DOE / NASA CONTRACTOR REPORT

DOE/NASA CR-150507

VERIFICATION TEST OF THE MSFC SOLAR SIMULATOR USING A HONEYWELL DOUBLE-COVERED LIQUID 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

(NASA-CR-150507) VERIFICATION TEST OF THE MSFC SOLAR SIMULATOR USING A HONEYWELL DOUBLE-COVERED LIQUID SOLAR COLLECTOR (Wyle Labs., Inc.) 17 p HC A02/MF A01 CSCL 10A N78-17473
Unclas
G3/44 05362

U.S. Department of Energy

Solar Energy

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. DOE/NASA CR 150507	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Verification Test of the MSFC Solar Simulator Using a Honeywell Double-Covered Liquid Solar Collector		5. REPORT DATE November 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K. Shih		8. PERFORMING ORGANIZATION REPORT # Wyle TR 531-06
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wyle Laboratories, Scientific Services and Systems Group, Solar Energy Sys Div, Huntsville, Alabama 35805		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. NAS8-32036
		13. TYPE OF REPORT & PERIOD COVERED Contractor Report
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration, Washington, D. C. 20546		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This work was accomplished under the technical supervision of Charles N. Thomas, Marshall Space Flight Center.

16. ABSTRACT

This test program was conducted to obtain additional verification data to support the utilization of the MSFC Solar Simulator for testing solar collectors. The Honeywell double-covered liquid solar collector no. 2 for which thermal performance data under natural outdoor conditions had been previously obtained was installed on the Solar Simulator and subjected to a series of eight tests under the conditions shown in Table I. Although these test conditions are not absolutely identical to those of the outdoor tests, they are considered to be sufficiently representative to provide a basis for an accurate comparative analysis of the data recorded for both test programs.

17. KEY WORDS	18. DISTRIBUTION STATEMENT Unclassified-Unlimited William A. Brooksbank, Jr. Manager Solar Heating & Cooling Project Office

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	16	NTIS

MSFC - Form 3292 (May 1969) For sale by the Nat'l Technical Information Service, Springfield, Va. 22151

TABLE OF CONTENTS

1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during a verification test program. The test program was conducted to obtain thermal performance data on the Honeywell double-covered liquid solar collector #2 under simulated conditions for comparison with the data obtained during outdoor testing of the same collector. 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 References 2.2 and 2.3. The results obtained during the outdoor test portion of the program are contained in Reference 2.4.

2.0 REFERENCES

2.1	EP-45 (76-82)	Outdoor/Indoor Test Comparison for Solar Collectors
2.2	MTCP-DC-SHAC-402	Procedure for Thermal Performance Evaluation of the Honeywell Solar Collectors
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
2.4	Wyle TR-531-04	Thermal Performance of Honeywell Double-Covered Liquid Solar Collector

3.0 MANUFACTURER

Honeywell
Minneapolis, Minnesota

3.1 Description of Test Specimen

Double glass cover - 3 feet wide, 4 feet long and 0.5 feet deep, weighing approximately 65 pounds dry. Iron oxide absorber surface with absorptivity of 0.91, emissivity of 0.37, with surface area of 10.23 square feet.

4.0 SUMMARY

This test program was conducted to obtain additional verification data to support the utilization of the MSFC Solar Simulator for testing solar collectors. The Honeywell double-covered liquid solar collector #2 for which thermal performance data under natural outdoor conditions had been previously obtained was installed on the Solar Simulator and subjected to a series of eight tests under the conditions depicted in Table I. Although these test conditions are not absolutely identical to those of the outdoor tests, they are considered to be sufficiently representative to provide a basis for an accurate comparative analysis of the data recorded for both test programs. A graphic representation of this analysis is presented in Figure 1. Table II contains the data obtained during the tests conducted on the simulator. Performance data concerning the outdoor portion of the test program are contained in Reference 2.4.

5.0 TEST CONDITIONS AND TEST REQUIREMENTS

5.1 Ambient Conditions

All tests were performed at local atmospheric pressure and the temperature of Building 4619. Tests were conducted at average solar flux levels of either 234 or 287 (BTU/Ft^2-Hr.)

5.2 Instrumentation and Equipment

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

Apparatus	Manufacturer/Model	Range and Accuracy
150°F Reference Junction	Pace/Model 150	150°F ± 1°F
Thermocouple (Copper-Constantan)	MSFC Supplied	0 to + 500°F ± 1.8°F
Resistance Thermometer	Thermo Systems, Inc./T200	0 to 500°F ± .05°F
Pyranometer	Eppley/8-48	0 - 400 BTU/Ft^2-Hr ± 5%
Flowmeter	Foxboro/Model 81	.1 to 2.5 GPM ± 1%
Anemometer	MSFC Supplied	Unknown
Floor Fan	MSFC Supplied	Not Applicable

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 flow rate of 120 pounds per hour at solar flux levels of 250 ± 40 BTU/Ft^2-Hr with a simulated wind condition of approximately 180° at 9 MPH. The following data were recorded for the test.

1) Collector side wall temperature (°F)
2) Absorber surface temperature - west side (°F)
3) Absorber surface temperature - south side (°F)
4) Absorber surface temperature - north side (°F)
5) Outer cover temperature (°F)
6) Inner cover temperature (°F)
7) Absorber surface temperature - center (°F)
8) Collector back side temperature (°F)
9) Ambient temperature (°F)
10) Liquid inlet temperature (°F)
11) Liquid outlet temperature (°F)
12) Liquid differential temperature (°F)
13) Liquid flow rate (Lbm/Hr)
14) Total solar flux (BTU/Ft^2-Hr)
15) Wind velocity (MPH)

Collector temperature measurements were taken from locations identified in Figure 2.

6.1.2 Procedure

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

1) Prepare test set-up; mount collector on test facility and connect instrumentation leads to data acquisition system. (See Figure 3 for typical collector set-up.)

2) Establish wind condition of approximately 180° at 9 MPH.

3) Establish liquid flow rate at 120 Lbm/Hr. (Figure 4 depicts the Liquid Flow System.)

4) Establish inlet temperature of 100°F.

5) Establish solar flux level at 234 BTU/Ft^2-Hr.

6) Stabilize above conditions and record data for 5 minute stabilized period.

7) Establish solar flux level at 287 BTU/Ft^2-Hr and repeat Step 6).

8) Repeat above steps as necessary to obtain required data at inlet temperature of 120°, 150° and 200°F.

NOTE: Steps 1, 2 and 3 are constants and should require no adjustments unless facility is shut down prior to completion of entire test series.

6.1.3 RESULTS

The results of the collector performance tests are shown in Table II. The values depicted for each data point were determined by averaging the data recorded for that point over a five minute period during which all tests requirements were continuously met. The number in parentheses below each value indicates the standard deviation about the mean of the data used in computing that value.

7.0 ANALYSIS

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)

A = Cross-sectional area (ft^2)

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

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

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

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

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

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

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

Notice that:

P_i = IA = Total Power Incident on the Collector

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

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

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:

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

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:

$$\text{Efficiency} = -\Gamma^{2}* (.11288) - \Gamma* (.50505) + (.70739)$$

Where:

$\Gamma = (t_{f,i}-t_a)/I$

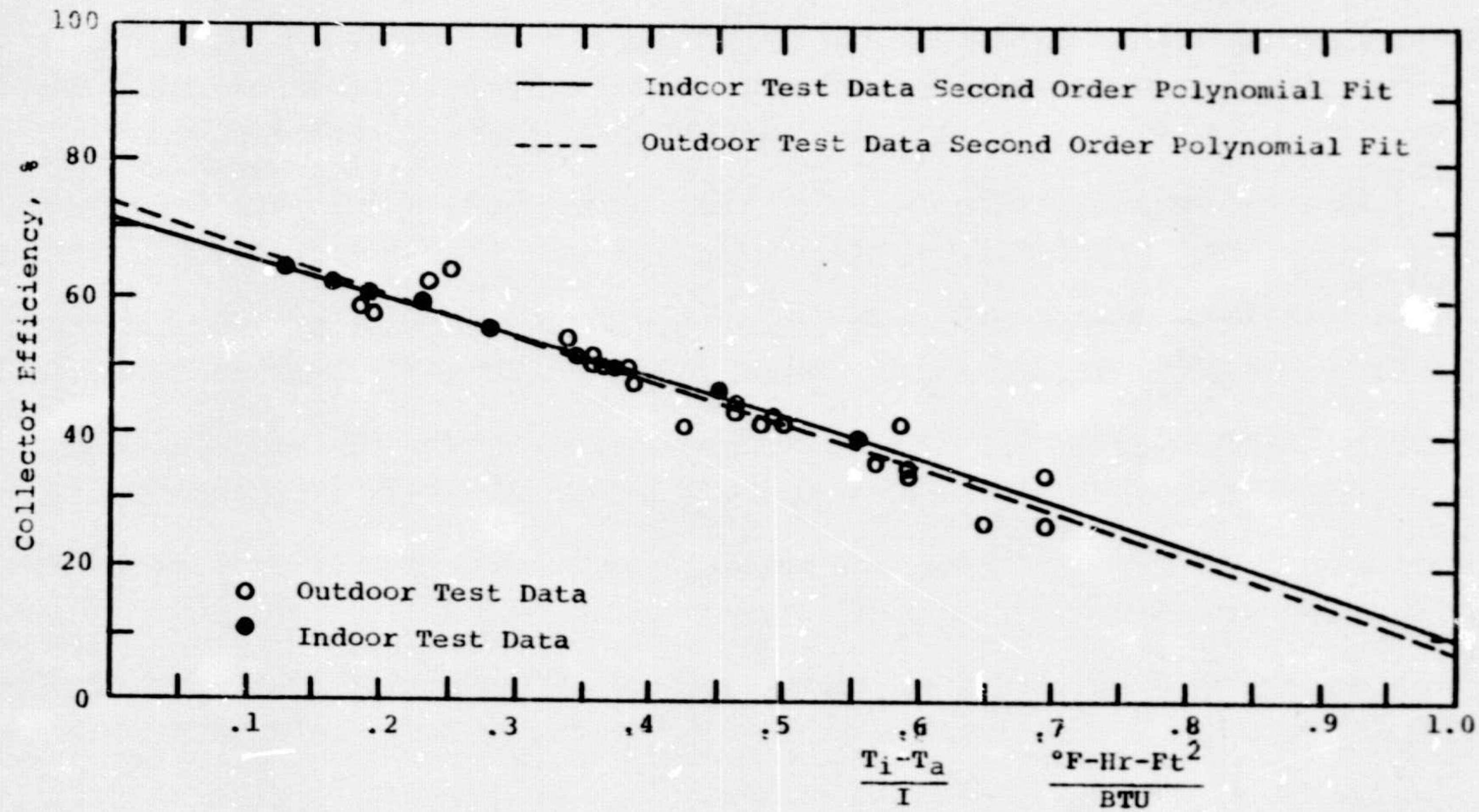

FIGURE 1. HONEYWELL COLLECTOR OUTDOOR AND SIMULATOR TEST COMPARISON

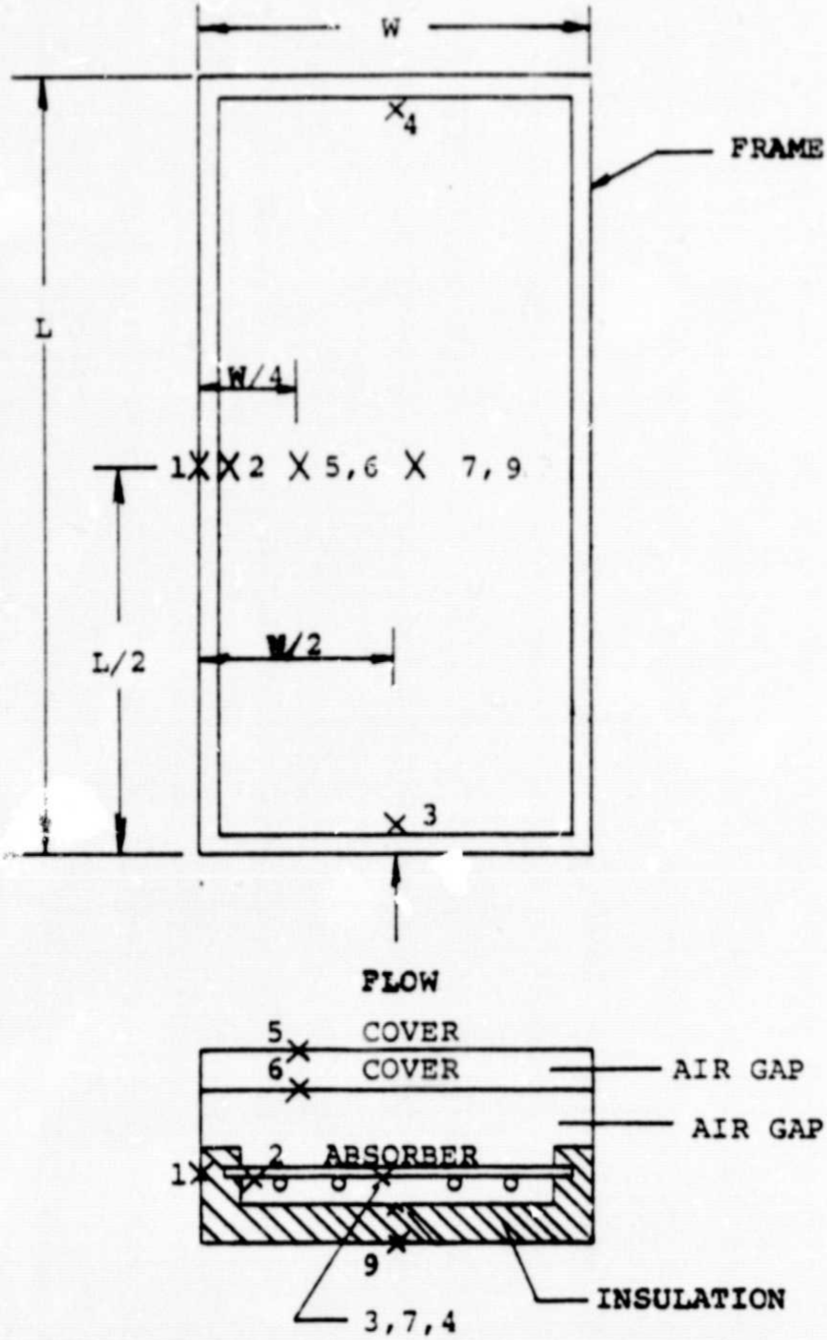

FIGURE 2. HONEYWELL #2 COLLECTOR INSTRUMENTATION

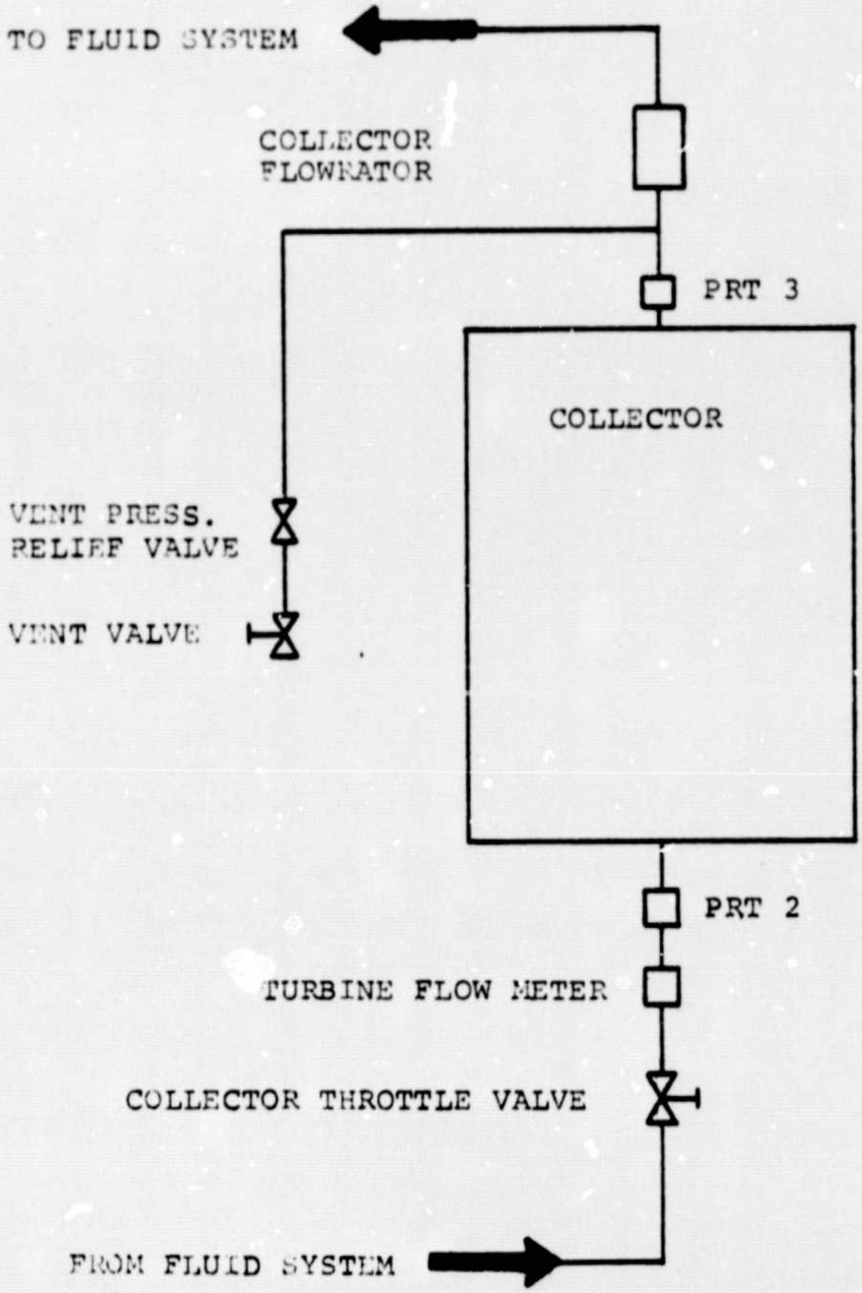

FIGURE 3. TYPICAL COLLECTOR SET UP FOR SIMULATOR FACILITY

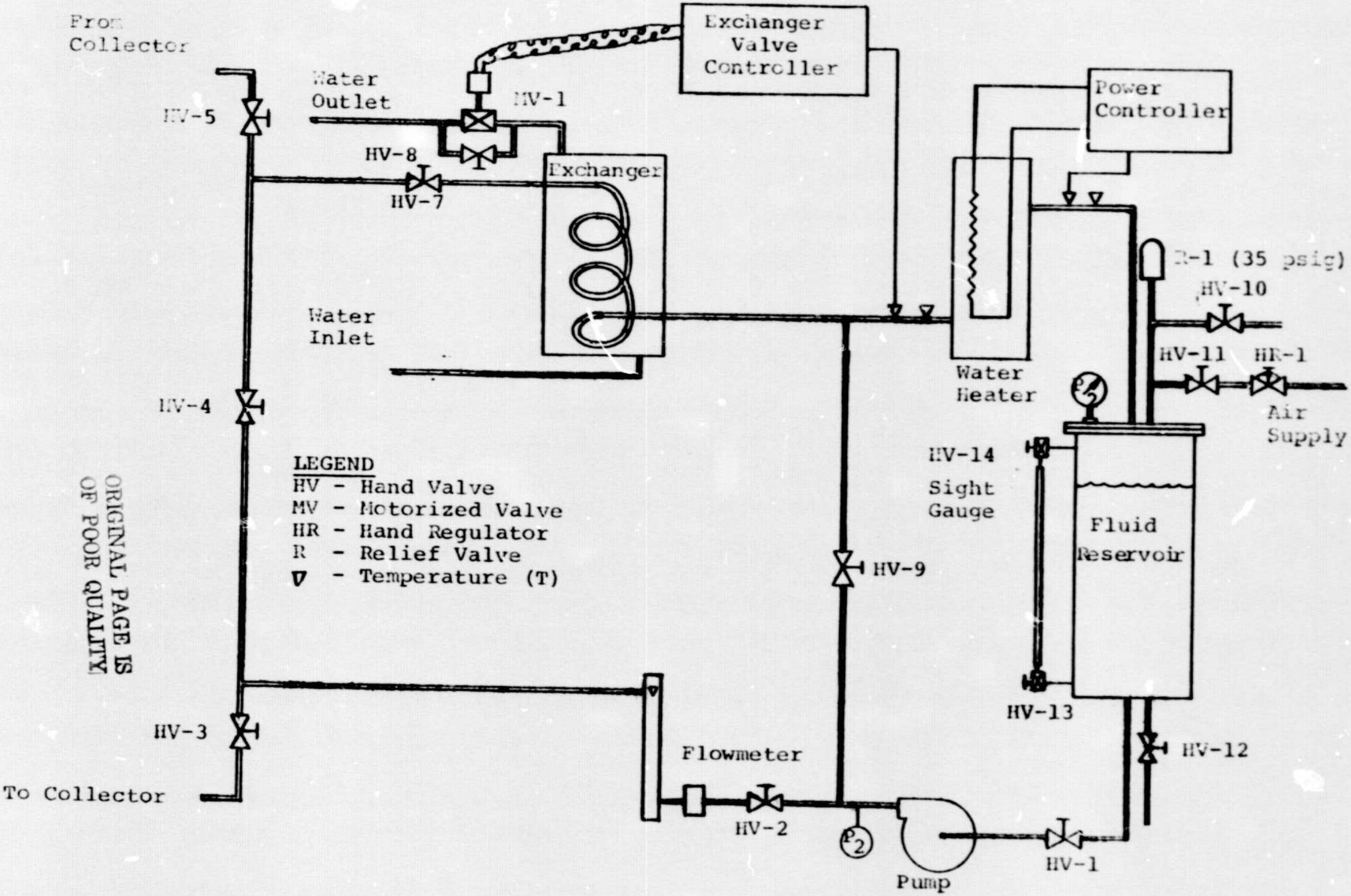

FIGURE 4. SOLAR COLLECTOR LIQUID TEST SET UP (Indoor)

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE I

HONEYWELL COLLECTOR SIMULATOR TEST CONDITIONS

Test No.	Inlet Temp. (°F)	Solar Flux (BTU/Ft^2-hr)	Flow Rate	Wind Condition
1	100	234	120 Lbm/Hr	Approximately 180°/9 MPH
2	100	287		
3	120	234		
4	120	287		
5	150	234		
6	150	287		
7	200	234		
8	200	287		

TABLE II.

HONEYWELL COLLECTOR SIMULATOR TEST RESULTS

TEST NUMBER	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Collector Side °F	71.6 (.4)	73.6 (.6)	74.0 (.2)	75.7 (.4)	78.2 (.5)	78.6 (.4)	77.9 (.4)	79.1 (.4)
West Surface °F	115.6 (.1)	118.3 (.1)	132.6 (.2)	135.9 (.2)	160.2 (0)	163.9 (.1)	205.3 (.1)	209.0 (.1)
South Surface °F	107.5 (.1)	108.3 (.1)	125.3 (.2)	127.0 (.1)	154.7 (.1)	156.5 (.1)	202.6 (.2)	204.2 (0)
North Surface °F	122.8 (0)	127.2 (.3)	139.9 (.2)	144.7 (.2)	167.1 (0)	172.6 (.2)	212.6 (.1)	218.0 (.1)
Outer Cover °F	78.4 (.1)	81.1 (.2)	82.2 (.2)	84.7 (.2)	89.4 (.6)	90.8 (.2)	94.2 (.1)	96.9 (.1)
Inner Cover °F	104.6 (0)	108.4 (.5)	113.7 (.1)	117.4 (.4)	128.3 (.3)	133.3 (.4)	152.3 (.1)	157.2 (.2)
Center Surface °F	117.0 (.1)	120.0 (.1)	134.3 (.2)	137.9 (.2)	162.4 (.1)	166.4 (.1)	209.0 (.2)	212.8 (.1)
Collector Back °F	65.5 (.2)	66.5 (.2)	69.4 (.1)	70.2 (.1)	73.1 (.2)	74.9 (.3)	80.8 (.2)	82.4 (.2)
Ambient °F	63.5 (.2)	63.8 (.3)	65.4 (.1)	65.8 (.3)	69.5 (.3)	69.8 (.6)	70.3 (.2)	70.7 (.1)
Wind Velocity (MPH)	7-10	7-10	7-10	7-10	7-10	7-10	7-10	7-10
Wind Direction (Degrees)	180	180	180	180	180	180	180	180
Solar Flux BTU/Ft^2-Hr.	234	287	234	287	234	287	234	287
Flowrate Lbm/Hr	120.3 (.8)	120.1 (.5)	119.6 (.3)	119.9 (.3)	120.5 (.5)	120.4 (.5)	120.6 (.4)	120.9 (.6)
T_{in} °F	101.8 (.2)	100.7 (.1)	120.0 (.1)	120.1 (.2)	150.5 (.1)	150.5 (.1)	200.2 (.1)	200.1 (0)
T_{out} °F	117.3 (.1)	120.3 (.2)	134.7 (.2)	138.4 (.2)	162.7 (.1)	166.8 (.1)	209.1 (.1)	213.4 (.1)
ΔT °F	15.5 (.1)	19.6 (.1)	14.7 (.1)	18.3 (.1)	12.3 (0)	16.3 (.1)	8.9 (0)	13.3 (.1)
Efficiency %	62.5 (.5)	64.1 (.3)	59.8 (.3)	60.7 (.1)	51.2 (.3)	55.5 (.2)	38.7 (.2)	46.8 (.3)
$(T_i-T_a)/I$ °F-Ft^2Hr/BTU	.16	.13	.23	.19	.35	.28	.56	.45

ORIGINAL PAGE IS OF POOR QUALITY

N O T I C E

When government drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the United States government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.