross area basis of 2.04 m^2 and irradiance normalization of 800 W/m^2

Linear Fit to Data:

	Gross Area Basis (A_G)	Absorber Area Basis (A_A)
η_0	0.3875	0.8239
U	1.082 $W/(m^2K)$	2.301 $W/(m^2K)$

8 Incidence angle modifier

Incident angle data was collected using an outdoor, steady state test method, per ISO 9806-1, §11, for a biaxial incident angle modifier, on an open rack mount, under the following conditions.

8.1. Test conditions

Test Method	Outdoor, Steady-state
Latitude [°]	33.5
Longitude [°]	111.9
Collector tilt [° from horizontal]	Tracking (manual)
Collector azimuth [° from south]	Tracking (manual)

8.2. Test results

Incidence Angle θ	5.82	23.43	42.58	
$K_{\theta b}$ (θ_L)	1.000	0.951	0.737	
Incidence Angle θ	5.82	34.75	49.85	58.08
$K_{\theta b}$ (θ_T)	1.000	1.087	1.130	0.826

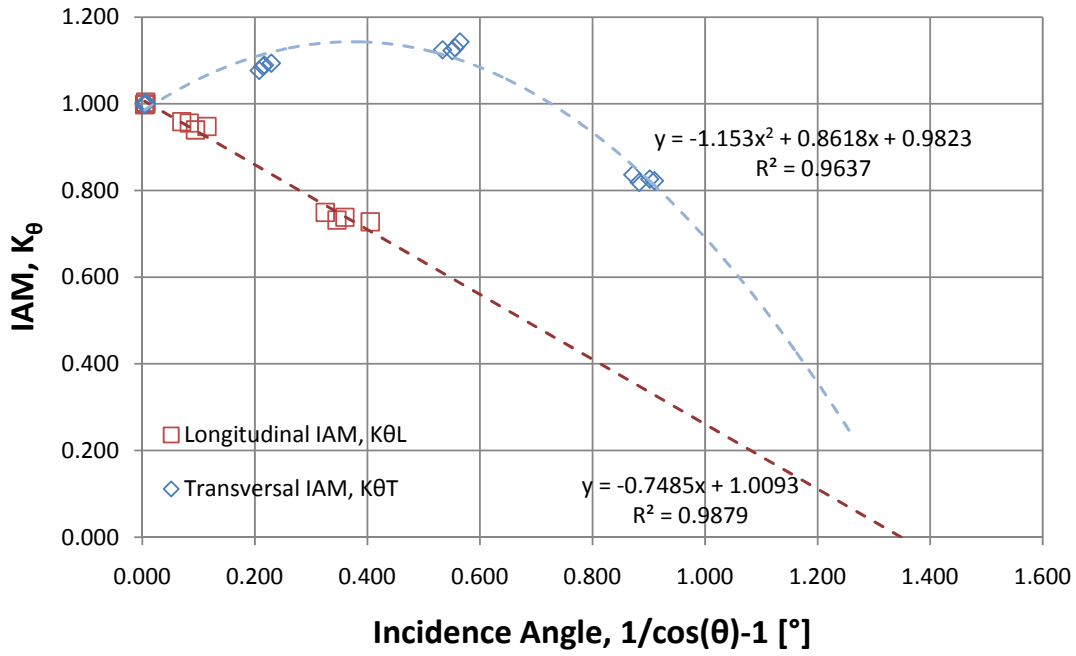


Figure 8-1 Incidence angle modifier observed points

For the calculation of IAM, the efficiency value was extrapolated to $(t_i-t_a)/G = 0$. To accomplish this, the heat loss values of the collector a_1=0.0151 and a_2=0.0152 were used.

In the Appendix, Tables A1-1 and A1-2 show the measured and calculated values for the longitudinal incidence angle modifier (IAM), respectively. Tables A1-3 and A1-4 show the measured and calculated values for the transversal incidence angle modifier (IAM), respectively.

9 Pressure drop across collector

Serial Number (or Selection Number if none provided)	SC20091101
Date	12/17/10
Inspector	M. Witt

9.1. Test conditions

Collector tilt [° from horizontal]	0° [horizontal]
Fluid used	Water (Tap)
Average fluid temperature [°C]	20.3
Average ambient temperature [°C]	22.5

9.2. Test results

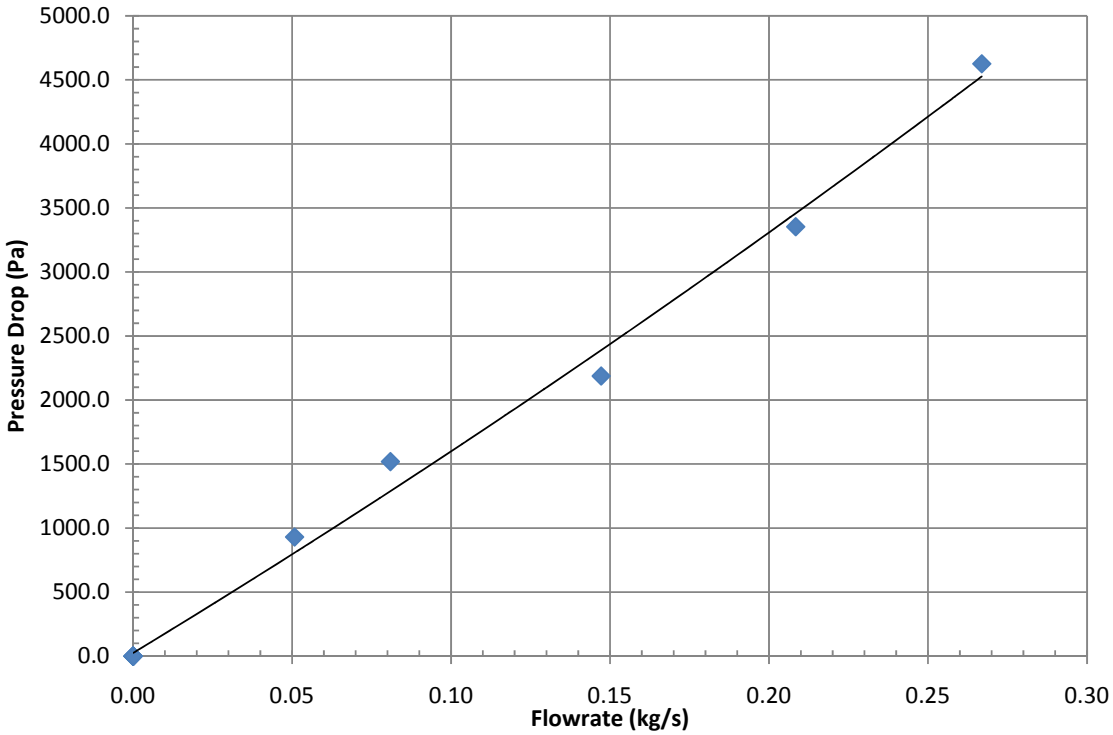


Figure 9-1 Pressure drop observed data points and curve fit

Pressure drop curve function	$\Delta P = 24.48 + 15{,}075\ \dot{m} + 6{,}723\ \dot{m}^2$

Appendix 1: Incidence angle modifier measured and calculated data

Table A1-1 Measured values for the **longitudinal** incidence angle modifier

Date	LT Start h:min	LT End h:min	LT Start h:min	LT End h:min	Irradiance, G (W/m2)	Ambient Temp [C]	Windspeed (m/s)	Inlet Temp [C]	Flowrate (kg/s)
1/21/2011	13:18	13:33	13:33	13:48	1060.62	19.09	1.43	19.88	0.0403
1/21/2011	13:33	13:48	13:48	14:03	1050.91	19.47	1.36	20.00	0.0400
1/21/2011	13:48	14:03	14:03	14:18	1039.43	20.21	1.46	20.03	0.0401
1/21/2011	14:03	14:18	14:18	14:33	1021.16	20.07	2.08	20.02	0.0400
1/20/2011	9:47	10:02	10:02	10:17	886.65	16.87	2.95	19.58	0.0420
1/20/2011	10:02	10:17	10:17	10:32	908.53	17.57	2.12	19.60	0.0421
1/20/2011	10:17	10:32	10:32	10:47	936.30	17.85	2.03	19.60	0.0422
1/20/2011	10:32	10:47	10:47	11:02	958.08	18.30	2.20	19.63	0.0423
1/28/2011	10:20	10:35	10:35	10:50	794.46	16.15	1.63	18.59	0.0413
1/27/2011	9:37	9:52	9:52	10:07	721.65	16.35	1.06	18.83	0.0415
1/27/2011	9:52	10:07	10:07	10:22	756.67	16.88	1.18	18.97	0.0414
1/27/2011	10:07	10:22	10:22	10:37	774.39	17.63	1.83	19.09	0.0415

Table A1-2 Calculated values for the **longitudinal** incidence angle modifier

Date	LT Start h:min	LT End h:min	LT Start h:min	LT End h:min	η_G	Temp-Corrected n_G	Incidence Angle Cos Factor [1/cos(θ)-1]	Incidence Angle	Longitudinal IAM, $K_{\theta L}$
1/21/2011	13:18	13:33	13:33	13:48	0.394	0.394	0.004	5.230	0.998
1/21/2011	13:33	13:48	13:48	14:03	0.395	0.395	0.004	5.349	0.999
1/21/2011	13:48	14:03	14:03	14:18	0.397	0.397	0.006	6.276	1.004
1/21/2011	14:03	14:18	14:18	14:33	0.395	0.395	0.006	6.411	0.999
1/20/2011	9:47	10:02	10:02	10:17	0.374	0.375	0.115	26.228	0.948
1/20/2011	10:02	10:17	10:17	10:32	0.371	0.371	0.095	23.993	0.940
1/20/2011	10:17	10:32	10:32	10:47	0.378	0.378	0.083	22.635	0.956
1/20/2011	10:32	10:47	10:47	11:02	0.379	0.379	0.070	20.850	0.959
1/28/2011	10:20	10:35	10:35	10:50	0.296	0.296	0.325	41.002	0.749
1/27/2011	9:37	9:52	9:52	10:07	0.287	0.288	0.405	44.626	0.728
1/27/2011	9:52	10:07	10:07	10:22	0.292	0.292	0.360	42.666	0.738

Table A1-3 Measured values for the **transversal** incidence angle modifier

	Pre-conditioning		Test Period		AVERAGES, 15-MIN SST PERIOD				
Date	LT Start h:min	LT End h:min	LT Start h:min	LT End h:min	Irradiance, G (W/m2)	Ambient Temp [C]	Windspeed (m/s)	Inlet Temp [C]	Flowrate (kg/s)
1/21/2011	13:18	13:33	13:33	13:54	1058.20	19.17	1.47	19.91	0.0402
1/21/2011	13:33	13:48	13:48	14:03	1050.91	19.47	1.36	20.00	0.0400
1/21/2011	13:48	14:03	14:03	14:18	1039.43	20.21	1.46	20.03	0.0401
1/21/2011	14:03	14:18	14:18	14:33	1021.16	20.07	2.08	20.02	0.0400
1/26/2011	11:46	12:01	12:01	12:16	905.60	19.11	1.52	18.94	0.0403
1/26/2011	12:01	12:16	12:16	12:31	921.84	19.58	2.56	18.95	0.0403
1/26/2011	12:16	12:31	12:31	12:46	917.06	19.51	1.45	18.89	0.0403
1/26/2011	12:31	12:46	12:46	13:01	921.90	19.72	2.29	18.92	0.0403
1/24/2011	10:40	10:55	10:55	11:11	728.78	15.07	1.98	19.36	0.0399
1/24/2011	10:55	11:10	11:10	11:25	747.64	15.45	2.46	19.37	0.0400
1/24/2011	11:10	11:25	11:25	11:40	748.33	15.58	1.96	19.37	0.0400
1/24/2011	11:25	11:40	11:40	11:55	753.37	16.65	1.83	19.38	0.0400
1/26/2011	14:11	14:26	14:26	14:41	549.01	21.62	0.00	22.50	0.0406
1/26/2011	14:26	14:41	14:41	14:56	548.46	22.31	0.00	22.49	0.0406
1/26/2011	14:41	14:56	14:56	15:11	535.09	22.59	0.00	22.51	0.0406
1/26/2011	14:52	15:07	15:07	15:27	540.42	22.24	0.00	22.50	0.0406

Table A1-4 Calculated values for the **transversal** incidence angle modifier

	Pre-conditioning		Test Period				IAM Curve		
Date	LT Start h:min	LT End h:min	LT Start h:min	LT End h:min	η_G	Temp-Corrected n_G	Incidence Angle Cos Factor [1/cos(θ)-1]	Incidence Angle	Transversal IAM, $K_{\theta T}$
1/21/2011	13:18	13:33	13:33	13:54	0.395	0.395	0.004	5.242	0.999
1/21/2011	13:33	13:48	13:48	14:03	0.395	0.395	0.004	5.349	0.998
1/21/2011	13:48	14:03	14:03	14:18	0.397	0.397	0.006	6.276	1.003
1/21/2011	14:03	14:18	14:18	14:33	0.395	0.395	0.006	6.411	0.999
1/26/2011	11:46	12:01	12:01	12:16	0.432	0.432	0.229	35.569	1.093
1/26/2011	12:01	12:16	12:16	12:31	0.426	0.426	0.208	34.101	1.076
1/26/2011	12:16	12:31	12:31	12:46	0.431	0.431	0.217	34.737	1.089
1/26/2011	12:31	12:46	12:46	13:01	0.429	0.429	0.215	34.585	1.086
1/24/2011	10:40	10:55	10:55	11:11	0.443	0.444	0.551	49.842	1.122
1/24/2011	10:55	11:10	11:10	11:25	0.444	0.444	0.533	49.297	1.124
1/24/2011	11:10	11:25	11:25	11:40	0.446	0.446	0.556	50.003	1.129
1/24/2011	11:25	11:40	11:40	11:55	0.451	0.452	0.565	50.270	1.142
1/26/2011	14:11	14:26	14:26	14:41	0.327	0.327	0.902	58.271	0.826
1/26/2011	14:26	14:41	14:41	14:56	0.324	0.324	0.883	57.920	0.819
1/26/2011	14:41	14:56	14:56	15:11	0.325	0.325	0.910	58.429	0.822
1/26/2011	14:52	15:07	15:07	15:27	0.331	0.331	0.871	57.699	0.836

Appendix 2: Exposure testing climate data

Day Count	Date	Radiation > 950 W/m2 [Hours]	Daily Irradiation [MJ/(m2*day)]	Avg Daily Temp [°C]	Total Daily Rainfall [in]
Day 1	10/7/2010	2.33	24.50	23.73	0.00
Day 2	10/8/2010	2.42	24.77	22.95	0.00
Day 3	10/9/2010	2.50	24.87	24.08	0.00
Day 4	10/10/2010	2.00	24.31	25.20	0.00
Day 5	10/11/2010	2.17	24.06	25.92	0.00
Day 6	10/12/2010	1.58	23.68	26.70	0.00
Day 7	10/13/2010	1.58	23.42	28.95	0.00
Day 8	10/14/2010	1.25	23.26	30.38	0.00
Day 9	10/15/2010	0.25	20.94	27.26	0.00
Day 10	10/16/2010	1.08	21.13	26.62	0.00
Day 11	10/17/2010	0.00	20.46	26.52	0.00
Day 12	10/18/2010	0.33	22.42	25.77	0.00
Day 13	10/19/2010	0.00	21.90	24.63	0.00
Day 14	10/20/2010	0.00	11.78	20.38	0.01
Day 15	10/21/2010	0.75	18.51	18.01	0.21
Day 16	10/22/2010	0.00	13.10	18.35	0.00
Day 17	10/23/2010	0.00	19.58	19.23	0.00
Day 18	10/24/2010	0.00	20.62	20.70	0.00
Day 19	10/25/2010	0.00	11.28	20.15	0.00
Day 20	10/26/2010	0.42	22.48	20.68	0.00
Day 21	10/27/2010	0.92	22.90	20.74	0.00
Day 22	10/28/2010	0.00	22.10	24.20	0.00
Day 23	10/29/2010	0.67	22.51	25.28	0.00
Day 24	10/30/2010	0.67	22.61	22.31	0.00
Day 25	10/31/2010	0.58	22.44	19.96	0.00
Day 26	11/1/2010	2.17	24.63	21.02	0.00
Day 27	11/2/2010	2.50	24.83	23.36	0.00
Day 28	11/3/2010	1.92	24.05	24.02	0.00
Day 29	11/4/2010	1.42	22.84	24.69	0.00
Day 30	11/5/2010	0.42	22.87	23.65	0.00
Day 31	11/6/2010	1.00	20.41	21.57	0.00
Day 32	11/7/2010	1.17	23.56	20.50	0.00
Day 33	11/8/2010	0.00	3.01	14.64	0.00
	CUMULATIVE	32.08	695.83	762.12	0.22

Appendix 3: Thermal performance test data

Table A3-1 **Measured** values for the efficiency test results

	Pre-conditioning		Test Period		AVERAGES, 15-MIN SST PERIOD							
Date	LT Start h:min	LT End h:min	LT Start h:min	LT End h:min	Irradiance, G (W/m2)	G_d/G ‡ [%]	E_L (W/m2)	Ambient Temp [C]	Windspeed (m/s)	Inlet Temp [C]	t_e-t_{in} [K]	Flowrate (kg/s)
1/20/2011	9:47	10:02	10:02	10:17	886.65	0.28	321.14	16.87	2.95	19.58	3.86	0.0420
1/20/2011	10:02	10:17	10:17	10:32	908.53	0.89	324.28	17.57	2.12	19.60	3.91	0.0421
1/20/2011	10:17	10:32	10:32	10:47	936.30	0.07	326.21	17.85	2.03	19.60	4.09	0.0422
1/20/2011	10:32	10:47	10:47	11:02	958.08	0.07	328.38	18.30	2.20	19.63	4.19	0.0423
1/21/2011	11:30	11:45	11:45	12:00	1017.50	0.07	318.24	17.36	2.18	39.06	4.41	0.0411
1/21/2011	11:45	12:00	12:00	12:15	1026.86	0.07	319.47	17.26	1.06	39.04	4.43	0.0412
1/21/2011	12:00	12:15	12:15	12:30	1026.65	0.06	323.34	17.74	1.45	39.07	4.47	0.0411
1/21/2011	12:15	12:30	12:30	12:45	1028.15	0.06	327.88	18.38	3.19	39.10	4.47	0.0411
1/20/2011	13:48	14:03	14:03	14:18	984.58	0.08	344.49	21.34	1.67	63.55	3.89	0.0419
1/20/2011	14:03	14:18	14:18	14:33	969.05	0.07	345.14	21.43	2.94	63.60	3.79	0.0419
1/20/2011	14:29	14:44	14:44	14:59	867.46	0.09	347.84	21.94	2.29	63.68	3.45	0.0419
1/20/2011	14:46	15:01	15:01	15:16	858.48	0.10	350.32	22.42	1.76	63.70	3.51	0.0419
1/20/2011	11:59	12:14	12:14	12:29	1021.65	0.08	337.35	19.96	1.57	88.01	3.40	0.0418
1/20/2011	12:14	12:29	12:29	12:44	1024.49	0.56	339.32	20.38	1.67	87.98	3.42	0.0418
1/20/2011	12:29	12:44	12:44	12:59	1021.98	0.45	342.58	21.03	2.29	88.06	3.43	0.0417
1/20/2011	12:44	12:59	12:59	13:14	1022.94	0.08	342.63	21.02	1.73	88.04	3.42	0.0418

‡ Note that the high values of diffuse fraction G_d/G, such as those greater to 15%, are not actual values but represent erroneous values due to shadow band misplacement. Actual values during testing were all less than 0.15.

Table A3-2 **Calculated** values for the efficiency test results where irradiance for normalization is G=800 W/m^2

	Pre-conditioning		Test Period		AVERAGES, 15-MIN SST PERIOD							
Date	LT Start h:min	LT End h:min	LT Start h:min	LT End h:min	t_m [C]	C_f [J/kgK]	Q_{dot} [W]	$(t_i-t_a)/G$ [m^2K/W]	$(t_i-t_a)^2/G$ [m^2K^2/W]	η_G	η_A	$(t_m-t_a)/G$ [m^2K/W]
1/20/2011	9:47	10:02	10:02	10:17	21.50	4181	678	0.0034	0.0093	0.374	0.796	0.0058
1/20/2011	10:02	10:17	10:17	10:32	21.55	4181	689	0.0025	0.0052	0.371	0.789	0.0050
1/20/2011	10:17	10:32	10:32	10:47	21.65	4181	723	0.0022	0.0039	0.378	0.804	0.0048
1/20/2011	10:32	10:47	10:47	11:02	21.73	4181	741	0.0017	0.0023	0.379	0.806	0.0043
1/21/2011	11:30	11:45	11:45	12:00	41.27	4179	758	0.0271	0.5887	0.365	0.776	0.0299
1/21/2011	11:45	12:00	12:00	12:15	41.25	4179	762	0.0272	0.5932	0.364	0.773	0.0300
1/21/2011	12:00	12:15	12:15	12:30	41.31	4179	769	0.0267	0.5691	0.367	0.780	0.0295
1/21/2011	12:15	12:30	12:30	12:45	41.34	4179	768	0.0259	0.5373	0.366	0.778	0.0287
1/20/2011	13:48	14:03	14:03	14:18	65.50	4188	683	0.0528	2.2277	0.340	0.722	0.0552
1/20/2011	14:03	14:18	14:18	14:33	65.50	4188	665	0.0527	2.2240	0.336	0.714	0.0551
1/20/2011	14:29	14:44	14:44	14:59	65.40	4188	606	0.0522	2.1773	0.343	0.730	0.0543
1/20/2011	14:46	15:01	15:01	15:16	65.46	4188	616	0.0516	2.1303	0.352	0.749	0.0538
1/20/2011	11:59	12:14	12:14	12:29	89.71	4205	598	0.0851	5.7880	0.286	0.609	0.0872
1/20/2011	12:14	12:29	12:29	12:44	89.69	4205	601	0.0845	5.7123	0.287	0.611	0.0866
1/20/2011	12:29	12:44	12:44	12:59	89.77	4205	601	0.0838	5.6164	0.288	0.612	0.0859
1/20/2011	12:44	12:59	12:59	13:14	89.75	4205	601	0.0838	5.6141	0.288	0.612	0.0859

Appendix 4: Photo documentation

Figure A4-1 External thermal shock

Figure A4-2 Final disassembly

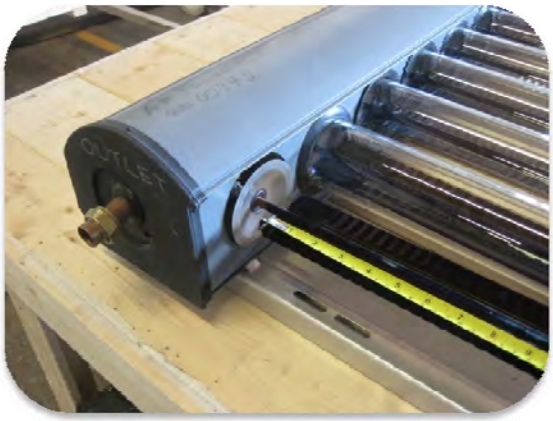


Figure A4-3 Final disassembly

Figure A4-4 Final disassembly

Appendix 5: Solar Collector Measurements (SRCC Reporting Requirement)

It is necessary to document every detail of the construction of the collector. Anything that could possibly be questioned in the future must be measured and described. These measurements are in addition to those required in the ISO 9806 standards.

Collector model:	TS-10-70PA
Date of measurements:	2/16/11
Person(s) making measurements:	M. Witt

Enclosure/Frame	
Depth of the collector enclosure (n/a for tubular)	N/A
Enclosure/Frame side material	Galvanized Steel
Enclosure/Frame back material	Galvanized Steel
Frame fastening methods (pop rivets, screws, etc.):	Screws
Dry Weight	36.435 kg
Fluid Capacity	1.2 L

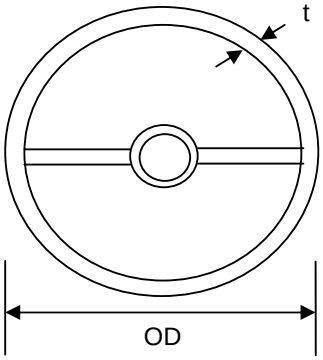
Glazing	
Number of covers/tubes, specify which:	10
Glazing thickness:	2.5 mm
Glazing dimensions (width or diameter and length):	L = 155.5 cm, d = 70 cm
Center to center distance between tubular glazings:	9.32cm
Surface characteristics (clear, textured, coated):	Clear

Absorber	
Materials (plate/fin and tube):	Tube with flat fin
Absorber plate/fin dimensions (width and length or diameter and length):	L = 167 cm, w = 62.3mm
Absorber plate or fin thickness:	Flat fin, t = 0.8 mm
Absorber Coating:	N/A
Flow pattern (include photograph or diagram):	Manifold/Header with indirect heat pipe
Glazing to absorber air space thickness (if tubes are on top of plate list distance from plate to glazing)	N/A
Bond between riser and fin/plate (mechanical, solder, weld-ultrasonic, laser)	N/A
Test Pressure:	160 psi

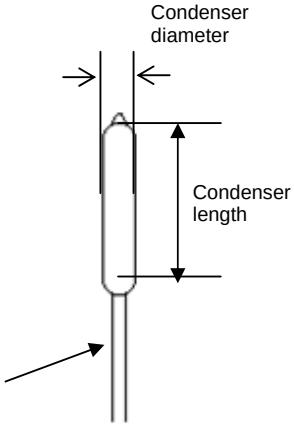
Caulking, sealants, gasket materials	
List all used in collector (i.e., glazing gasket, inlet/out tube gaskets, etc.)	I/O tube gasket material: ✓ EPDM silicone rubber
	For evacuated tubes, heat transfer grease supplied. ✓ Yes. ☐ No.

(1) Determined by test laboratory
(2) Reviewed manufacturer information
(3) Manufacturer specification

Tubular collectors:

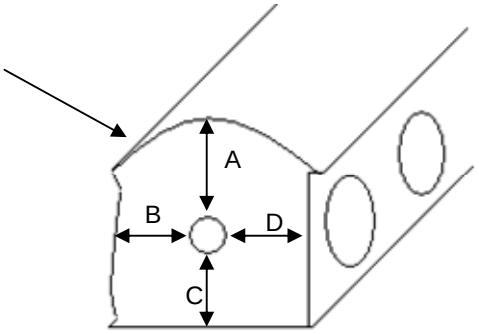


Header	
Header tube outside diameter:	2.2 cm
Header tube wall thickness:	1.34 mm
Header configuration:	Indirect



Heat pipe	
center to center distance between heat pipes:	9.32 cm
length of heat pipe & wall thickness:	L = 177.7 cm, t =?
dimensions of condenser:	L = 62.5mm, d = 14mm
details of connection between condenser and header:	Indirect opening with heat transfer grease

Insulation		
	Type of insulation	Thickness (mm)
Manifold A:	Rock/Mineral Wool	69.4
Manifold B:	Rock/Mineral Wool	76.7
Manifold C:	Rock/Mineral Wool	66.2
Manifold D:	Rock/Mineral Wool	72.8



(1) Determined by test laboratory
(2) Reviewed manufacturer information
(3) Manufacturer specification