348
1-14-80

HR 509

DOE/NASA CONTRACTOR
REPORT

DOE/NASA CR-161253

THERMAL PERFORMANCE EVALUATION OF THE SUNCATCHER SH-11 (LIQUID) SOLAR COLLECTOR

Prepared by

Wyle Laboratories
Solar Energy Systems Division
Huntsville, Alabama 35805

MASTER

Under subcontract to IBM Federal Systems Division, Huntsville, Alabama

Contract NAS8-32036

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agents the United States Department of Energy, the United States National Aeronautics and Space Administration, nor any federal employees, nor any of their contractors, subcontractors or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represent that its use would not infringe privately owned rights.

1. REPORT NO. DOE/NASA CR-161253	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Thermal Performance Evaluation of the Suncatcher SH-11 (Liquid) Solar Collector		5. REPORT DATE July 1979	
		6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT #	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wyle Laboratories Solar Energy Systems Division Huntsville, Alabama 35805		10. WORK UNIT NO.	
		11. CONTRACT OR GRANT NO. NAS8-32036	
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, DC 20546		13. TYPE OF REPORT & PERIOD COVERED Contractor Report	
		14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This work was done under the technical management of Mr. Charles N. Thomas, George C. Marshall Space Flight Center, Alabama.			
16. ABSTRACT <p>This report contains the procedures used and the results obtained during the evaluation test program on the Solar Unlimited, Inc., Suncatcher SH-11 (Liquid) Solar Collector. The flat-plate collector case assembly is made of .08 inch aluminum 3003 H14 rivited with fiber-glass board insulation. The absorber consists of collared aluminum fins mechanically bonded to 3/8 inch copper tubing and coated with 3M "Nextel" black. Water is used as the working fluid. The glazing is made of a single glass, 1/8 inch water white, tempered and anti-reflective. The collector weight is 85 pounds with overall external dimensions of about 35.4" x 82.0" x 4.0".</p> <p>The test program was conducted to obtain thermal performance data on the Solar Unlimited Suncatcher SH-11 solar collector under simulated conditions. These tests were conducted using the MSFC Solar Simulator.</p>			
17. KEY WORDS		18. DISTRIBUTION STATEMENT UC-59c Unclassified-Unlimited WILLIAM A. BROOKSBANK, JR. Mgr, Solar Energy Applications Projects	
19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 21	22. PRICE NTIS

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

		<u>Page No.</u>
1.0	PURPOSE	1
2.0	REFERENCES	1
3.0	COLLECTOR DESCRIPTION	1
4.0	SUMMARY	2
5.0	TEST CONDITIONS AND TEST EQUIPMENT	3
	5.1 Ambient Conditions	5
	5.2 Instrumentation and Equipment	5
6.0	TEST REQUIREMENTS AND PROCEDURES	4
	6.1 Collector Preconditioning	4
	6.2 Collector Time Constant Test	5
	6.3 Collector Thermal Efficiency Test	6
	6.4 Post Thirty-Day Stagnation Re-test	9
7.0	ANALYSIS	10
	7.1 Thermal Performance Test	10
	7.2 Time Constant Test	13
	7.3 Post Thirty-Day Stagnation Re-test	14
Table I	Thermal Performance Test Data for the Suncatcher Solar Collector	15
Figure 1	Thermal Efficiency of the Suncatcher SH-11 Collector with 0.5 GPM Flowrate	17
Figure 2	Time Constant Test of the Suncatcher SH-11 Solar Collector	18
Figure 3	Post Thirty-Day Stagnation Thermal Efficiency Re-test	19

1.0 PURPOSE

The purpose of this document is to present the test procedures used during the performance of an evaluation test program. The test program was conducted to obtain thermal performance data on the Solar Unlimited Suncatcher SH-11 solar collector under simulation conditions.

The test was conducted utilizing the MSFC Solar Simulator in accordance with the test requirements specified in Reference 2.1 and the procedures contained in References 2.2 and 2.3.

2.0 REFERENCES

2.1	ASHRAE 93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors
2.2	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
2.3	NBSIR 78-1305A	Provisional Flat Plate Solar Collector Testing Procedures

3.0 COLLECTOR DESCRIPTION

Manufacturer:	Solar Unlimited, Inc.		
Manufacturer's Address:	4310 Governors Drive Huntsville, Alabama 35802		
Model Number:	SH-11		
Type:	Flat Plate		
Working Fluid:	Water		
Gross Collector Area, Ft ² :	20.14		
Overall external dimensions:	Width, inches:	35.375	
	Length, inches:	82.00	
	Thickness, inches:	4.00	
	Aperture area, ft ² :	18.0	
Collector glazing:	Single glass 1/8" water white, $\tau = 0.916$		
Weight, lbs.	Empty:	85	
	Full:	91	

SUMMARY

This test program was conducted to evaluate the thermal performance of a Suncatcher SH-11 liquid, flat plate, solar collector under simulated conditions. The test conditions and the data obtained during the test program are listed in Table I for the thermal performance test. A graphic presentation of the data obtained from the performance tests is shown in Figure 1. A time constant test was also conducted to determine transient effects on the collector. The results of this test are shown in Figure 2.

The load test was not requested and therefore not performed. The post 30-day stagnation test was performed to determine the amount of degradation, if any. The results of the re-test for thermal efficiency are shown in Figure 3.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests were performed at ambient conditions existing in Building 4619 at the time of the tests.

5.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC-MMI-5300.4C, Metrology and Calibration. A listing of the equipment used in each test follows:

<u>Apparatus</u>	<u>Manufacturer/Model</u>	<u>Range/Accuracy</u>
Pyranometer	Eppley - PSP	0-800 BTU/Ft ² ·Hr $\pm$ 3%
Liquid Loop	MSFC Supplied	.1 - 1/2 GPM
Directional Anemometer	Supplied by AMC	0 - 30 MPH
Flowmeter	Foxboro/1/2-2 81T3C1	.1 - .91 $\pm$ 1% GPM
Temperature Transducer	Analog Devices	0 - 500°F $\pm$ 0.1°F
Platinum Resistance Thermometer	Hy-Cal	0 - 500°F $\pm$ 0.5°F
Digital Printer	Doric Digitrend 220	0 - 500 MV $\pm$ 2%
Fans	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006
Differential Pressure Transducer	Statham	0 - 10 PSID $\pm$ 1%

All transducers, with the exception of the Eppley PSP pyranometer used in recording test data, are calibrated by either NASA or AMC calibration laboratories as required by MSFC MMI 5300.4C. The PSP pyranometer was calibrated by the manufacturer. The stated accuracy of individual transducers reflects the overall expected accuracy through the data acquisition system.

6.0 TEST REQUIREMENTS AND PROCEDURES

6.1 Collector Preconditioning

6.1.1 Requirement

The collector shall be mounted on an outdoor passive test stand at an angle of 45° from the horizontal and facing south. The inlet and outlet ports to the collector shall be capped to prevent flow. The upper cap shall contain a small vent hole. The preconditioning shall consist of at least three days exposure during which the mean incident solar radiation measured in the plane of the collector shall be $1500 \text{ BTU/Ft}^2 \cdot \text{day}$. During this preconditioning, the following data shall be recorded within two hours of solar noon when the insolation is constant and above a minimum of $200 \text{ BTU/Hr} \cdot \text{Ft}^2$ in the plane of the collector. Data recorded shall be the average for at least a 20 minute period at quasi-steady state conditions.

1. Insolation rate.
2. Ambient temperature.
3. Wind velocity and direction.
4. Absorber surface temperature at either 4 or 5 locations.

6.1.2 Procedure

1. Mount test specimen as described above.
2. Connect instrumentation.
3. Record data as described above.

6.1.3 Results

Preconditioning was achieved. Collector was not furnished with absorber surface temperature sensors.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2 Collector Time Constant Test

6.2.1 Requirements

The collector time constant shall be determined by abruptly reducing the solar flux to zero. This will be done with the inlet temperature adjusted to within $\pm 2^\circ\text{F}$ of ambient while the liquid is flowing at $14.7 \text{ lbm/hr}\cdot\text{ft}^2$. These are recommended flowrates. The manufacturer's flowrates should be used when specified. The differential temperature across the collector shall be monitored to determine the time required to reach the condition of:

$$\frac{\Delta T(t)}{\Delta T_i} = .368$$

where $T(t)$ is the differential temperature at time t after the solar flux is reduced to zero and ΔT_i is the differential temperature prior to the power down of the solar simulator. The liquid to be used as the collector heat transfer medium shall be as specified by the manufacturer. If this liquid is not specified, use water as the fluid.

The following data will be recorded for the test:

- (1) Solar flux.
- (2) Ambient temperature.
- (3) Inlet liquid temperature.
- (4) Collector differential temperature.
- (5) Liquid flow rate.
- (6) Specified heat transfer medium.

6.2.2 Procedure

1. Adjust the liquid flow rate to 0.5 GPM.
2. Adjust the inlet temperature to ambient $\pm 2^\circ\text{F}$.
3. Power up the solar simulator and establish a solar flux level of $260 \text{ BTU/Ft}^2\cdot\text{Hr}$.
4. Establish wind speed of 7.5 mph.
5. Record data for five minutes at above stabilized conditions.
6. Power down solar simulator.
7. Record the change of ΔT across the collector.

6.2.3 Results

The results obtained during the time constant test are shown in Figure 2.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Thermal Efficiency Test

6.3.1 Requirements

Utilizing the MSFC Solar Simulator and the portable liquid loop, parametric performance evaluation data shall be recorded of the following test variables and conditions. The liquid to be used is the manufacturer's recommended heat transfer fluid. If not specified, the test shall be performed using water as the working fluid.

<u>Variable/Condition</u>	<u>Requirement</u>
(1) Collector inlet liquid temperature differential above existing ambient temperature level	0°F, 25°F, 50°F, 75°F, and 100°F
(2) Collector outlet liquid temperature	Measured data
(3) Incident solar flux level	250, 300 BTU/Hr·Ft ² ·°F
(4) Liquid flow rate through collector	0.5 GPM
(5) Wind speed	7.5 MPH
(6) Ambient air temperature	Existing room condition

6.3.2 Procedure

1. Mount test specimen on test table at a 45° angle with reference to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 45° with reference to the floor.
3. Using the procedure contained in Reference 2.3, align the test table so the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the loop of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all liquid lines.
5. Connect instrumentation leads to data acquisition system.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Thermal Efficiency Test (Continued)

6.3.2 Procedure (Continued)

6. Assure that data acquisition system is operational.
7. Perform sensor accuracy verification tests.
8. Establish required wind speed.
9. Start liquid flow loop and establish the required flow rate.
10. Establish the required inlet temperature.
11. Power up solar simulator in accordance with Reference 2.2 and establish the required solar flux level.
12. Record data for a minimum of five minutes at these stabilized conditions.
13. Repeat Steps 9 through 12 as necessary to complete all the required test conditions with independent tests as specified below:

Test No.	Inlet Liquid Temperature Differential Above Existing Ambient Temp., °F	Solar Flux BTU/Hr·Ft ² °F	Liquid Flow Rate GPM	Wind Speed, MPH
1	0	250	0.50	7.5
2	0	300	0.50	7.5
3	25	250	0.50	7.5
4	25	300	0.50	7.5
5	50	250	0.50	7.5
6	50	300	0.50	7.5
7	75	250	0.50	7.5
8	75	300	0.50	7.5
9	100	250	0.50	7.5
10	100	300	0.50	7.5

14. Upon completion of testing, power down simulator and liquid loop in accordance with Reference 2.2.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Thermal Efficiency Test (Continued)

6.3.3 Results

The results of the thermal efficiency test are shown in Table I and are presented graphically in Figure 1.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.4 Post Thirty-Day Stagnation Thermal Efficiency Re-Test

6.4.1 Requirements

Test procedures and requirements will be identical to the thermal efficiency test of Section 6.3.

6.4.2 Results

The results of the post thirty-day stagnation test are presented in Figure 3, along with the pre-test data for comparison and indication of degradation.

7.0

ANALYSIS

7.1

Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m} C_{tf} (t_{f,e} - t_{f,i})}{I} \quad (1)$$

where:

q_u = rate of useful energy extracted from the Solar Collector (BTU/Hr)

A = Gross collector area (Ft²)

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area (BTU/Hr·Ft²)

$\dot{m}$ = Mass flow rate of the transfer liquid through the collector per unit area of the collector (Lbm/Ft²·Hr)

C_{tf} = Specific heat of the transfer liquid (BTU/Lb·°F)

$t_{f,e}$ = Temperature of the transfer liquid leaving the collector (°F)

$t_{f,i}$ = Temperature of the transfer liquid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta = \frac{(\dot{m}A)C_{tf} (t_{f,e} - t_{f,i})}{(IA)} = \frac{\dot{M} C_{tf} (t_{f,e} - t_{f,i})}{P_i} \quad (2)$$

Notice that:

$P_i = IA$ = Total Power Incident on the Collector.

$\dot{m}A = \dot{M}$ = Total Mass Flow Rate through the Collector.

Therefore, $\dot{M} C_{tf}(t_{f,e} - t_{f,i})$ = Total Power Collected by the Collector.

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{P_{abs}}{P_{inc}} \quad (3)$$

where:

P_{abs} = Total collected power

P_{inc} = Total incident power

This value of efficiency is expressed as a percentage by multiplying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{P_{abs}}{P_{inc}} \times 100 \quad (4)$$

or, from Equation (2), collector efficiency is defined by the equation:

$$\% \text{ Eff.} = \frac{\dot{M} C_{tf} (t_{f,e} - t_{f,i})}{P_i} \times 100 \quad (5)$$

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at sixty-second intervals. The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$$\left((t_i - t_a) / I \right)$$

where:

t_i = Liquid inlet temperature ($^{\circ}\text{F}$)

t_a = Ambient temperature ($^{\circ}\text{F}$)

I = Incident flux per unit area ($\text{BTU}/\text{Hr} \cdot \text{Ft}^2$)

The abscissa term $\left((t_i - t_a) / I \right)$ was used to normalize the effect of operating at different values of I , t_i and t_a . The results are found in Figure 1. The results of second order polynomial analyses are included in Figure 1. The second order polynomial to best describe the test results is:

$$\text{Efficiency} = a_0 + a_1 \tau + a_2 \tau^2$$

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

$$\mathcal{J} = (T_i - T_a)/I$$

and the coefficients are determined to be:

<u>Flow Rate (GPM)</u>	<u>0.5</u>
a ₀	0.728
a ₁	-1.046
a ₂	-0.497

The average F_{RUL} for the thermal performance test is indicated by the a₁ coefficient for the first order curve fit polynomial which was determined to be -1.26.

7.0 ANALYSIS (Continued)

7.2 Time Constant Test

Two methods are proposed by ASHRAE 93-77 for conducting a time constant test; however, due to facility limitations, only the first method could be used. This method consisted of shutting down the simulator and maintaining a constant flow rate and inlet temperature while obtaining data.

According to the definition of time constant given in 93-77, it is the time required for the ratio of the differential temperature at time τ to the initial differential temperature to reach .368. It can be expressed as:

$$\frac{T_{f,e,\tau} - T_{f,i}}{T_{f,e,ini} - T_{f,i}} = .368 \quad (1)$$

If the inlet liquid temperature cannot be controlled to equal the ambient air temperature, then the following equation must be used.

$$\frac{FR_{UL} (T_{f,i} - T_a) + \frac{\dot{m}C_p}{A_g} (T_{f,e,\tau} - T_{f,i})}{FR_{UL} (T_{f,i} - T_a) + \frac{\dot{m}C_p}{A_g} (T_{f,e,ini} - T_{f,i})} = .368 \quad (2)$$

where:

$T_{f,e,\tau}$ Exit liquid temperature at time τ

$T_{f,i}$ Inlet liquid temperature

$T_{f,e,ini}$ Initial exit liquid temperature

$\dot{m}$ Liquid mass flow rate, Lb/Hr

C_p Specific heat of liquid, BTU/Lb·°F

A_g Gross collector area, Ft²

FR_{UL} Negative of the slope determined from the thermal efficiency curve

The inlet temperature was maintained within $\pm 2^\circ\text{F}$ of the ambient; hence, equation (1) was used for evaluation. From Figure 2 the time constant was determined to be 2 minutes and 52 seconds.

7.0 ANALYSIS (Continued)

7.3 Post Thirty-Day Stagnation Thermal Efficiency Re-Test

ASHRAE 93-77 does not provide a procedure for this test; therefore, the procedure outlined in NBSIR 78-1305A was used. As indicated in Figure 3, the primary degradation appears in the F_{RUL} value for the collector, indicating a noticeable deterioration of the insulative properties of the collector. A comparison of the second order least squares curve fit co-efficients before and after the thirty-day stagnation (shown below) amplify the conclusion that the transmissivity and the absorptivity are not significantly changed, but the heat loss rate (slope of the curve) is increased.

$$a_0 = 0.728$$

$$a_1 = -1.046$$

Before

$$a_2 = -0.497$$

$$a_0 = 0.723$$

$$a_1 = -1.213$$

After

$$a_2 = -0.349$$

The average F_{RUL} for the thermal performance is indicated by the a_1 coefficient for the first order curve fit polynomial. The values of a_1 before and after the thirty-day stagnation are -1.26 and -1.38, respectively.

TABLE I
THERMAL PERFORMANCE TEST DATA
SUNCATCHER SOLAR COLLECTOR SH-11

Ambient °F	66.2	68.4	75.4	76.2	77.1	77.0	76.7	77.6		
T _{in} °F	82.3	83.3	98.6	98.5	128.7	128.8	148.4	148.8		
T _{out} °F	95.8	99.2	111.9	114.2	139.3	141.4	157.4	159.7		
ΔT °F	13.5	15.9	13.3	15.7	10.6	12.6	9.0	10.9		
Solar Flux BTU/Hr·Ft ²	254.5	300.9	254.5	300.9	254.5	300.9	254.92	300.9		
Flow Rate GPM	.501	.497	.498	.500	.510	.507	.499	.509		
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5		
Efficiency %	65.82	65.04	64.16	64.42	52.00	52.05	42.94	44.93		
$(T_i - T_a) / I^\circ F \cdot Hr \cdot Ft^2 / BTU$	.0633	.0495	.0910	.0741	.2024	.1722	.2813	.2366		

TABLE I (Continued)

THERMAL PERFORMANCE TEST DATA
SUNCATCHER SOLAR COLLECTOR SH-11

Ambient °F	76.0	73.3	71.8	75.3	87.5	88.5				
T _{in} °F	181.8	181.8	78.2	126.1	190.7	164.5				
T _{out} °F	186.7	188.8	95.0	138.2	196.6	175.1				
ΔT °F	4.9	7.0	16.8	12.1	5.9	10.6				
Solar Flux BTU/Hr·Ft ²	254.4	300.9	290.9	290.9	290.9	290.9				
Flow Rate GPM	.496	.501	.506	.502	.501	.490				
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5				
Efficiency %	22.98	28.08	72.4	51.1	24.4	43.2				
$(T_i - T_a) / I^\circ F \cdot Hr \cdot Ft^2 / BTU$	.4151	.3606	.022	.175	.355	.261				

17

Figure 1. Thermal Efficiency of the Suncatcher SH-11 Solar Collector With Water at 0.5 GPM

18

Differential Temperature - ($T_{out,f} - T_{in,f}$)

20

Collector Shaded

10

$\tau = 2 \text{ minutes, } 52 \text{ seconds}$

0

0

1

2

3

Time - Minutes

Figure 2. Suncatcher SH-11 Solar Collector Time Constant Test Results

Figure 3. Comparison of Pre and Post 30-Day Stagnation Thermal Efficiency of the Suncatcher SH-11 Solar Collector with Water at 0.5 GPM