DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-161253

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

Prepared by

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Contract NAS8-32036

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For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy

TABLE OF CONTENTS

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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

4.0 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:

Apparatus	Manufacturer/Model	Range/Accuracy
Pyranometer	Eppley - PSP	0-800 $BTU/Ft^2 \cdot Hr \pm 3\%$
Liquid Loop	MSFC Supplied	.1 - 1/2 GPM
Directional Anemometer	Supplied by AMC	0 - 30 MPH
Flowmeter	Foxboro/1/2-2 81T3C1	.1 - .91 ± 1% GPM
Temperature Transducer	Analog Devices	0 - 500°F ± 0.1°F
Platinum Resistance Thermometer	Hy-Cal	0 - 500°F ± 0.5°F
Digital Printer	Doric Digitrend 220	0 - 500 MV ± 2%
Fans	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006
Differential Pressure Transducer	Statham	0 - 10 PSID ± 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 BTU/Ft^2·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 BTU/Hr·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°F of ambient while the liquid is flowing at 14.7 $lbm/hr \cdot ft^2$. 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°F.

3. Power up the solar simulator and establish a solar flux level of 260 $BTU/Ft^2 \cdot Hr$.

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.

Variable/Condition	Requirement
(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:

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

where:

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

A = Gross collector area (Ft^2)

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$)

$\dot{m}$ = Mass flow rate of the transfer liquid through the collector per unit area of the collector ($Lbm/Ft^2 \cdot Hr$)

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:

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

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:

$$\eta = \frac{Pabs}{Pinc} \qquad (3)$$

where:

Pabs = Total collected power

Pinc = Total incident power

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

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \qquad (4)$$

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

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

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 (°F)

t_a = Ambient temperature (°F)

I = Incident flux per unit area (BTU/Hr·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:

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

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

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

and the coefficients are determined to be:

Flow Rate (GPM)	0.5
a_0	0.728
a_1	-1.046
a_2	-0.497

The average $F_R U_L$ for the thermal performance test is indicated by the a_1 coefficient for the first order curve fit polynomial which was determined to be -1.26.

7.0 <u>ANALYSIS</u> (Continued)

7.2 <u>Time Constant Test</u>

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:

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

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

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

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, Ft^2
$F_R U_L$	Negative of the slope determined from the thermal efficiency curve

The inlet temperature was maintained within ± 2°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 $F_R U_L$ 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 $F_R U_L$ 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		
(Ti-Ta)/I°F·Hr·Ft^2/BTU	.0633	.0495	.0910	.0741	.2024	.1722	.2813	.2366		

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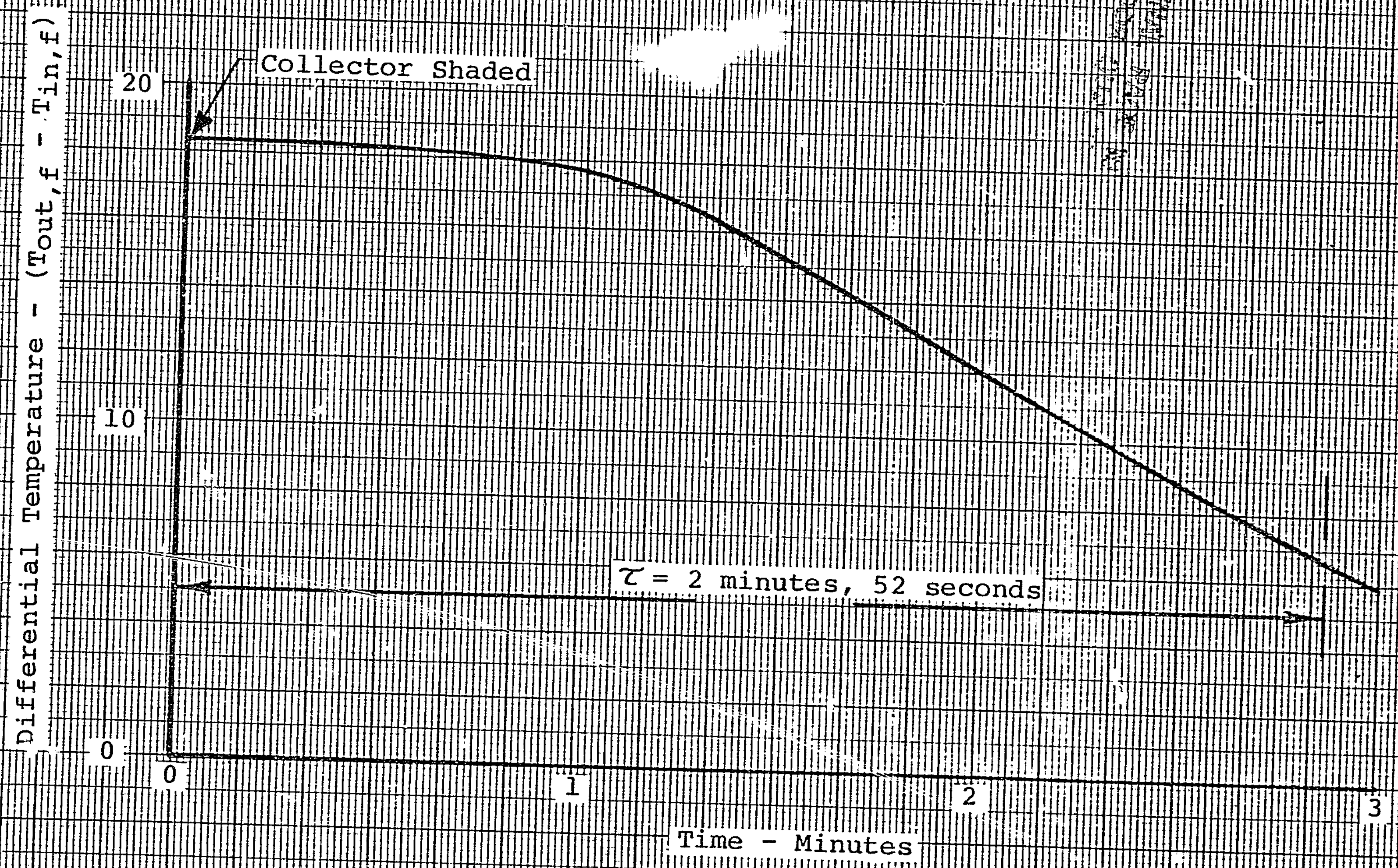

Figure 2. Suncatcher SH-11 Solar Collector Time Constant Test Results

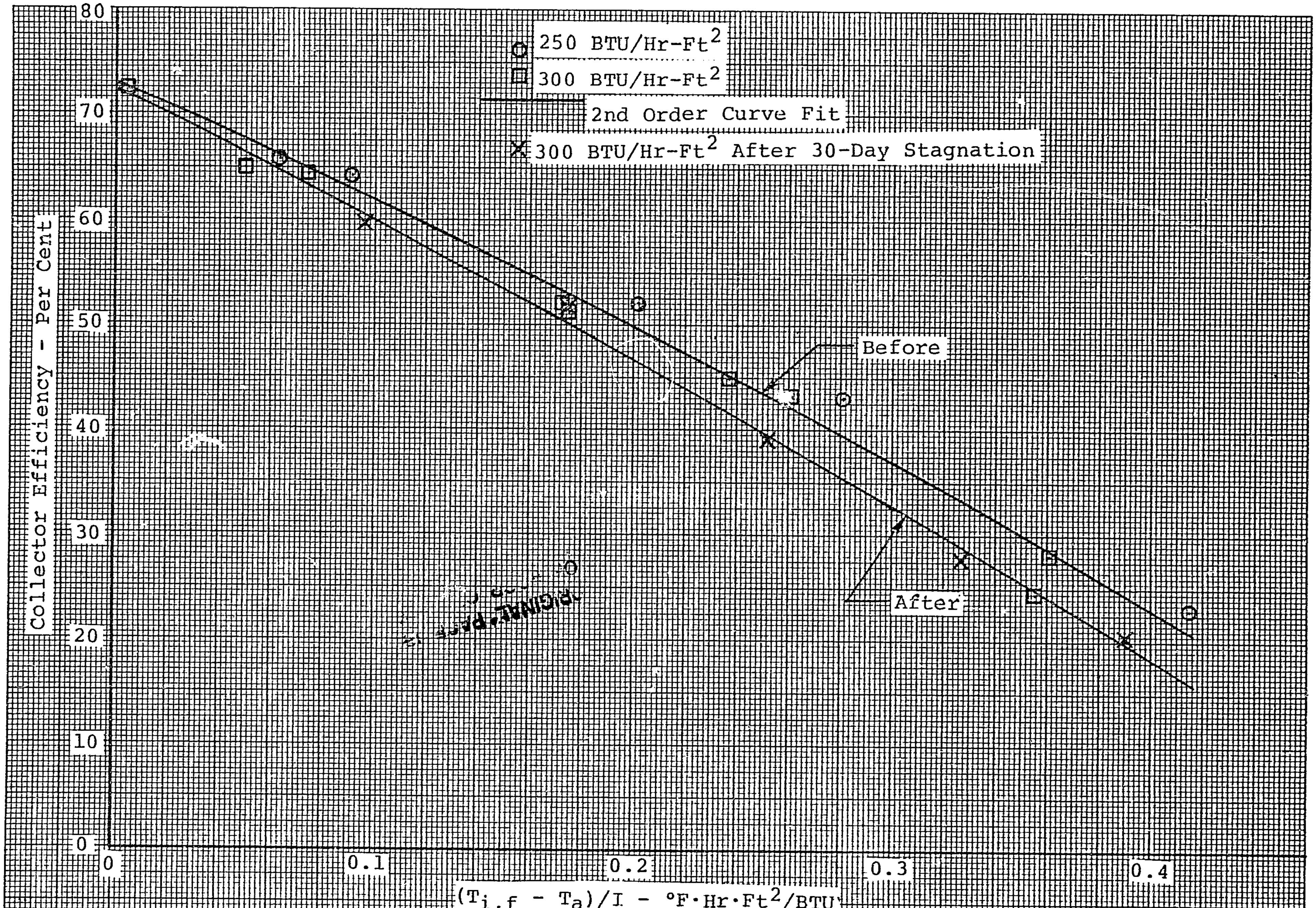

Figure 3. Comparison of Pre and Post 30-Day Stagnation Thermal Efficiency of the Suncatcher SH-11 Solar Collector with Water at 0.5 GPM