348
3/15/79

DR. 2337

DOE/NASA CONTRACTOR
REPORT

DOE/NASA CR-161093

LONG-TERM WEATHERING EFFECTS ON THE THERMAL PERFORMANCE OF THE LIBBEY-OWENS-FORD (LIQUID) SOLAR COLLECTOR

Prepared by

Wyle Laboratories
Solar Energy Systems Division
Huntsville, Alabama 35805

Under subcontract with IBM Corporation, Federal Systems Div, Huntsville, Ala. 35805

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

MASTER

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-161093		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Long Term Weathering Effects on the Thermal Performance of the Libbey-Owens-Ford (Liquid) Solar Collector				5. REPORT DATE January 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 35803				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO. NAS8-32036	
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 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 test procedures used during the performance of an evaluation test program, conducted to obtain the thermal performance data on the solar collector following long term exposure to natural weathering conditions. The total weathering period was about fourteen and one-half months.</p> <p>The test article is a flat-plate solar collector that uses liquid as the heat transfer medium. The overall dimensions of the collector are 3' x 7' x 4-3/4". The absorber plate is No. 110 copper and is .021" thick. It has a double glass cover of 1/8" tempered glass, and weighs approximately 130 pounds.</p> <p>The initial thermal performance evaluation test and results, before long term exposure to weathering conditions, are contained in report, DOE/NASA CR-150508. Libbey-Owens-Ford solar collector static load test information is contained in report, DOE/NASA CR-150852.</p>					
17. KEY WORDS			18. DISTRIBUTION STATEMENT UC-59 c Unclassified-Unlimited William A. Brooksbank, Jr. Mgr, Solar Heating and Cooling Project Office;		
19. SECURITY CLASSIF. (of this report) Unclassified		20. SECURITY CLASSIF. (of this page) Unclassified		21. NO. OF PAGES 12	
				22. PRICE NTIS	

1. REPORT NO. DOE/NASA CR-161093		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Long Term Weathering Effects on the Thermal Performance of the Libbey-Owens-Ford (Liquid) Solar Collector				5. REPORT DATE January 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 35803				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO. NAS8-32036	
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 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 This report contains test procedures used during the performance of an evaluation test program, conducted to obtain the thermal performance data on the solar collector following long term exposure to natural weathering conditions. The total weathering period was about fourteen and one-half months. The test article is a flat-plate solar collector that uses liquid as the heat transfer medium. The overall dimensions of the collector are 3' x 7' x 4-3/4". The absorber plate is No. 110 copper and is .021" thick. It has a double glass cover of 1/8" tempered glass, and weighs approximately 130 pounds. The initial thermal performance evaluation test and results, before long term exposure to weathering conditions, are contained in report, DOE/NASA CR-150508. Libbey-Owens-Ford solar collector static load test information is contained in report, DOE/NASA CR-150852.					
17. KEY WORDS			18. DISTRIBUTION STATEMENT UC-59 c , Unclassified-Unlimited William A. Brooksbank, Jr. Mgr, Solar Heating and Cooling Project Office;		
19. SECURITY CLASSIF. (of this report) Unclassified		20. SECURITY CLASSIF. (of this page) Unclassified		21. NO. OF PAGES 12	
				22. PRICE NTIS	

TABLE OF CONTENTS

		<u>Page No.</u>
1.0	SUMMARY	1
2.0	PURPOSE	2
3.0	REFERENCES	2
4.0	TEST REQUIREMENTS AND PROCEDURES	3
	4.1 Collector Thermal Efficiency Test Requirements	3
	4.2 Test Procedure	3
5.0	ANALYSIS	5
	5.1 Thermal Performance Test	5
TABLE I	LIBBEY-OWENS-FORD COLLECTOR PERFORMANCE RECHECK AFTER LONG TERM EXPOSURE TO NATURAL WEATHERING CONDITIONS	8
TABLE II	LIBBEY-OWENS-FORD COLLECTOR THERMAL PERFORMANCE TEST DATA - 10 MPH WIND BEFORE LONG TERM EXPOSURE	9
Figure 1	Libbey-Owens-Ford Collector Indoor Thermal Performance Test Results	10

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

Deq

SUMMARY

Thermal performance tests were conducted on the Libbey-Owens-Ford liquid collector, following long term exposure to natural weathering conditions. The collector was mounted on the weathering test stand at the Solar Test Facility at Marshall Space Flight Center, Alabama, with exposure to the natural ambient environment. The collector was under stagnation conditions from June 1, 1977, to August 15, 1978. The collector was retested at the Marshall Space Flight Center Solar Simulator on August 21, 1978. The total weathering period was approximately fourteen and one-half months.

Visual inspection of the collector, prior to the re-test, indicated noticeable clouding of the inner cover glass, probably resulting from out gassing of the insulation. The absorber plate also showed some discoloration. The test results indicated that performance degradation had occurred at inlet temperatures significantly above ambient. The change in the slope of the efficiency curve, from the original data, is a direct indicator of an increase in the collector heat loss coefficient.

2.0

PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during an evaluation test program. The test program was conducted to obtain thermal performance data on a Libbey-Owens-Ford double-covered liquid solar collector under simulated conditions (Reference 3.1), following long term exposure to natural weathering conditions. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test procedures specified in Reference 3.2 and the test requirements of Reference 3.3.

3.0

REFERENCES

3.1	WYLE TR-531-07	Indoor Test for Thermal Performance Evaluation of the Libbey-Owens-Ford Solar Collector
3.2	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
3.3	ASHRAE-93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors
3.4	ASHRAE-93-P	Method of Testing Solar Collectors Based on Thermal Performance

4.0

TEST REQUIREMENTS AND PROCEDURES

4.1

Collector Thermal Efficiency Test Requirements

Thermal performance evaluation criteria shall correspond to that of Reference 3.1 with the exception that gross collector area is used according to Reference 3.3. The original data was based on the aperture area according to Reference 3.4. Reference 3.4 was superseded by Reference 3.3, which is the current standard. The original data has been modified based on this standard for comparative purposes as shown in Figure 1 and Table II. Data shall be obtained at inlet temperatures of 0, 25, 50 and 100°F above the ambient temperature at a liquid flow rate of 290 lb/hr (0.58 GPM) at a solar insolation rate of 300 BTU/Hr·Ft² and a wind speed of 7.5 mph. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet liquid temperature.
3. Collector outlet liquid temperature.
4. Collector differential temperature.
5. Differential pressure across collector.
6. Liquid flow rate.
7. Insolation rate.
8. Wind speed.

4.2

Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 45° with respect to the floor.
3. Align the test table so that the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the top of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all pipes.
5. Assure that data acquisition system is operational.
6. Start liquid flow loop and establish a flow rate of 290 Lb/Hr (0.58 GPM).

4.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

4.2 Test Procedure (Continued)

7. Establish the wind speed of 7.5 mph.
8. Power up simulator and establish a solar flux level of 300 BTU/Ft²·Hr.
9. Determine the ambient air temperature.
10. Adjust the inlet temperature of the collector to the ambient air temperature value.
11. After steady state conditions have been established, record data for a minimum of five minutes.
12. Repeat steps 9, 10, and 11, changing the liquid inlet temperature as necessary until data has been obtained for each test condition specified in Paragraph 4.1.
13. Upon completion of testing, power down simulator and liquid loop.
14. Inform data control group that simulator operation has terminated.

5.0

ANALYSIS

5.1

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.

5.0 ANALYSIS (Continued)

5.1 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:

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

Each term in Equation (5) was measured and recorded independently during the test. 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

$$((t_i - t_a)/I)$$

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 $((t_i - t_a)/I)$ was used to normalize the effect of operating at different values of I , t_i and t_a . The results are shown graphically in Figure 1 with the supporting test data given in Table I. An update of the original efficiency data is shown in Table II, based on the gross collector area.

5.0

ANALYSIS AND RESULTS (Continued)

5.1

Thermal Performance Test (Continued)

Reference 3.3 uses the following terms relating to the thermal efficiency graph:

$F_R \alpha \tau$ = intercept of the efficiency curve on the ordinate axis

$F_R U_L$ = the negative of the slope of the efficiency curve

F_R = the solar heat removal factor

α = absorptance of the collector surface for solar radiation

τ = transmittance of the solar collector cover plate

U_L = solar collector heat transfer loss coefficient

Although the value of $F_R \alpha \tau$ was not significantly changed by weathering, the slope, $F_R U_L$, did increase noticeably. Assuming that F_R , α , and τ did not change as indicated above, then the heat loss coefficient, U_L , increased as a result of the weathering. This is supporting evidence that the cloudiness on the inner cover plate was due to out-gassing of the insulation, resulting in poorer performance.

TABLE I

LIBBEY-OWENS-FORD COLLECTOR PERFORMANCE RECHECK
 AFTER LONG TERM EXPOSURE TO NATURAL WEATHERING CONDITIONS
 7.5 MPH WIND

Ambient Air Temperature (T_a), °F	82.1	83.6	80.0	80.6	81.9
Fluid Inlet Temperature (T_i), °F	89.6	105.9	129.3	156.8	180.3
Fluid Outlet Temperature (T_e), °F	103.8	119.6	141.1	166.9	188.7
Differential Fluid Temperature (ΔT), °F	14.2	13.7	11.8	10.1	8.4
Total Solar Flux (I), BTU/Hr·Ft ²	305.2	305.2	305.2	305.2	305.2
Flow Rate, GPM	0.537	0.582	0.581	0.581	0.588
$(T_i - T_a)/I$ °F·Hr·Ft ² /BTU	0.024	0.073	0.161	0.249	0.322
Efficiency (η), %	64.8	61.8	52.7	44.8	37.4
Specific Gravity	0.996	0.993	0.986	0.980	0.971

TABLE II
LIBBEY-OWENS-FORD COLLECTOR THERMAL PERFORMANCE TEST DATA - 10 MPH WIND
BEFORE LONG TERM EXPOSURE

Collector Side °F	80.9	67.5	83.9	84.2	86.1	84.5	72.6	74.2	79.8	80.1
Collector Back °F	81.3	68.7	84.9	85.3	86.6	85.3	73.5	75.3	81.1	81.7
Outer Cover °F	86.0	75.9	90.7	91.9	92.3	92.7	81.7	85.1	90.9	93.0
North Surface °F	101.8	101.1	121.9	124.8	139.3	142.9	164.1	167.8	207.8	211.2
Center Surface °F	97.4	96.7	118.1	120.4	136.8	138.9	161.5	164.5	206.3	209.2
West Surface °F	97.5	96.6	118.2	120.5	135.8	139.0	161.3	164.4	205.6	208.7
South Surface °F	90.0	88.6	111.4	112.0	129.5	132.0	156.0	158.1	201.8	204.0
Ambient °F	72.9	58.0	74.0	74.3	74.7	74.1	59.0	59.6	63.4	62.3
T _{in} °F	77.6	74.5	100.8	99.9	120.2	120.6	149.9	149.5	199.8	199.8
T _{out} °F	91.7	89.0	112.7	114.2	131.0	133.3	157.4	158.5	203.1	205.2
T °F	14.1	15.5	11.9	14.3	10.7	12.7	7.5	10.1	3.3	5.4
Solar Flux BTU/Hr·Ft ²	231.0	271.8	231.2	272.3	233.6	270.0	231.8	270.8	234.5	273.7
Flow Rate Lb/Hr	291.2	290.5	290.6	289.8	290.3	289.3	291.5	291.6	289.8	289.3
Wind Speed mph	10	10	10	10	10	10	10	10	10	10
Efficiency %	66.0	61.7	56.8	57.9	51.8	53.5	37.5	42.9	16.6	23.8
(T _i -T _a) / I °F·Hr·Ft ² /BTU	.021	.061	.116	.094	.195	.172	.392	.332	.582	.502

Figure 1. Libbey-Owens-Ford Collector Indoor Thermal Performance Test Results