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LONG-TERM WEATHERING EFFECTS ON THE THERMAL PERFORMANCE OF THE LENNOX/HONEYWELL (LIQUID) SOLAR COLLECTOR

Prepared by

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16. ABSTRACT

This report presents the test procedures used and the results obtained during the evaluation test program of the Lennox/Honeywell double covered liquid solar collector. The tests were performed under simulated conditions, following long-term exposure to natural weathering conditions.

The Lennox/Honeywell collector is a flat-plate solar collector. The absorber plate is steel with copper tubes bonded on the upper surface, and is coated with black chrome with an absorptivity factor of .95 and emissivity factor of .12. It has a double glass cover of 1/8-inch tempered glass and weighs about 153 pounds. The overall dimensions of the collector are 3' x 6' x 6-1/2".

For further information on the Lennox/Honeywell collector test procedures and performance evaluation, see DOE/NASA CR-150510.

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SUMMARY

Thermal performance tests were conducted on the Lennox/Honeywell double-covered liquid solar 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 September 11, 1978. The collector was retested at the Marshall Space Flight Center Solar Simulator on September 13, 1978. The total weathering period was approximately fifteen and one-half months.

Visual inspection of the collector, prior to re-test, indicated slight discoloration of the absorber plate. The test results indicated that performance degradation had occurred and the lack of change in the slope of the efficiency curve, from the original data, is a direct indicator of no increase in the collector heat loss coefficient. The change in the intercept of the efficiency curve on the ordinate axis implies that the absorptivity and/or transmissivity has decreased as a result of the weathering.

1.0 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 Lennox/Honeywell double-covered liquid solar collector under simulated conditions (Reference 2.1), 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 2.2 and the test requirements of Reference 2.3.

2.0 REFERENCES

2.1	DOE/NASA CR-150510	Indoor Test for Thermal Performance Evaluation of the Lennox/Honeywell Solar Collector
2.2	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
2.3	ASHRAE 93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors
2.4	ASHRAE 93-P	Method of Testing Solar Collectors Based on Thermal Performance

3.0 TEST REQUIREMENTS AND PROCEDURES

3.1 Collector Thermal Efficiency Test Requirements

Thermal performance evaluation criteria shall correspond to that of Reference 2.1 with the exception that gross collector area is used according to Reference 2.3. The original data was based on the aperture area according to Reference 2.4. Reference 2.4 was superceded by Reference 2.3, 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, 75, and 100°F above the ambient temperature at a liquid flow rate of 225 lb/hr (0.45 GPM) at a solar insolation rate of 300 BTU/Hr·Ft^2 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.

3.2 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.

3.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

3.2 Test Procedure (Continued)

6. Start liquid flow loop and establish a flow rate of 225 Lb/Hr (0.45 GPM).

7. Establish the wind speed of 7.5 mph.

8. Power up simulator and establish a solar flux level of 300 $BTU/Ft^2 \cdot Hr$.

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 3.1.

13. Upon completion of testing, power down simulator and liquid loop.

4.0 ANALYSIS OF RESULTS

4.1 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:

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

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:

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

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.

4.0 ANALYSIS AND RESULTS (Continued)

4.1 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:

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

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

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

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 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.

4.1 Thermal Performance Test (Continued)

Reference 2.3 uses the following terms relating to the thermal efficiency graph:

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

F_RU_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

A comparison of the before and after weathering efficiency curves indicates that the slope, F_RU_L, did not change noticeably; however, the value of $F_R\alpha\tau$ did change significantly. With no noticeable change in the transmissivity of the cover plates, the conclusion would be that the absorptivity has degraded as a result of the weathering.

TABLE I

LENNOX/HONEYWELL COLLECTOR PERFORMANCE RECHECK AFTER LONG TERM EXPOSURE TO NATURAL WEATHERING CONDITIONS 7.5 MPH WIND

Ambient Air Temperature (T_a), °F	81.4	81.2	81.0	78.4	79.7
Fluid Inlet Temperature (T_i), °F	86.7	107.1	132.7	150.5	184.2
Fluid Outlet Temperature (T_e), °F	100.5	119.9	144.5	161.3	193.8
Differential Fluid Temperature (ΔT), °F	13.8	12.8	11.8	10.8	9.6
Total Solar Flux (I), $BTU/Hr \cdot Ft^2$	295.4	295.4	295.4	299.1	299.1
Flow Rate, GPM	.472	.470	.464	.463	.472
$(T_i - T_a)/I$ $°F \cdot Hr \cdot Ft^2/BTU$	.018	.088	.175	.241	.349
Efficiency (η), %	61.1	56.7	51.2	45.9	41.2
Specific Gravity	.997	.993	.935	.981	.970

TABLE II

LENNOX/HONEYWELL COLLECTOR PERFORMANCE TEST DATA
BEFORE LONG TERM WEATHER EXPOSURE
10 MPH WIND

Collector Side °F	97.5	100.1	99.5	101.4	101.5	94.3	101.6	101.0	100.6
Collector Back °F	80.2	85.2	86.9	88.9	90.2	87.6	90.2	94.4	94.4
Outer Cover °F	91.0	94.0	95.0	95.8	97.2	92.0	96.7	98.1	98.7
Surface - North °F	121.4	138.0	144.3	156.0	161.7	179.0	188.0	224.6	231.5
Surface - Center °F	116.6	133.2	138.9	151.2	156.3	175.1	183.0	220.8	227.2
Surface - East °F	116.3	132.5	137.9	150.0	154.9	172.9	181.1	217.4	223.6
Surface - South °F	109.5	126.8	131.8	145.6	150.1	170.8	177.6	217.2	222.8
Ambient °F	79.7	81.4	82.4	83.0	84.4	78.7	79.5	80.7	80.9
T_{in} °F	81.3	99.5	99.7	119.5	119.4	149.7	149.6	199.6	199.8
T_{out} °F	98.1	115.7	118.7	134.6	137.3	161.1	165.1	208.6	211.5
ΔT °F	16.8	16.2	19.0	15.1	17.9	11.4	15.5	9.0	11.7
Flow Rate Lb/Hr	224.8	225.1	224.3	225.6	223.5	224.2	224.3	226.1	224.4
Flux $BTU/Hr \cdot Ft^2$	255.4	255.0	297.9	255.0	297.6	243.6	297.0	243.6	283.0
Efficiency %	64.5	64.2	64.1	61.2	61.5	48.7	54.7	39.2	43.2
$(T_i - T_a)/I$ $°F \cdot Hr \cdot Ft^2/BTU$	.006	.071	.058	.143	.118	.291	.236	.488	.420

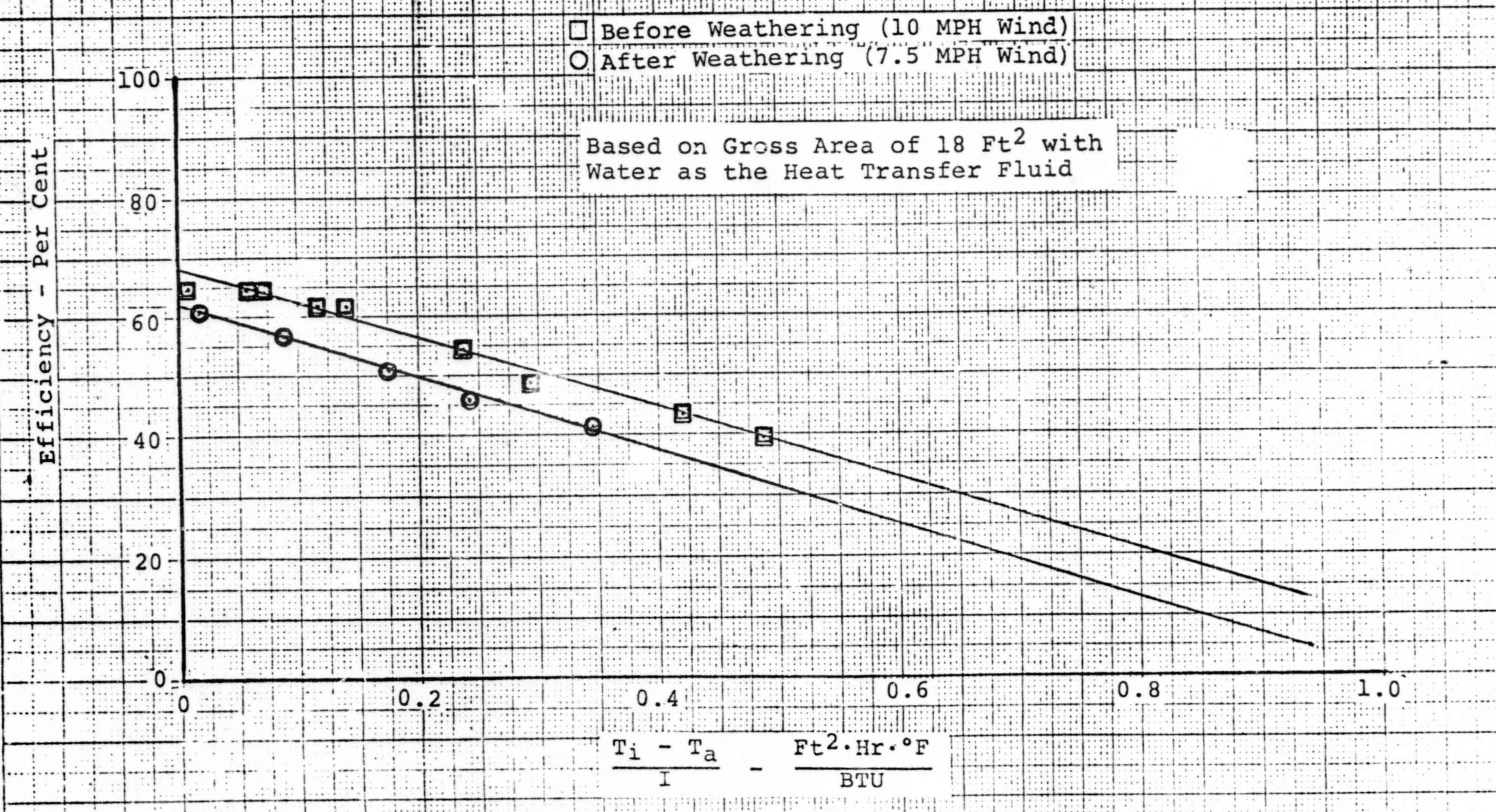

Figure 1. Lennox/Honeywell Collector Indoor Thermal Performance Test Results

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