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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150497

PERFORMANCE EVALUATION OF TWO BLACK NICKEL AND TWO  
BLACK CHROME SOLAR COLLECTORS

Prepared by

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Under sub-contract to

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TWO BLACK NICKEL AND TWO BLACK CHROME SOLAR  
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**Solar Energy**

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16. ABSTRACT <p>This test program was based on the evaluation of four unique solar collectors described below:</p> <ul style="list-style-type: none"> <li>(a) Black Nickel Collector Surface with a desiccant drying bed.</li> <li>(b) Black Nickel Collector Surface without a desiccant drying bed.</li> <li>(c) Black Chrome Collector Surface with a desiccant drying bed.</li> <li>(d) Black Chrome Collector Surface without a desiccant drying bed.</li> </ul> <p>The test program included three distinct phases: Initial performance evaluation, natural environmental aging, and post-aging performance evaluation. Phase I and II were undertaken by J. C. Reily, ET44, MSFC, and phase III was undertaken by Wyle Laboratories (R. Losey). Results of Phase III testing conclusively indicated a higher normalized efficiency for Black Chrome surfaces when compared to Black Nickel. Analysis of these results with data obtained from NASA TMX-3226 (Reference 2, 5) is shown in Figure 3. The results are tabulated in Tables 2, 3, 4, and 5.</p>				
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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 performance of an evaluation test program. The test program was conducted to determine the comparative efficiency of Black Nickel versus Black Chrome type solar collecting surfaces, according to the evaluation requirements specified in Reference 2.1.

2.0

REFERENCES

- 2.1 EH31 (75-49) Evaluation Program on Black Chrome and Black Nickel Solar Collectors
- 2.2 MTCP-FA-SHAC-401 Procedure for Operating the MSFC Solar Subscale Facility
- 2.3 MTCP-DC-SHAC-401 Test Plan for Black Nickel/Black Chrome Solar Collectors
- 2.4 AVO 76-108 Summary Request for Current SHAC Test Tasks
- 2.5 NASA TM X-3226 Comparison under a Simulated Sun of Two Black-Nickel-Coated Flat-Plate Solar Collectors with a Non-Selective Black-Paint-Coated Collector
- 2.6 NBS TECH NOTE 899 Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices
- 2.7 Johnson, S.M. and Simon, F. F., "Comparison of Flat-Plate Collector Performance Obtained Under Controlled Conditions in a Solar Simulator", Paper Presented at 'Sharing The Sun!' Joint Conference of the American Section, International Solar Energy Society and Solar Energy Society of Canada, Inc., August 15-20, 1976, Winnipeg.

3.0

MANUFACTURER

National Aeronautics and Space Administration  
Marshall Space Flight Center  
Test Laboratory, Fabrication Division  
Huntsville, Alabama

SUMMARY

This test program was based on the evaluation of four unique solar collectors described below:

- a) Black Nickel Collector Surface with a desiccant drying bed.
- b) Black Nickel Collector Surface without a desiccant drying bed.
- c) Black Chrome Collector Surface with a desiccant drying bed.
- d) Black Chrome Collector Surface without a desiccant drying bed.

The test program included three distinct phases:

- a) Phase I - Initial performance evaluation
- b) Phase II - Natural environmental aging
- c) Phase III - Post-aging performance evaluation.

The test program was undertaken by two groups:

- a) MSFC/ET44, J.C. Reily - Phases I and II
- b) Wyle Laboratories, R.E. Losey - Phase III.

Results of Phase III testing conclusively indicated a higher normalized efficiency for Black Chrome Collector surfaces when compared to Black Nickel. Analysis of these results with data obtained from NASA TM X-3226 (Reference 2.5) is shown in Figure 3. Tabulation of these results is shown in Tables 2, 3, 4 and 5.

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## 5.0 TEST CONDITIONS AND TEST EQUIPMENT

### 5.1 Ambient Conditions

Test conditions included seasonal ambient conditions. Phase I testing occurred during the winter months, while Phase III occurred during the summer months. Performance evaluation testing occurred only during daylight hours with the solar flux greater than 250 BTU/Hr-Ft<sup>2</sup> for an extended period of time.

### 5.2 Instrumentation and Equipment

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

<u>Apparatus</u>	<u>Manufacturer/Model</u>	<u>Range &amp; Accuracy</u>
150°F Reference Junction	Pace/Model 150	150°F <u>+1°F</u>
RH Monitor	Phys-Chemical Res. Corporation/Humeter	0 to 100% <u>+2.5%</u>
Thermocouple	Copper/Constantan	-300 to +700°F <u>+1°F</u>
Resistance Thermometer	Thermal Systems Inc/T200	0 to 500°F <u>+0.05°F</u>
Flowmeter	Foxboro/Model 81	0.1 to 2.5 GPM <u>+1%</u>

## 6.0 REQUIREMENTS, PROCEDURES AND RESULTS

### 6.1 Test Title

Initial Performance Evaluation

#### 6.1.1 Requirements

The requirements of this test were to obtain performance information under the conditions described in Table 1. The following data was recorded for each panel:

- 1) Collector inlet fluid temperature (°F)
- 2) Collector outlet fluid temperature (°F)
- 3) Collector surface temperature - 3 points (°F)

- 4) Collector fluid flow rate (GPM)
- 5) Internal collector panel relative humidity (%RH)
- 6) Solar flux (BTU/HR-Ft<sup>2</sup>)
- 7) Collector desiccant bed temperature (°F)
- 8) Collector desiccant bed cover temperature (°F)

6.1.2 Procedures } (Performed by MSFC ET-44  
 6.1.3 Results } and not included in  
 this report.)

6.2 Test Title

Natural Environmental Aging

6.2.1 Requirements

The requirement of this test was to obtain information concerning the effect of environmental exposure for a period of time exceeding six (6) months.

6.2.2 Procedures

For the purpose of this test, all collectors were mounted facing South at a 45° angle to the horizon. They were exposed to the ambient outdoor environment from January 1976 to August 1976.

6.2.3 Results

The only apparent deterioration of the collectors during the environmental aging phase occurred to three tedlar inner covers. This deterioration was noted on August 12, 1976. Upon removal of these covers, they were sent to EH-33 for evaluation.

6.3 Test Title

Post-Aging Performance Evaluation

6.3.1 Requirements

The requirement of this test was to obtain performance information under the conditions described in Table 1. The following data was recorded for each panel:

- 1) Collector inlet fluid temperature (°F)
- 2) Collector outlet fluid temperature (°F)

- 3) Collector surface temperature - 3 points (°F)
- 4) Collector fluid flow rate (GPM)
- 5) Internal collector panel relative humidity (%RH)
- 6) Solar flux (BTU/Hr-Ft<sup>2</sup>)
- 7) Collector desiccant bed temperature (°F)
- 8) Collector desiccant bed cover temperature (°F)

### 6.3.2 Procedure

The procedure followed for each of the first three test conditions indicated in Table 1 may be found in Appendix A to this report. For the stagnation test condition, the facility fluid loop was secured and collectors drained. All valves and controls referred to are identified in Figures 1 and 2.

### 6.3.3 Results

The results of this test are shown in Tables 2 through 5. Each test result cell is determined by averaging that cell over a period of time in which the test requirements are continuously met. The number in parentheses with each result cell indicates the standard deviation about the mean for all the data represented by the cell.

### 6.3.4 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:

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

where:

- $q_u$  = rate of useful energy extracted from the Solar Collector (BTU)
- $A$  = Cross-sectional area (ft<sup>2</sup>)
- $I$  = Total solar energy incident upon the plane of the solar collector per unit time per unit area (BTU/Hr-Ft<sup>2</sup>)

$\dot{m}$  = Mass flow rate of the transfer fluid through the collector per unit cross-sectional area of the collector (Lb/Ft<sup>2</sup>·Hr)

$C_{t,f}$  = 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:

$$\eta = \frac{(\dot{m}A) C_{tf} (t_{fe} - t_{fi})}{(IA)} = \frac{\dot{M} C_{tf} (t_{fe} - t_{fi})}{P_i} \quad (2)$$

Notice that:

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

$\dot{m}A = \dot{M}$  = Total Mass flow rate through the Collector

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

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:

$$\text{Collector Efficiency} = \frac{P_{\text{abs}}}{P_{\text{inc}}} \times 100 \quad (4) \quad \textcircled{A}$$

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

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

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at two-minute intervals. The mean value of efficiency was determined over a fifteen-minute period during which the test conditions remained quasi-steady state. Each fifteen-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus  $((t_{\text{fi}} - t_{\text{a}}) / I)$ , where:

$t_{\text{f,i}}$  = Fluid inlet temperature ( $^{\circ}\text{F}$ )

$t_{\text{a}}$  = Ambient temperature ( $^{\circ}\text{F}$ )

$I$  = Incident flux per unit area ( $\text{BTU}/\text{Hr}\cdot\text{Ft}^2$ )

The abscissa term  $((t_{\text{fi}} - t_{\text{a}}) / I)$  was used to normalize the effect of operating at different values of  $I$ ,  $t_{\text{f,i}}$  and  $t_{\text{a}}$ . The results of this analysis are found in Figure 3.

Linear analysis was also performed on each group of data described by a particular collector. Results are presented in Figure 3 along with data made available by NASA Lewis Research Center in References 2.5 and 2.7. Based on the current test results and analyses, test conditions with inlet fluid temperatures near ambient temperature should be included in future tests.

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test results and analyses, only black chrome shows good correlation to a first order polynomial. Furthermore, no test requirements were specified by Reference 2.1 to cover the low value of  $(t_{fi} - t_a)/I$ . To evaluate collector performance, test conditions with inlet fluid temperatures near ambient temperature should be included in future tests.

TABLE 1. PHASE 1 AND 3 TEST CONDITIONS

Condition Number	Inlet Temp °F	Flow Rate (GPM)	Solar Flux (BTU/Hr-Ft <sup>2</sup> )
1	160	0.2-0.5	260-280
2	180	0.2-0.5	260-280
3	200	0.2-0.5	260-280
4	Stagnation	0.0	260-280

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TABLE 2. PHASE 3, CONDITION 1 RESULTS

	Black Nickel Without Desiccant	Black Nickel With Desiccant	Black Chrome Without Desiccant	Black Chrome With Desiccant
Collector Inlet Temp (°F)	162.6 (1.0) *	171.01 (1.2)	162.11 (1.1)	172.5 (1.1)
Collector Outlet Temp (°F)	171.0 (1.2)	179.8 (1.5)	172.5 (1.2)	182.4 (1.4)
Collector Surface Temp (°F)	163.1 (1.2)	180.4 (2.4)	168.4 (1.2)	178.2 (1.5)
Collector Flow Rate (GPM)	0.2	0.2	0.2	0.2
Internal Relative Humidity (%RH)	54.1 (0.7)	32.3 (0.8)	49.8 (0.9)	35.9 (0.1)
Solar Flux (BTU/Hr-Ft <sup>2</sup> )	260.11 (5.99)	260.11 (5.99)	260.11 (5.99)	260.11 (5.99)
Collector Desiccant Bed Temp (°F)		125.0 (1.4)		185.6 (2.1)
Collector Desiccant Bed Cover (°F)		187.1 (3.7)		197.9 (2.7)

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TABLE 3. PHASE 3, CONDITION 2 RESULTS

	Black Nickel Without Desiccant	Black Nickel With Desiccant	Black Chrome Without Desiccant	Black Chrome With Desiccant
Collector Inlet Temp (°F)	180.9 (0.1) *	188.6 (0.7)	180.4 (0.1)	190.4 (0.4)
Collector Outlet Temp (°F)	188.5 (1.0)	196.5 (1.0)	190.3 (0.6)	199.6 (1.0)
Collector Surface Temp (°F)	180.1 (0.3)	190.0 (1.2)	186.0 (0.8)	195.1 (0.8)
Collector Flow Rate (GPM)	0.2	0.2	0.2	0.2
Internal Relative Humidity (%RH)	44.0 (0.5)	24.1 (0.7)	46.0 (0.1)	34.8 (0.1)
Solar Flux (BTU/Hr-Ft <sup>2</sup> )	268.10 (5.61)	268.10 (5.61)	268.10 (5.61)	268.10 (5.61)
Collector Desiccant Bed Temp (°F)		133.4 (0.3)		191.4 (1.9)
Collector Desiccant Bed Cover (°F)		189.2 (1.9)		200.6 (1.4)

\* Standard Deviation



TABLE 4. PHASE 3, CONDITION 3 RESULTS

	Black Nickel Without Desiccant	Black Nickel With Desiccant	Black Chrome Without Desiccant	Black Chrome With Desiccant
Collector Inlet Temp (°F)	200.2 (0.3)*	207.9 (0.6)	200.0 (0.3)	209.1 (0.7)
Collector Outlet Temp (°F)	207.9 (0.5)	216.0 (0.4)	209.1 (0.6)	218.3 (0.4)
Collector Surface Temp (°F)	197.3 (0.5)	207.0 (1.6)	204.0 (0.6)	212.5 (1.7)
Collector Flow Rate (GPM)	0.2	0.2	0.2	0.2
Internal Relative Humidity (%RH)	41.7 (1.0)	20.8 (1.4)	46.7 (0.6)	---
Solar Flux (BTU/Hr-Ft <sup>2</sup> )	268.43(4.74)	268.41(4.60)	268.38(4.47)	268.26(4.29)
Collector Desiccant Bed Temp (°F)		145.6 (1.1)		203.0 (2.2)
Collector Desiccant Bed Cover (°F)		202.8 (2.7)		214.3 (2.3)

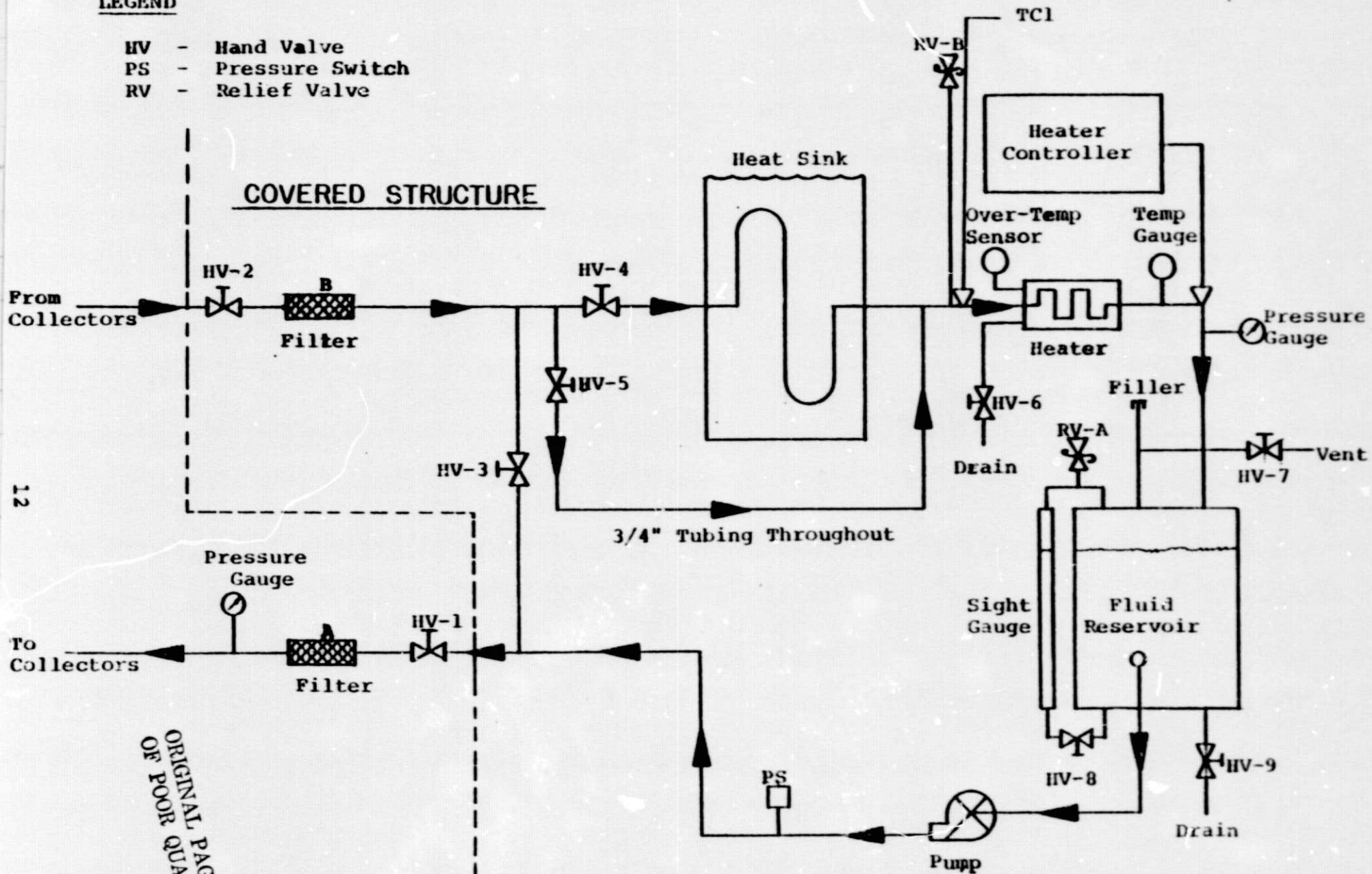
TABLE 5. PHASE 3, CONDITION 4 RESULTS

	Black Nickel Without Desiccant	Black Nickel With Desiccant	Black Chrome Without Desiccant	Black Chrome With Desiccant
Collector Surface Temp (°F)	325.4 (0.6)*	281.2 (2.8)	338.6 (1.2)	336.1 (1.3)
Internal Relative Humidity (%RH)	40.3	36.0	40.0	40.0
Solar Flux (BTU/Hr-Ft <sup>2</sup> )	276.86(2.42)	276.86(2.42)	276.86(2.42)	276.86(2.42)
Collector Desiccant Bed Temp (°F)		138.5 (0.83)		242.2 (0.61)
Collector Desiccant Bed Cover (°F)		219.4 (0.98)		248.6 (0.5)

\* Standard Deviation

**LEGEND**

- HV - Hand Valve
- PS - Pressure Switch
- RV - Relief Valve



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FIGURE 1. MSFC SOLAR SUBSCALE TEST FACILITY FLOW DIAGRAM

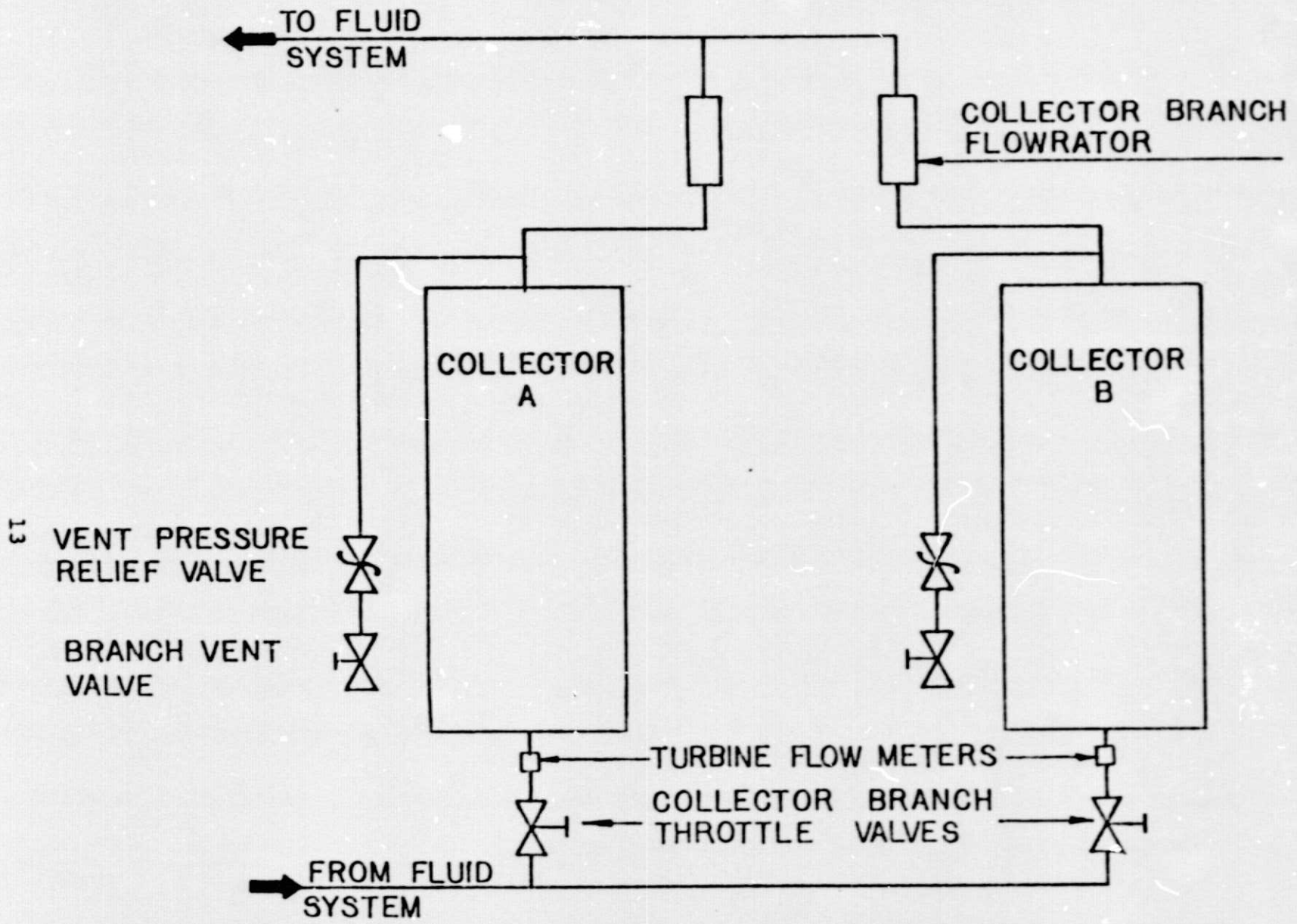


FIGURE 2. TYPICAL COLLECTOR SET UP FOR SUBSCALE FACILITY

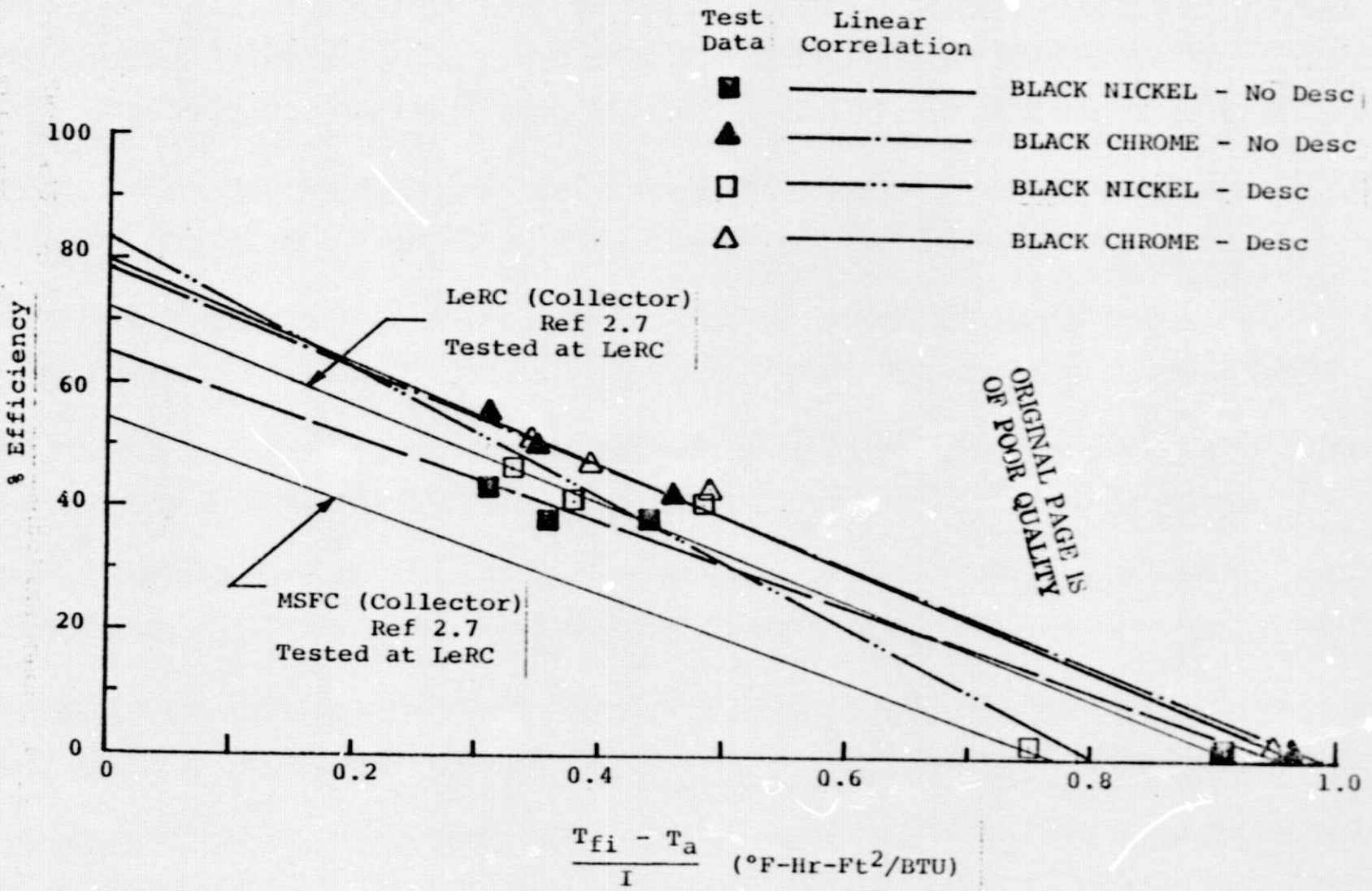


FIGURE 3. BLACK NICKEL/BLACK CHROME PERFORMANCE TEST ANALYSIS

(A)

APPENDIX A

CHECKLIST FOR THE  
SUBSCALE LIQUID FLOW SYSTEM

PRIOR TO TESTING --

- 1.0 Assure that:
  - a) Fluid reservoir is at least 75% full.
  - b) Fluid pump is OFF.
  - c) Fluid heater is OFF.
  - d) Hand Valves HV1, HV2, HV4, HV6, HV8 and HV9 are CLOSED.
  - e) Hand Valves HV3, HV5, HV7 and Collector Branch Throttle Valves are OPEN.
  - f) Vent Valves to each Collector Branch are CLOSED.
- 2.0 Turn ON fluid pump.
- 3.0 Set power controller to proper set point -- Consult Controller Manual -- for the desired INLET TEMPERATURE.
- 4.0 Assure that: H-P Computer System is functioning.
- 5.0 Turn ON heater controller.
- 6.0 OPEN HV2 completely.
- 7.0 SLOWLY OPEN HV1. [A surge of fluid into the collectors could cause personal harm or property damage.]
- 8.0 Adjust HV3 to obtain approximately 0.5 GPM as indicated on the minimum reading flow rate indicator. [A wait of several minutes may be necessary to clear the system of air.]
- 9.0 Adjust independent Collector Branch Throttle Valves as necessary to balance the flow in all branches.
- 10.0 Monitor heater inlet temperature and adjust HV-4 as necessary to obtain a temperature approximately 5°F below the desired Collector inlet temperature.
- 11.0 Adjust the heater controller as necessary to obtain the desired Collector inlet temperature.
- 12.0 Allow the Collector fluid inlet temperature to stabilize at the proper temperature test parameter.

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- 13.0 Adjust HV3 as necessary to obtain the proper flow test parameter. (Adjustment of HV1 may be necessary at low flow rates.)

IF system is stable, i.e., test parameters have not varied by +1% over the past 10 minutes, and the test parameters are at their proper values, i.e., Q, F, T-IN are at the value requested for the particular test, THEN the test is ready to begin.

DURING THE TEST --

- 1.0 Adjust and record as necessary:
- a) Collector Throttle Valves to maintain balanced Collector Branch flow.
  - b) HV3 to maintain proper flow rate.
  - c) Power set point to maintain proper temperature of inlet fluid.
  - d) HV4 to maintain heater inlet temperature 5°F below the Collector inlet temperature.
- 2.0 Underline the printed time if the solar flux falls below the prescribed flux level.
- 3.0 Notify Test Director if solar flux is less than the prescribed test flux level for a period greater than 10 minutes.

AFTER THE TEST --

- 1.0 Turn OFF power controller.
- 2.0 OPEN HV3 and HV4.
- 3.0 Turn OFF fluid pump.
- 4.0 OPEN HV8, Throttle Valves and Vent Valves to each Collector Branch.
- 5.0 Turn OFF teletype.

## N O T I C E

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