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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150508

INDOOR TEST FOR THERMAL PERFORMANCE EVALUATION OF LIBBEY-OWENS-FORD SOLAR COLLECTOR

Prepared by

Wyle Laboratories
Solar Energy Systems Division
Huntsville, Alabama 35805

Under sub-contract to

IBM Corporation, Federal Systems Division, Huntsville, Alabama 35805

Contract NAS8-32036

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

for the U. S. Department of Energy

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16. ABSTRACT

This test program was conducted to evaluate the thermal performance of a Libbey-Owens-Ford liquid collector under simulated conditions. The test conditions and the thermal performance data obtained during the tests conducted on the simulator are described. In addition, a time constant test and incident angle modifier test were conducted to determine the transient effect and the incident angle effect on the collector.

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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 Libbey-Owens-Ford double-covered liquid solar collector under simulated conditions. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test requirements specified in Reference 2.1 and the procedures contained in Reference 2.2.

2.0 REFERENCES

2.1	ASHRAE-93-P	Method of Testing Solar Collectors Based on Thermal Performance
2.2	MTCP-DC-SHAC-407	Test Procedure For Thermal Performance Evaluation of Libbey-Owens-Ford Solar Collector
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility

3.0 MANUFACTURER

Libbey-Owens-Ford
811 Madison Avenue
Toledo, Ohio 43695

3.1 DESCRIPTION OF TEST SPECIMEN

The test article is a flat plate solar collector that uses liquid as the heat transfer medium. The absorber plate is #110 copper and is .021" thick. The absorber surface is 19.74 square feet and over-all dimensions of the collector are 3'x7'x4 3/4". It has a double glass cover of 1/8" tempered glass, and weighs approximately 130 pounds.

4.0 SUMMARY

This test program was conducted to evaluate the thermal performance of a Libbey-Owens-Ford liquid collector under simulated conditions. The test conditions and the thermal performance data obtained during the tests conducted on the simulator are listed in Tables I through IV, respectively. A graphic presentation of the data obtained is also presented in Figure 1. In addition, a time constant test and incident angle modifier test were conducted to determine the transient effect and the incident angle effect on the collector. The results of these tests are presented in Figures 2 through 4 and Tables V and VI.

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 5300.4 C, Metrology and Calibration. A standard test setup is depicted in Reference 2.3.

Apparatus	Manufacturer/Model	Range and Accuracy
Liquid loop	MSFC Supplied	.1-1.12 GPM
Reference Junction	Pace/150	150 ±1°F
Thermocouple	MSFC Supplied	0-500°F ±1.8°F
Flowmeter	Foxboro/1/2-2 81T361	.1-1.2 ±1% GPM
Resistance Thermometer	Thermal Systems/T200	0-500 ±.05°F
Radiometer	Eppley/8-48	0-400 ±10% BTU/Hr·Ft^2
Directional Anemometer	MSFC Supplied	0-60 MPH
Floor Fans	MSFC Supplied	NA
Solar Simulator	MSFC Supplied	See SHC 3006
Thermopile	Medtherm	0-20°F ±.05°F

6.0 REQUIREMENTS, PROCEDURES AND RESULTS

6.1 Indoor Thermal Performance Evaluation Test

6.1.1 Requirements

The requirements of this test were to obtain performance information at 100, 120, 150 and 200°F inlet temperatures with a controlled liquid flow rate of 290 pounds per hour at solar flux levels of 230 and 270 BTU/Hr·Ft^2 with simulated wind conditions of 0, 10 and 13 MPH. The following data were recorded for the test.

1.	Collector side wall temperature	(°F)
2.	Collector back side temperature	(°F)
3.	Collector outer cover temperature	(°F)
4.	Absorber surface temperature - North side	(°F)
5.	Absorber surface temperature - Center	(°F)
6.	Absorber surface temperature - West side	(°F)
7.	Absorber surface temperature - South side	(°F)
8.	Ambient temperature	(°F)
9.	Liquid inlet temperature	(°F)
10.	Liquid outlet temperature	(°F)
11.	Liquid differential temperature	(°F)
12.	Solar flux	(BTU/Hr·Ft^2)
13.	Flow rate	(Lb/Hr)
14.	Wind speed	(MPH)

Collector temperature measurements were taken from locations identified in Figure 5.

6.1.2 Procedure

This test program was conducted in accordance with detailed procedures contained in Reference 2.2. Briefly stated, these procedures required the following:

1. Prepare test setup; mount collector on test facility and connect instrumentation leads to data acquisition system.

2. Establish required liquid flow rate.

3. Establish required inlet temperature of 100°F.

4. Establish required solar flux level at 230 BTU/Hr·Ft^2.

5. Establish required wind speed of 0 MPH.

6. Record data for 5 minute stabilized period.

7. Repeat above steps as necessary to obtain data under all conditions listed in Table I.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.1.3 Results

The results obtained during these tests are contained in Figure 1 and Tables II through IV.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.2 Time Constant Test

6.2.1 Requirements

The requirements of this test were to obtain the time constant for the collector at inlet temperature controlled to ambient air temperature with the solar flux level of 230 BTU/Hr·Ft^2, and liquid flow rate of 290 Lb/Hr. The following data were recorded for the test.

1.	Collector side wall temperature	(°F)
2.	Collector back side temperature	(°F)
3.	Collector outer cover temperature	(°F)
4.	Absorber surface temperature - North side	(°F)
5.	Absorber surface temperature - Center	(°F)
6.	Absorber surface temperature - West side	(°F)
7.	Absorber surface temperature - South side	(°F)
8.	Ambient temperature	(°F)
9.	Liquid inlet temperature	(°F)
10.	Liquid outlet temperature	(°F)
11.	Liquid differential temperature	(°F)
12.	Solar flux	(BTU/Hr·Ft^2)
13.	Flow rate	(Lb/Hr)
14.	Wind speed	(MPH)

6.2.2 Procedure

1. Establish required liquid flow rate.
2. Establish required inlet temperature.
3. Establish required solar flux level.
4. Establish required wind speed.
5. Record data for 5 minute stablized period.
6. Shut off solar simulator and maintain the inlet conditions.
7. Record the change of differential temperature on a strip chart recorder.

6.2.3 Results

The results obtained during these tests are contained in Figure 2 and Table V.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.3 Incident Angle Modifier Test

6.3.1 Requirements

The requirements of this test were to determine the effect of incident angle on the collector at inlet temperature controlled to ambient air temperature with a liquid flow rate of 290 Lb/Hr with the collector tilted at 45°, 60° and 75° with respect to the solar simulator surface. The following data were recorded for the test.

1.	Collector side wall temperature	(°F)
2.	Collector back side temperature	(°F)
3.	Collector outer cover temperature	(°F)
4.	Absorber surface temperature - North side	(°F)
5.	Absorber surface temperature - Center	(°F)
6.	Absorber surface temperature - West side	(°F)
7.	Absorber surface temperature - South side	(°F)
8.	Ambient temperature	(°F)
9.	Liquid inlet temperature	(°F)
10.	Liquid outlet temperature	(°F)
11.	Liquid differential temperature	(°F)
12.	Solar flux	($BTU/Hr \cdot Ft^2$)

6.3.2 Procedure

1. Set up collector at required tilt angle.

2. Establish required flow rate.

3. Establish required inlet temperature.

4. Establish solar simulator flux level.

5. Record the flux level on the collector surface.

6. Record data for 5 minute stablized period.

7. Repeat above steps as necessary to complete the required tests.

6.3.3 Results

The results obtained during the test are depicted in Figures 3 and 4, and Table VI.

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:

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

where:

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

A = Total 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 ($Lbm/Hr \cdot Ft^2$) Ⓐ

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:

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

Notice that:

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

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

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

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7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{P_{abs}}{P_{inc}} \tag{3}$$

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:

$$\text{Collector Efficiency} = \frac{P_{abs}}{P_{inc}} \times 100 \tag{4}$$

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

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

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at seventy-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

$$\left((t_{f,i} - t_a)\ /I\right)$$

where:

$t_{f,i}$ = Liquid inlet temperature (°F)

t_a = Ambient temperature (°F)

I = Incident flux per unit area (BTU/Hr·Ft^2)

The abscissa term $\left((t_{f,i} - t_a)\ /I\right)$ was used to normalize the effect of operating at different values of I, $t_{f,i}$ and t_a. The results are found in Figure 1.

The result of second order polynomial analysis is shown in Figure 1. The second order polynomial to best describe the test results is:

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

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

$\mathcal{T} = (t_{f,i} - t_a)\ I$

and the coefficients are determined to be:

WIND	0 MPH	10 MPH	13 MPH
a_0	.705195	.693373	.711841
a_1	-.615549	-.603090	-.717747
a_2	-.305296	-.486951	-.432540

7.0 ANALYSIS (Continued)

7.2 Time Constant Test

Two methods are proposed by ASHRAE 93-P 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-P, 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 can not be controlled to equal the ambient air temperature, then the following equation must be used

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

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 = 290 Lb/Hr
C_p	Specific heat of liquid = .78 BTU/Lb·°F
A	Collector area = 19.74 Ft^2
$F_R U_L$	Negative of the slope determined from the thermal efficiency curve

During the time constant test, the inlet liquid temperature could not be controlled to within ±2°F of ambient air temperature, hence equation (2) must be used for evaluation. From the performance curve, it is found that $F_R U_L$ = .747. Equation (2) becomes

$$\frac{.747\ (83.1-72.3) + 11.602\ (t_{f,e,\tau} - 83.1)}{.747\ (83.1-72.3) + 11.602\ (\quad 13.24\quad)} = .368$$

7.0 ANALYSIS (Continued)

7.2 Time Constant Test (Continued)

or

$$\frac{t_{f,e\ \tau} - t_{f,i}}{t_{f,e,ini} - t_{f,i}} = .335$$

From Figure 2 the time constant was determined to be 1 minute and 45 seconds.

7.0 ANALYSIS (Continued)

7.3 Incident Angle Modifier Test

Two methods are proposed by ASHRAE 93-P for incident angle modifier tests. For the MSFC Solar Simulator Facility, only method 1, (tilting the collector) is applicable. The collector was adjusted so that the incident radiation angles were 45°, 60° and 75° to the normal of the collector surface.

According to 93-P, the incident angle modifier is defined as

$$K_{\alpha\tau} = \frac{\eta}{F_R(\tau\alpha)_n} \qquad (1)$$

where η = efficiency at tilted angle

$F_R(\alpha\tau)_n$ = Intercept of efficiency curve at normal incident angle

For equation (1) to be applicable, the inlet liquid temperature must be controlled to within ±2°F of the ambient air temperature. In cases where the inlet liquid temperature can not be controlled to within ±2°F the following equation must be used to evaluate the incident angle modifier

$$K_{\alpha\tau} = \frac{\eta + F_F U_L \dfrac{T_{f,i} - T_a}{I}}{F_R(\alpha\tau)_n} \qquad (2)$$

where:

$F_R U_L$ is the negative of the slope determined from the thermal efficiency curve.

Table VI shows that the inlet liquid temperatures were not within ±2°F of ambient air temperature. Hence, equation (2) was used for evaluation.

$$K_{\alpha\tau} = \frac{\eta + .747 \dfrac{T_{f,i} - T_a}{I}}{.71}$$

The results of this computation is shown on Table VI and plotted against incident angle in Figure 3 and plotted against $\frac{1}{\cos \theta i} - 1$ in Figure 4.

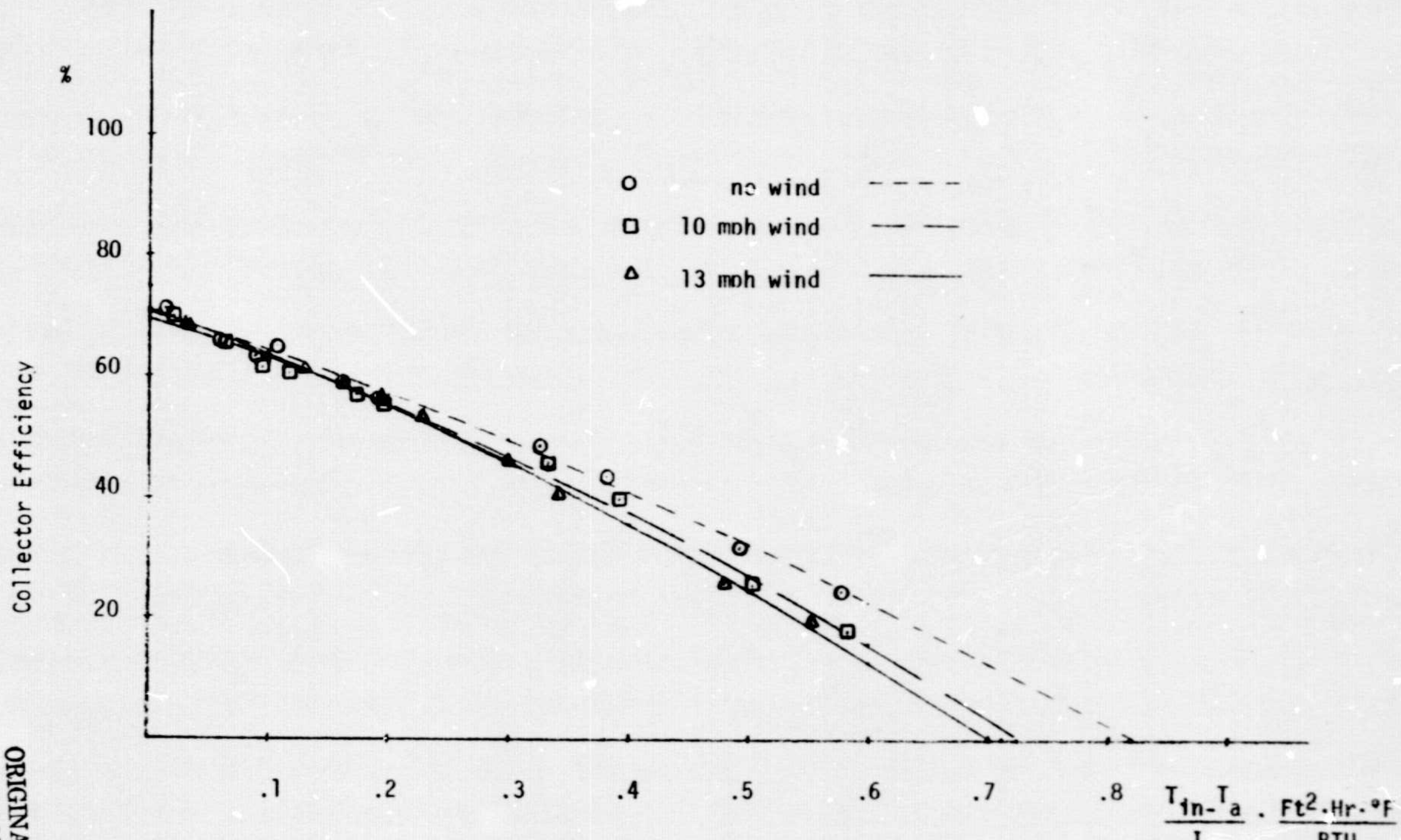

Figure 1. Libbey-Owens-Ford Collector Indoor Thermal Performance Test Results

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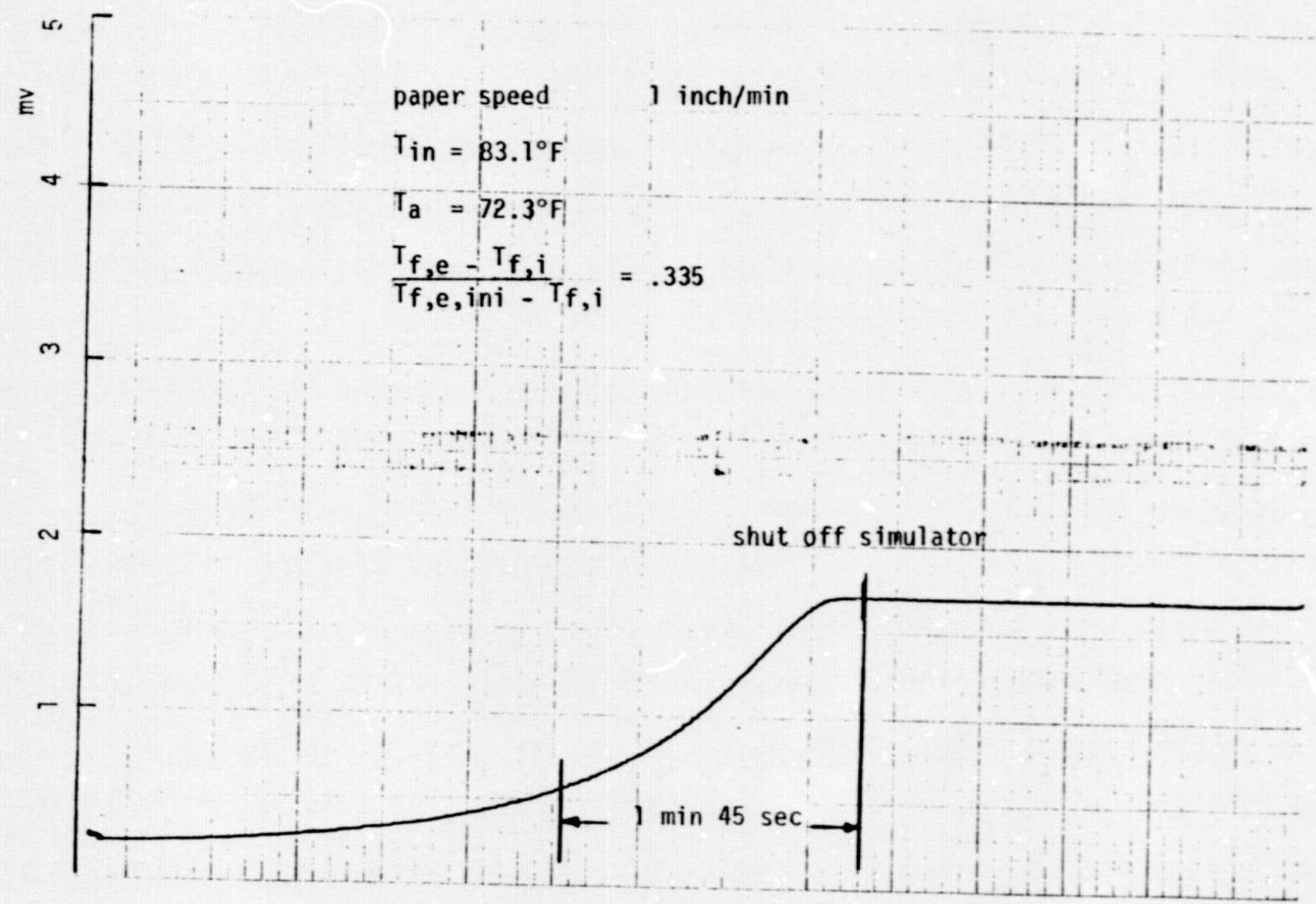

Figure 2. Libbey-Owens-Ford Collector Time Constant Test Results

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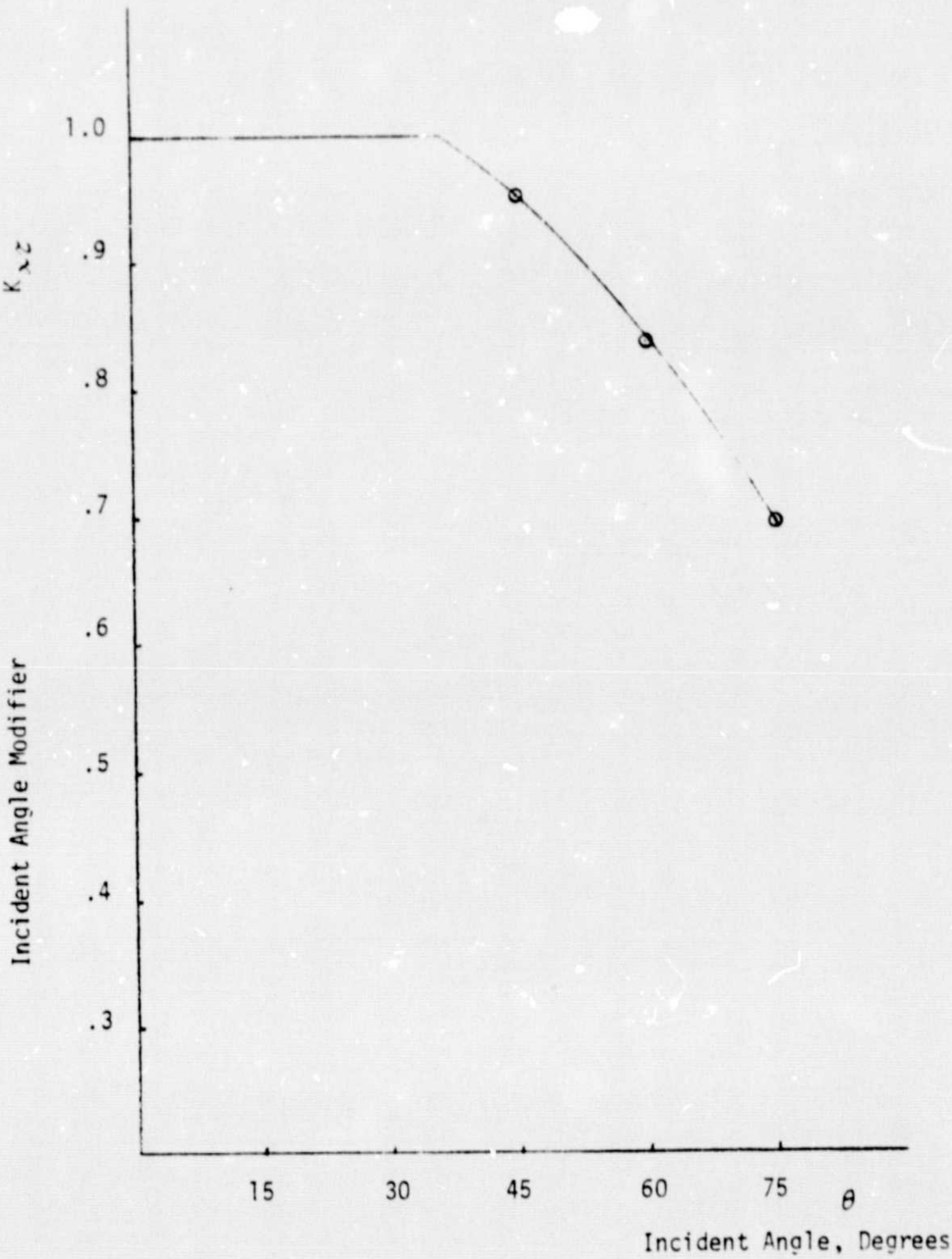

Figure 3. Libbey-Owens-Ford Collector Incident Angle Modifier Test Results

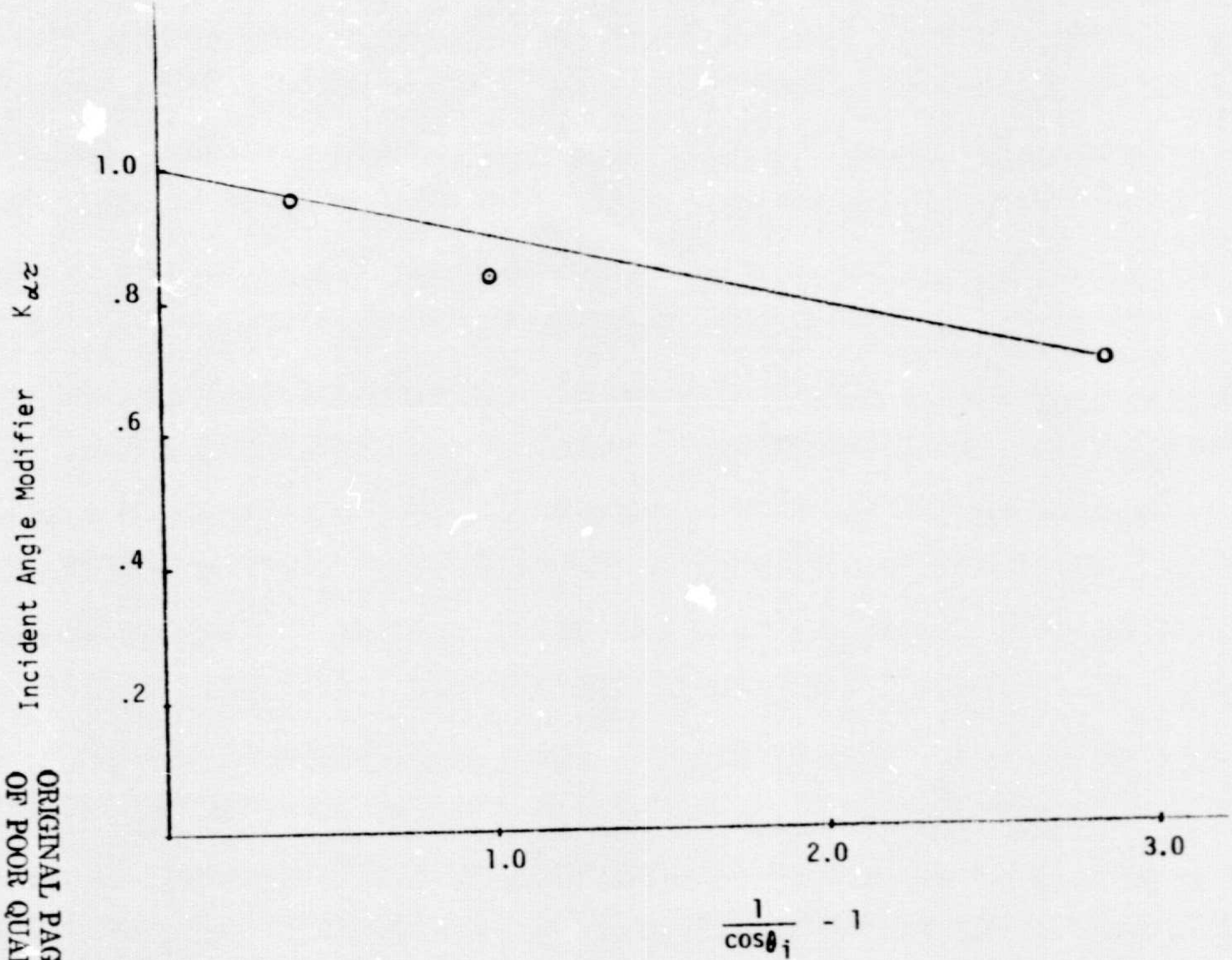

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Figure 4. Libbey-Owens-Ford Collector Incident Angle Modifier Test Pesults

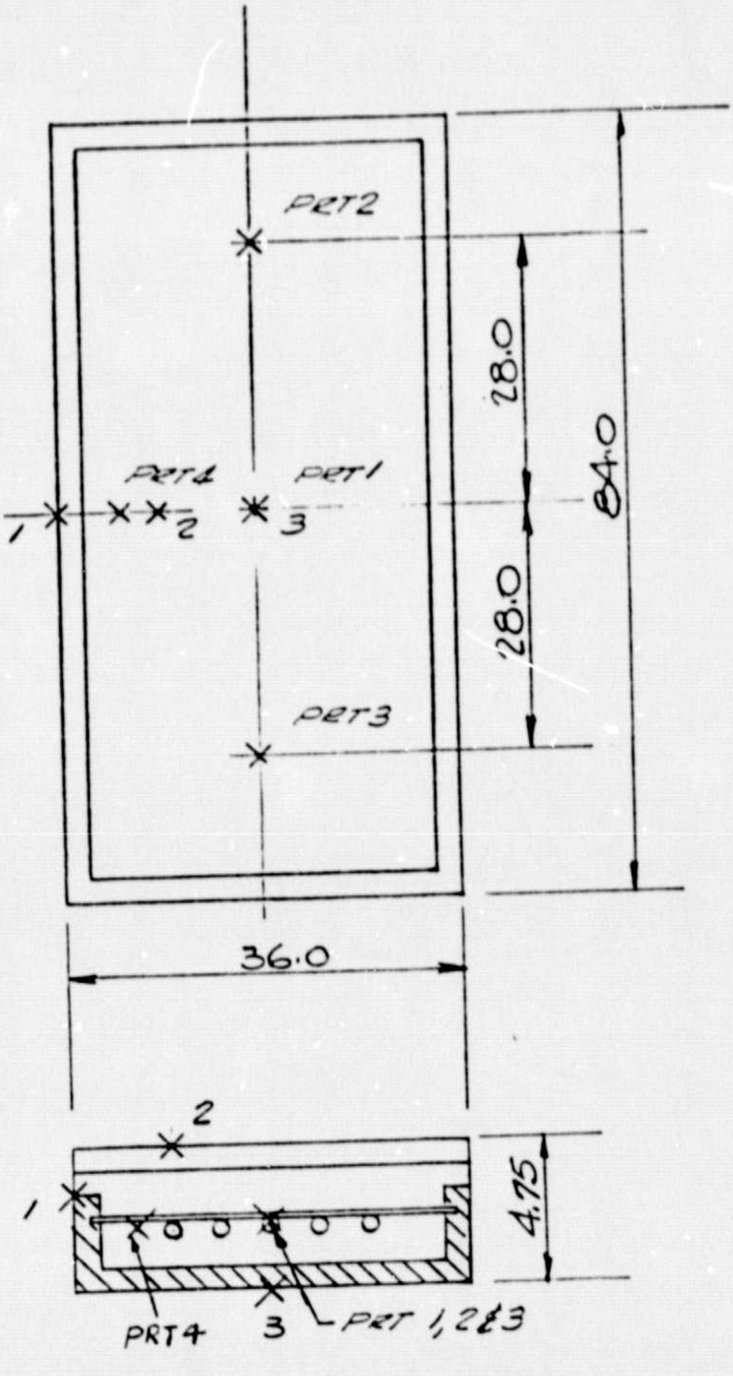

Figure 5. Libbey-Owens-Ford Collector Instrumentation Locations

TABLE I.

LIBBEY-OWENS-FORD COLLECTOR SIMULATOR TEST CONDITIONS

Solar Flux BTU/Hr·Ft^2	Inlet Temp. °F	Flow Rate Lb/Hr	Wind MPH
230, 270	100, 120, 150, 200	290	0, 10, 13

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TABLE II

LIBBEY-OWENS-FORD COLLECTOR THERMAL PERFORMANCE TEST DATA - NO WIND

Collector Side °F	91.6	71.1	85.4	92.5	93.3	96.5	85.3	86.5	96.7	96.9
Collector Back °F	94.0	73.3	96.3	96.1	96.4	100.7	88.6	90.3	101.2	101.4
Outer Cover °F	104.8	86.0	108.9	111.1	110.4	116.1	106.7	111.2	124.3	127.3
North Surface °F	103.2	101.7	122.0	125.3	139.4	143.6	164.5	168.4	209.9	213.3
Center Surface °F	98.9	97.1	118.1	120.8	135.8	139.4	161.9	165.9	208.1	211.0
West Surface °F	99.0	97.1	118.2	121.1	136.0	139.8	161.6	165.1	207.8	210.8
South Surface °F	91.3	89.1	111.2	113.3	129.5	132.4	156.2	158.6	203.3	205.4
Ambient °F	75.4	59.2	75.4	75.9	76.3	76.7	60.9	61.1	64.8	65.3
T_{in} °F	78.5	75.0	99.9	99.8	120.0	120.5	149.3	149.3	200.1	199.9
T_{out} °F	92.8	90.5	112.6	114.6	131.0	133.8	157.6	160.1	204.7	206.8
ΔT °F	14.3	15.6	12.7	14.8	11.0	13.3	8.3	10.7	4.6	6.9
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	289.6	290.1	290.3	289.2	289.8	291.1	290.7	290.3	290.4	289.7
Wind Speed mph	0	0	0	0	0	0	0	0	0	0
Efficiency %	71.2	65.8	65.0	63.5	56.3	59.3	43.7	48.5	24.9	31.8
$(T_i-T_a)/I$ °F·Hr·Ft^2/BTU	.013	.058	.106	.088	.191	.162	.381	.326	.577	.492

TABLE III

LIBBEY-OWENS-FORD COLLECTOR THERMAL PERFORMANCE TEST DATA - 10 MPH WIND

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
ΔT °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 %	70.2	65.6	60.4	61.6	55.1	56.9	39.9	45.6	17.7	25.3
$(T_i - T_a)/I$ °F·Hr·Ft^2/BTU	.021	.061	.116	.094	.195	.172	.392	.332	.582	.502

TABLE IV

LIBBEY-OWENS-FORD COLLECTOR THERMAL PERFORMANCE TEST DATA - 13 MPH

Collector Side °F	81.1	82.1	73.8	76.8	79.5	82.4	84.4	87.2	90.9	92.1
Collector Back °F	82.0	83.4	76.3	79.7	81.6	84.5	86.1	89.1	92.7	94.1
Outer Cover °F	84.1	86.2	80.5	84.3	85.2	88.5	90.7	93.8	98.9	100.5
North Surface °F	102.3	105.6	120.1	124.2	138.4	142.3	164.0	168.6	207.6	211.3
Center Surface °F	99.0	102.1	116.6	120.0	135.2	138.3	161.5	165.4	206.2	209.2
West Surface °F	99.3	102.4	116.3	120.2	135.2	138.5	161.5	165.5	205.8	209.1
South Surface °F	91.8	94.1	110.2	112.8	129.1	131.5	156.1	159.2	201.8	204.2
Ambient °F	71.9	71.8	63.5	65.3	67.8	69.1	70.3	71.3	71.9	72.2
T_{in} °F	79.6	79.7	100.3	100.4	120.4	120.4	149.9	150.8	199.7	200.0
T_{out} °F	93.4	95.6	111.7	114.4	130.8	133.2	157.6	160.7	203.1	205.5
ΔT °F	13.8	15.8	11.5	14.1	10.3	12.8	7.7	9.9	3.4	5.5
Solar Flux BTU/Hr·Ft^2	231.1	265.1	230.1	271.2	232.2	268.8	234.1	266.0	231.1	267.0
Flow Rate Lb/Hr	290.1	290.1	290.8	290.4	291.0	289.6	291.2	291.6	289.4	290.9
Wind Speed mph	13	13	13	13	13	13	13	13	13	13
Efficiency %	68.4	68.7	58.7	61.1	53.4	57.2	40.5	46.0	19.2	26.0
$(T_i-T_a)/I$ °F·Hr·Ft^2/BTU	.033	.030	.160	.129	.227	.191	.340	.299	.553	.470

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TABLE V

LIBBEY-OWENS-FORD COLLECTOR TIME CONSTANT TEST DATA

Time	8:58:49	9:0:14	9:1:39	9:3:4	9:4:30	9:5:55	9:7:20	9:8:45	9:10:10
Collector Side °F	80.6	80.8	81.1	81.1	81.3	81.4	80.6	78.7	77.9
Collector Back °F	72.3	72.4	72.6	72.6	72.7	72.8	72.9	72.8	72.8
Outer Cover °F	85.5	85.7	85.8	86.1	86.1	86.3	85.9	82.2	80.7
North Surface °F	107.2	107.2	107.4	107.4	107.5	107.7	93.3	88.5	87.0
Center Surface °F	103.3	103.2	103.3	103.4	103.5	103.5	93.5	87.7	86.2
West Surface °F	102.6	102.6	102.7	102.9	102.9	103.0	90.2	86.6	85.5
South Surface °F	95.0	95.0	95.0	95.1	95.2	95.3	88.0	83.6	82.9
Ambient °F	72.3	72.4	72.3	72.4	72.3	72.7	72.5	72.3	72.5
T_{in} °F	83.0	83.0	83.1	83.2	83.2	83.3	83.4	83.4	83.3
T_{out} °F	96.2	96.3	96.3	96.4	96.5	96.6	90.4	86.2	85.1
ΔT °F	13.25	13.25	13.22	13.22	13.26	13.30	7.04	2.83	1.82
Solar Flux BTU/Hr·Ft^2	247	247	247	247	247	247	0	0	0
Flow Rate Lb/Hr	294.1	293.6	293.6	293.5	293.3	293.2	292.9	292.0	291.1
Wind Speed mph	10	10	10	10	10	10	10	10	10

TABLE VI

LIBBEY-OWENS-FORD COLLECTOR INCIDENT ANGLE MODIFIER TEST DATA

Incident Angle	45	60	75
North Surface °F	101.9	94.9	87.2
Center Surface °F	98.8	92.8	86.8
West Surface °F	98.0	92.3	87.6
South Surface °F	92.5	87.6	82.8
Ambient °F	76.3	77.3	78.2
T_{in} °F	83.2	81.8	80.8
T_{out} °F	93.2	88.6	84.5
ΔT °F	10.02	6.81	3.73
Solar Flux BTU/Hr·Ft^2	178.9	136.9	90.2
Flow Rate Lb/Hr	292.5	290.0	289.6
Efficiency %	64.7	57.0	47.3
$K_{\alpha\tau}$	.951	.837	.696

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