DOE/NASA CONTRACTOR REPORT

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THERMAL PERFORMANCE EVALUATION OF MSFC HOT AIR COLLECTORS WITH VARIOUS FLOW CHANNEL DEPTHS

Prepared by

Wyle Laboratories
Solar Energy Systems Division
Huntsville, Alabama 35805

Under subcontract with

IBM Corporation, Federal Systems Division Huntsville, Alabama 35805

Contract NAS8-32036

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George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

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Solar Energy

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~~This report presents~~ The test procedures used and the results obtained during the evaluation test program on the MSFC air collector with flow channel depth of 3 in., 2 in., and 1 in., under simulated conditions are presented.

The MSFC hot air collector consists of a single glass cover with a non-selective coating absorber plate and using air as the heat transfer medium. The absorber panel consisted of a thin flat sheet of aluminum.

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1.0 PURPOSE

The purpose of this documentation is to present the test results obtained during the performance of an evaluation test program. The evaluation test program was conducted to determine the thermal performance data on the new generation of MSFC air collectors with a flow channel depth of 3 in., 2 in., 1 in. and 1/2 in. under simulated conditions. The test was conducted utilizing the MSFC Solar Simulator in accordance with the test requirements specified in References 2.1 and 2.2 and the procedures contained in Reference 2.3.

2.0 REFERENCES

2.1	ASHRAE 93-77	Method of Testing Solar Collectors Based on Thermal Performance
2.2	EP45 (77-115)	Thermal Analysis and Development of the MSFC Air Collector
2.3	MTCP-DC-SHAC-416	MSFC Hot Air Collector Indoor Thermal Performance Test Procedure

3.0 MANUFACTURER

Marshall Space Flight Center
Huntsville, Alabama

3.1 DESCRIPTION OF TEST SPECIMEN

The MSFC hot air collector consists of a single glazed cover with a non-selective coating absorber plate and using air as the heat transfer medium. The collector frame is constructed with rigid urethane foam.

4.0 SUMMARY

This test program was conducted to evaluate the thermal performance of a new generation of MSFC air collector with various flow channel depths under simulated conditions. The test conditions and the thermal performance data obtained during the tests conducted on the simulator are listed in Tables II through VI, respectively. A graphic presentation of the data obtained is also presented in Figures 1 through 4 for thermal performance data and Figure 5 for pressure drop data.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests shall be performed in the existing environment of Building 4619.

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 5300.4C, Metrology and Calibration. A listing of the equipment used in this test follows:

Apparatus	Manufacturer/Model	Range/Accuracy
Pyranometer	Eppley PSP	0-800 $BTU/Ft^2 \cdot Hr$/±5%
Air Source	MSFC Supplied	30 - 200 SCFM
Wind Sensor	MSFC Supplied	0 - 60 MPH
Flow Sensor	Cox-Turbine C-L-32	20 - 250 ACFM ± 2%
Differential Pressure Sensor	MSFC Supplied	0 - 2 in. H_2O ± 5%
Thermocouples	MSFC Supplied/Type T	0 - 500°F ± 1.8°F

6.0 TEST REQUIREMENTS AND PROCEDURES

6.1 Collector Thermal Performance Test

6.1.1 Evaluation Requirements

Utilizing the MSFC Solar Simulator and the portable hot air loop, performance evaluation data were obtained at inlet temperatures of 100°F and 150°F with insolation rate of 250 BTU/Ft^2·Hr and a wind speed of 7.5 MPH. The air flow rates were controlled to 30, 90 and 150 SCFM. The depth of flow channel inside the collector was adjusted to 3, 2, 1 and 1/2 inches. The test conditions are listed in Table I. The following data were recorded during the test:

1. Absorber surface temperature - 3 locations (°F)
2. Inlet air temperature (°F)
3. Outlet air temperature (°F)
4. Air flow rate (SCFM)
5. Collector differential pressure ("H_2O)
6. Insolation rate (BTU/Ft^2·Hr)
7. Air flow channel depth (Inch)
8. Wind speed (MPH)

6.1.2 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. Insulate all ducts.
4. Connect instrumentation leads to data acquisition system.
5. Assure that data acquisition system is operational.
6. Establish required wind speed.
7. Start air flow loop and establish the required flow rate.
8. Establish the required inlet temperature.
9. Power up Solar Simulator and establish the required insolation rate.
10. Record data for a minimum of five minutes at three stabilized conditions.
11. Insert flow channel spacers as necessary to obtain specified flow channel depth and repeat Steps 7 through 10.
12. Upon completion of testing, power down Solar Simulator and air loop.
13. Inform data control group that simulator operation has terminated.

6.1.3 Results

The results obtained during these tests are contained in Figures 1 through 5 and Tables II through VI.

7.0 ANALYSIS

The analysis of the data contained in this report is in accordance with the National Bureau of Standards and ASHRAE recommended approach.

The efficiency of a collector is:

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

where

- q_u = rate of useful energy extracted from the solar collector (BTU/hr)
- A = overall cross sectional area of collector (ft^2)
- I = total solar energy incident upon the plant 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 ($Lb/Ft^2\text{-}Hr$)
- 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 collector area, we get:

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

Notice that

- P_i = IA = total power incident on the collector (BTU/Hr)
- $\dot{M}$ = $\dot{m}A$ = total mass flow rate through the collector (Lb/Hr)

For an air collector system, the mass flow rate is obtained by multiplying the density of the air with the volume flow rate of the air through collector.

$$\dot{M} = \rho_{tf}\dot{V} \qquad (3)$$

where

- ρ_{tf} = Density of the transfer fluid (Lb/Ft^3)
- $\dot{V}$ = Volume flow rate (SCFM) x 60

Since $\dot{M}C_{tf}(T_{f,e} - t_{f,i})$ = total power collected by the collector, the collector efficiency can be expressed in

$$\eta = \frac{P_{abs}}{P_{inc}} \qquad (4)$$

where

P_{abs} = total absorbed power

P_{inc} = total incident power

The present collector efficiency is defined as

$$\% \text{ eff} = \frac{\dot{M}C_{tf}(T_{f,e} - t_{f,i})}{P_i} *100 \qquad (5)$$

The efficiency calculations were made for all test data and are included in Tables II through V. Figures 1 through 4 present plots of efficiency versus the normalized factor for flow channel depths of 3 in., 2 in., 1 in., and 1/2 in., respectively.

TABLE I

MSFC HOT AIR COLLECTOR EFFICIENCY TEST CONDITIONS

Flow Channel Depth (Inches)	Inlet Temp. (°F) \ Flow Rate CFM	Test Designation 30	90	150
3	100 150	1 4	2 5	3 6
2	100 150	7 10	8 11	9 12
1	100 150	13 16	14 17	15 18
1/2	100 150	19 22	20 23	21 24

Q = 250 BTU/Ft^2·Hr

Wind = 7.5 MPH (from south)

Tilt Angle = 45°

TABLE II

MSFC HOT AIR COLLECTOR THERMAL PERFORMANCE TEST DATA - 3" FLOW DEPTH

North East Surface °F (6)	165	145	135	186	173	162				
South East Surface °F (5)	176	159	144	196	183	175				
South Surface °F (4)	167	151	138	195	183	175				
South West Surface °F (3)	167	143	130	194	178	169				
North West Surface °F (2)	175	154	143	199	183	175				
Ambient °F	85	85	86	84	83	82				
T_{in} °F	100.1	100.8	101.3	150.1	150.2	149.8				
T_{out} °F	126.4	117.6	113.2	166.9	158.0	155.6				
ΔT °F	26.3	16.8	11.9	16.8	7.6	5.8				
Solar Flux BTU/Hr·Ft^2	250	250	250	250	250	250				
Flow Rate SCFM	30	90	150	30	90	150				
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5				
Efficiency %	18.9	36.3	42.8	12.1	16.8	20.9				
(Ti-Ta) /I °F·Hr·Ft^2/BTU	0.060	0.062	0.061	0.264	0.269	0.271				
ΔP in. H_2O	0.0092	0.0369	0.1015							

TABLE III

MSFC HOT AIR COLLECTOR THERMAL PERFORMANCE TEST DATA - 2" FLOW DEPTH

North East Surface °F (6)	160	134	125	188	174	167	199	193	191	
South East Surface °F (5)	179	154	141	198	184	176	206	200	195	
South Surface °F (4)	170	148	135	193	182	176	203	200	195	
South West Surface °F (3)	164	136	124	189	174	166	199	193	189	
North West Surface °F (2)	175	148	135	191	180	173	200	196	193	
Ambient °F	86.8	87.6	85.7	85.6	82.1	84.4	81.8	87.1	88.3	
T_{in} °F	100	100	100.7	150.5	150.7	150.5	180.9	180.4	180.2	
T_{out} °F	129.8	119.6	115.5	163.0	158.7	1-5.4	181.5	182.2	180.8	
ΔT °F	29.8	19.6	14.8	12.5	8.0	4.9	0.64	1.8	0.6	
Solar Flux BTU/Hr·Ft^2	250	250	250	250	250	250	250	250	250	
Flow Rate SCFM	30	90	150	30	90	150	30	90	150	
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	
Efficiency %	21.5	42.3	53.3	9.0	17.3	17.7	0.5	3.9	2.2	
(Ti-Ta) /I °F·Hr·Ft^2/BTU	0.053	0.050	0.060	0.260	0.027	0.027	0.396	0.373	0.368	
ΔP in. H_2O										

TABLE IV

MSFC HOT AIR COLLECTOR THERMAL PERFORMANCE TEST DATA - 1" FLOW DEPTH

North East Surface	°F (6)	140	120	115	168	156	161	181	177		
South East Surface	°F (5)	162	138	128	180	168	171	188	182		
South Surface	°F (4)	168	145	137	180	173	174	189	185		
South West Surface	°F (3)	142	116	107	166	151	155	178	171		
North West Surface	°F (2)	150	125	118	170	157	162	179	174		
Ambient	°F	81.0	81.6	82.2	82.0	83.6	85.4	79.5	80.5		
T_{in}	°F	99.3	100.3	100.2	140.5	139.7	150.3	164.6	165.7		
T_{out}	°F	136.3	124.2	116.8	161.1	153.2	157.4	171.4	169.0		
ΔT	°F	37.0	23.9	116.6	20.6	13.5	7.1	6.8	3.3		
Solar Flux	$BTU/Hr \cdot Ft^2$	257	257	257	257	257	257	257	257		
Flow Rate	SCFM	30	90	150	30	90	150	30	90		
Wind Speed	MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5		
Efficiency	%	25.9	50.2	58.2	14.4	28.3	24.8	4.8	6.9		
(Ti-Ta) /I	$°F \cdot Hr \cdot Ft^2/BTU$	0.071	0.0073	0.070	0.228	0.218	0.254	0.331	0.332		
ΔP	in. H_2O	0.0369	0.1845	0.517							

TABLE V

MSFC HOT AIR COLLECTOR THERMAL PERFORMANCE TEST DATA - 1/2" FLOW DEPTH

North East Surface °F (6)	130	115	116	169	163	160	180	176	174	
South East Surface °F (5)	158	134	133	189	177	170	195	188	184	
South Surface °F (4)	155	139	137	187	187	174	195	193	188	
South West Surface °F (3)	151	125	126	187	174	171	193	185	182	
North West Surface °F (2)	165	154	137	190	184	178	195	194	188	
Ambient °F	86.4	81.3	87.5	88.1	82.5	83.1	83.7	84.9	84.7	
T_{in} °F	98.7	100.6	100.7	148.5	149.6	150.2	164.3	164.7	165.3	
T_{out} °F	146.3	127.5	123.1	167.3	162.6	156.2	178.1	170.1	166.7	
ΔT °F	47.6	26.9	22.4	18.8	13.0	6.0	13.8	5.4	1.4	
Solar Flux BTU/Hr·Ft^2	250	250	257	257	257	257	257	257	257	
Flow Rate SCFM	30	90	150	30	90	150	30	90	150	
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	
Efficiency %	34.3	58.1	78.5	13.2	27.3	21.0	9.7	11.4	5.0	
(Ti-Ta) /I °F·Hr·Ft^2/BTU	0.049	0.077	0.051	0.235	0.261	0.261	0.314	0.311	0.314	
ΔP in. H_2O	0.074	0.443	0.996							

TABLE VI

MSFC HOT AIR COLLECTOR PRESSURE DROP TEST DATA - 2" FLOW DEPTH

North East Surface °F (6)										
South East Surface °F (5)										
South Surface °F (4)										
South West Surface °F (3)										
North West Surface °F (2)										
Ambient °F										
T_{in} °F										
T_{out} °F										
ΔT °F										
Solar Flux BTU/Hr·Ft^2										
Flow Rate SCFM	28	59	96	135	154					
Wind Speed MPH										
Efficiency %										
(Ti-Ta) /I °F·Hr·Ft^2/BTU										
ΔP in. H_2O	0.0185	0.0461	0.1338	0.2214	0.2952					

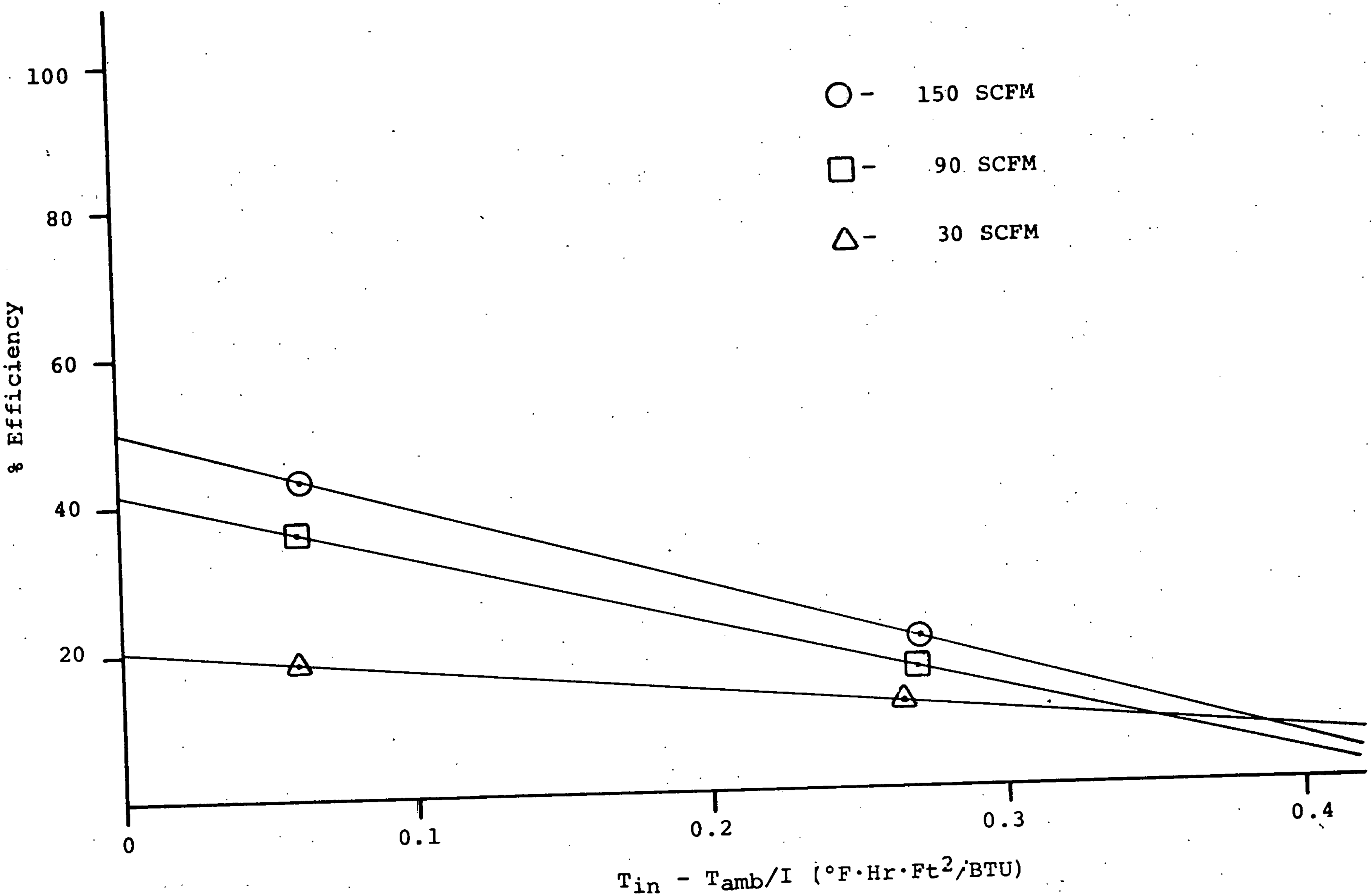

Figure 1. MSFC Hot Air Collector Thermal Performance Test Data - 3 In. Flow Depth

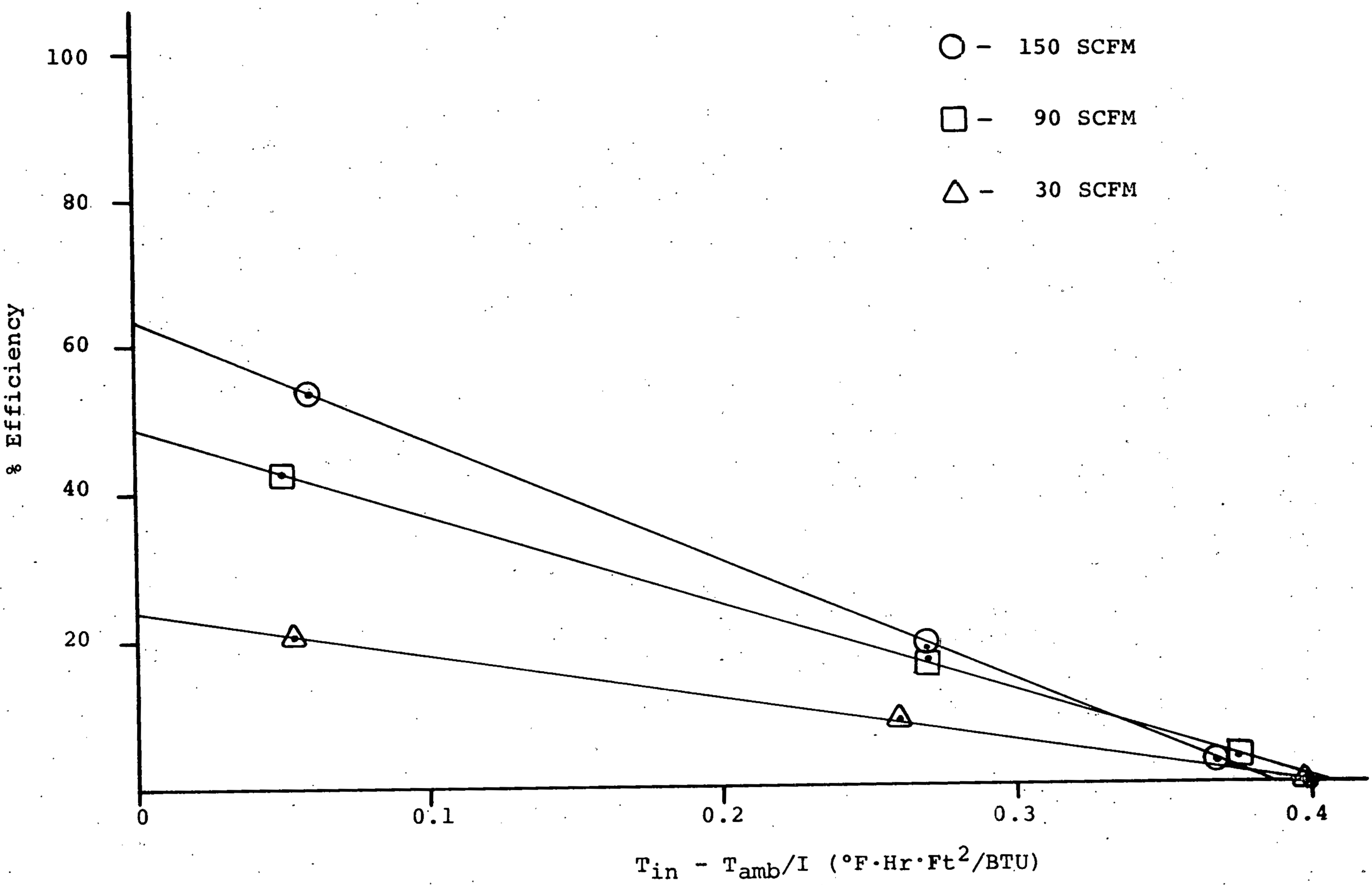

Figure 2. MSFC Hot Air Collector Thermal Performance Test Data - 2 In. Flow Depth

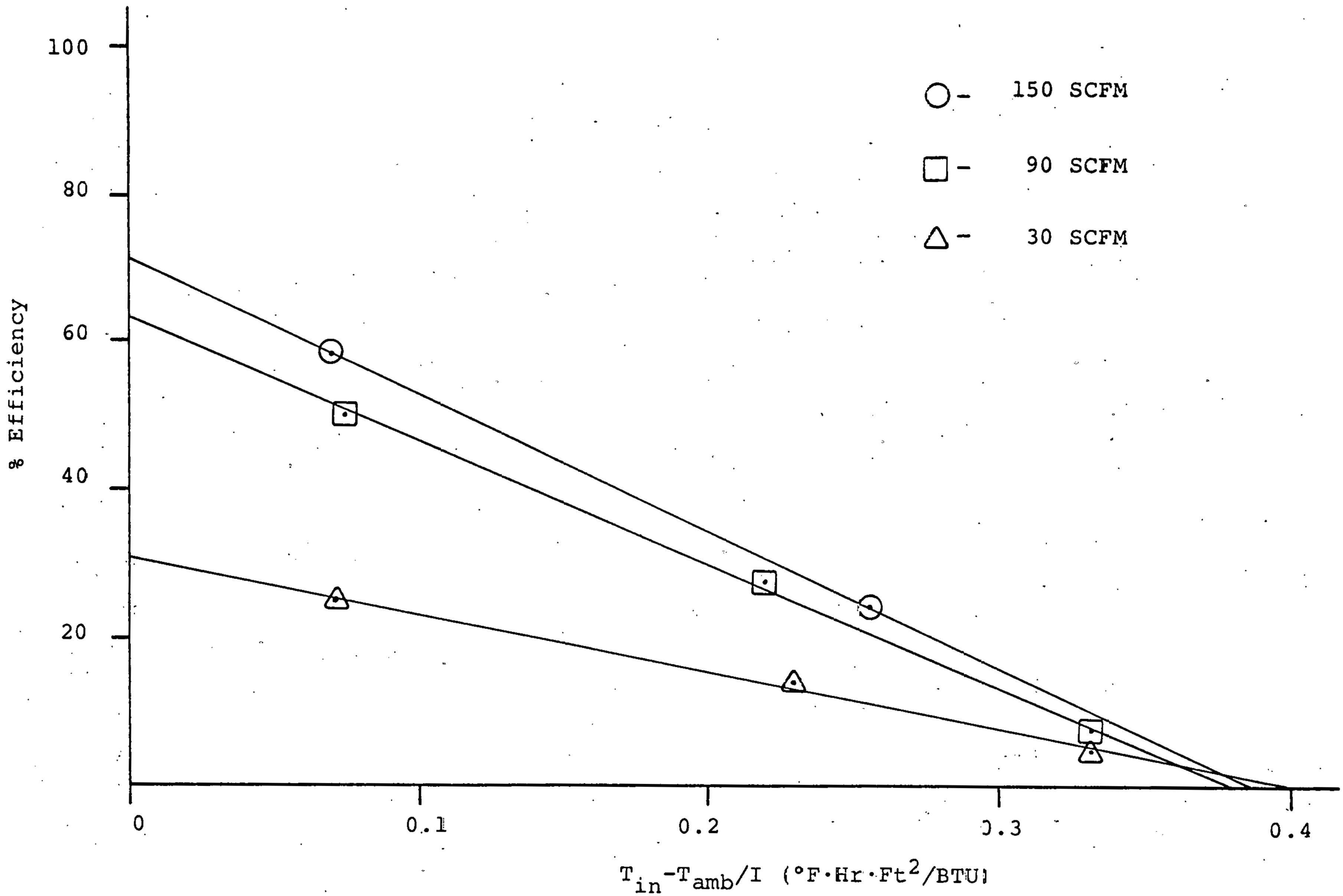

Figure 3. MSFC Hot Air Collector Thermal Performance Test Data - 1 In. Flow Depth

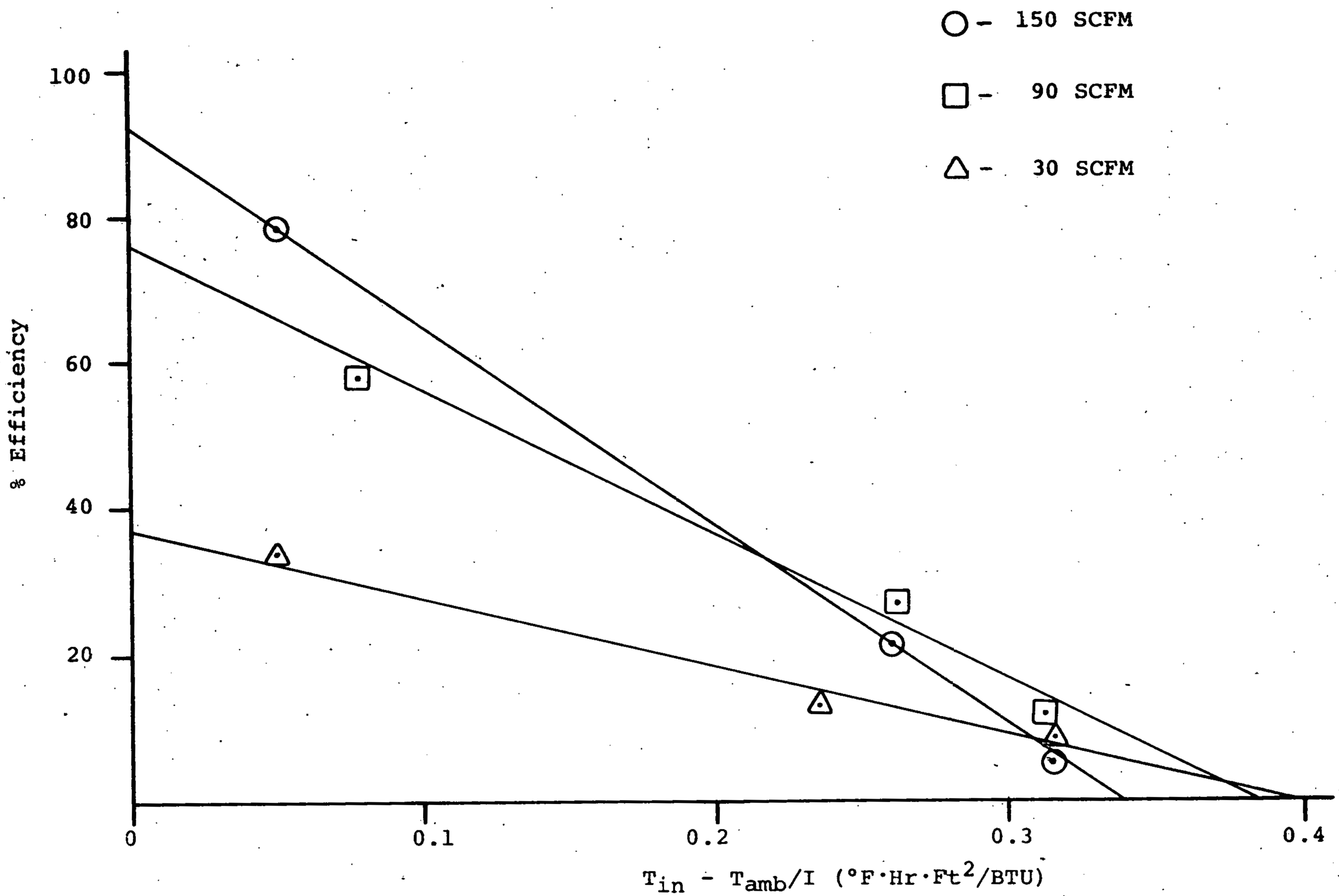

Figure 4. MSFC Hot Air Collector Thermal Performance Test Data - 1/2 In. Flow Depth

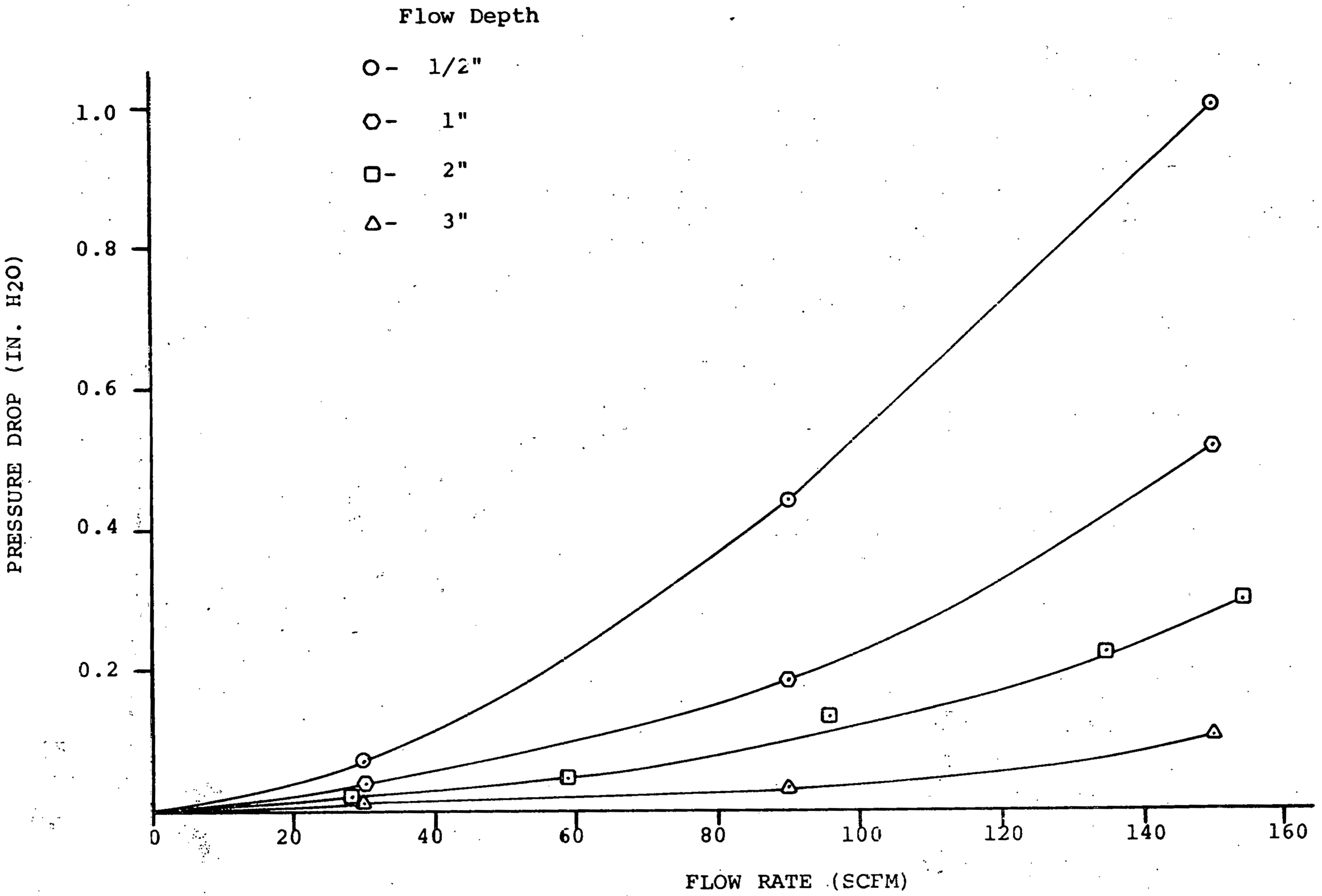

Figure 5. MSFC Hot Air Collector Pressure Drop Test Data

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