Sun Systems, Inc.

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MASTER

For:
HOT WATER
HEATING
SWIMMING POOLS
AIR CONDITIONING

November, 1979

DOUBLE ABSORBER PLATE

FINAL TECHNICAL REPORT

(PERIOD FROM OCTOBER 1, 1977 - NOVEMBER 15, 1978)

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TABLE OF CONTENTS

Abstract

Background

Discussion of Results

Plans for Future Work

Appendix: Thermal Evaluation Tests

Report Distribution

ABSTRACT

An improved solar air collector has been developed.

BACKGROUND

Sun Systems, Inc. had developed an air collector that avoids the high air side pressure drops and the use of inlet and outlet header ducts to connect collectors in parallel. The precontract collector design is shown in Figures 1 and 2. The major novelty of the collector rests in having two absorber plates which heat a relatively broad air passage. The current collector utilizes a 4 mil fiberglass reinforced plastic sheet ("Kalwall") outer glazing, a 1 mil fluorocarbon ("Teflon") inner anticonvection layer/inner glazing, a partially blackened (50%) absorbing) 4 mil fiberglass reinforced plastic sheet ("Kalwall") and a "flat black" aluminum inner absorber backed by a 1 1/2 inch thickness of fiberglass insulation.

FIBERGLASS REINFORCED
PLASTIC COVER

ANTICONVECTION LAYER

AIR SPACES

ABSORBER PLATE
HALF BLACKED

HOT AIR PASSAGE
1.5 INCH DEEP

ABSORBER PLATE
COMPLETELY BLACK

INSULATION

SUN SYSTEMS HOT AIR PANEL

FIGURE 2

DISCUSSION OF RESULTS

The major goal of the program was to develop a commercially viable air heater retaining the advantage of low-absorber surface to air temperature differences and of low pressure drops of the pre-contract collector.

Task 1: Preliminary Collector Panel Testing.

As described in detail in Quarterly Reports (one and two) a three collector array of the pre-contract design was fabricated and tested. The efficiency of the array was identical with the results obtained for a single collector by the University of Connecticut (see First Quarterly Report).

Task 2: Collector Array Test and Evaluation.

A ten panel array employing techniques developed under the contract was fabricated and installed on a flat roof of the Sun Systems, Inc. facility - See Third Quarterly Report. Due to the late award of the contract it was not possible to run this array during a heating season. During the period May 8, 1978 - November 8, 1978, the array received insolation of 754 kilowatt hours/square meter in a stagnant condition without any adverse effect. The glazing remained quite clean and now has a dull matte-like finish (caused by modest accumulated dirt) rather than the original finish which has substantial glare.

Task 3: Evaluation of Half Black Absorber Plate Options.

As previously reported (First, Second and Third Quarterly Reports) a detailed evaluation of replacements for the pre-contract "half painted" absorber led to the selection of a bronze plastic sheet manufactured by "Filon". Tests of a collector fabricated from this absorber were carried out by the University of Connecticut (see Appendix). This collector is at least comparable in performance to the pre-contract collector. Unfortunately, the testing at the University of Connecticut was carried out at a lower flow rate, 107-119 SCFM, than the pre-contract collector, 120-130 SCFM, so that direct comparisons can not be made with complete certainty. Since efficiency is flow rate dependent, the final collector of this contract is believed to be superior in performance to the pre-contract collector in all respects.

Task 4: Value Engineering of Preferred Collector Options.

The collector designed selected under this contract consists of an aluminum pan fabricated from readily available four foot by eight foot aluminum flat stock, a commercially available outer double glazing, Rohm and Haas "Twinwall", and commercially available absorber plates. We believe that two areas for further improvement remain (see "Plans for Future Work" Section).

DISCUSSION OF RESULTS (cont'd)

1. Restrictions on collector size by utilizing a box made from sheet aluminum lead to adverse cost effects.
2. The male/female flange arrangement developed for making collector arrays, while satisfactory in the three collector array, leads to major installation difficulties as tested in the ten collector array since it is difficult to obtain aluminum pans of the required edge flatness.

Task 5: Reports and Meetings.

P. Hayes attended a contractor's meeting at Sandia, Albuquerque. P. Hayes and E. Berman reviewed the program with S. L. Sargent of U. S. D.O.E.

PLANS FOR FUTURE WORK

We believe that a superior solar air collector having commercial viability, especially in Europe where the attractive appearance of the collector is of great importance, can be developed from progress made under the contract.

Funds permitting, we intend to make the following changes in the Double Absorber air collector. Rather than using an aluminum pan, we intend to use extruded aluminum sides in a "picture frame" arrangement (see next two pages). In this way, the collector size will not be limited by availability of sheet aluminum. Since most of the collector components are most available as four feet by eight foot pieces, our standard collector will be this size. Going to aluminum extruded sides will allow us to manifold the collectors into arrays at minimum cost and maximum utility since the sides are rigid enough to be interconnected within the tolerances required. In addition, the aluminum sides will be sufficiently rigid that costs of mounting the arrays will be substantially reduced.

Estimated factory cost of a thirty-two square foot double absorber air collector employing extruded aluminum sides is \$170, yielding an estimated distributor selling price of \$285 or less than \$9 per square foot.

SUN SYSTEMS INC.
 (LEFT SIDE) AIR HEATER (PROPOSED)
 MATERIAL: .030 ALUMINUM

SUN SYSTEMS INC.
(RIGHT SIDE) AIR HEATER (PROPOSED)

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THERMAL EVALUATION TESTS
OF
SUN SYSTEMS INCORPORATED
AIR HEATING FLAT PLATE COLLECTOR

Prepared by:

Solar Energy Evaluation Center
University of Connecticut

for

Sun Systems Incorporated
Milton, Massachusetts

1.0 Introduction

The University of Connecticut Solar Energy Evaluation Center has conducted tests to evaluate the thermal performance of a flat-plate solar collector for Sun Systems Incorporated. This manufacturer desired performance data from an independent test laboratory for developmental and promotional purposes. The collector was tested according to the guidelines presented in the ASHRAE Standard 93-77 publication. An efficiency plot along with tables describing environmental and test conditions for each data point are presented in this report.

AIR RIG SCHEMATIC

1. BAFFLE PLATE
2. NOZZLE INLET PRES. TAPS
3. NOZZLE OUTLET PRES. TAPS
4. NOZZLE
5. WET & DRY BULB THERMISTORS
6. WET BULB RESERVOIR

7. INLET TEMP. THERMISTOR
8. OUTLET TEMP. THERMISTOR
9. DELTA-T THERMOPILE
10. COLLECTOR INLET PRES. MANIFOLD
11. COLLECTOR OUTLET PRES. MANIFOLD
12. AIR FLOW CONTROL VALVE

FIGURE 1

As the air leaves the collector it passes over the outlet pressure taps, the outlet portion of the twelve junction thermopile and the outlet thermistor. The air flow enters a control valve next and then the flow measuring apparatus which consists of a baffle plate, a receiving chamber, a 2.0 inch flow measuring nozzle with four evenly spaced pressure taps at the inlet and the outlet (to measure the static pressure drop), a wet and dry bulb thermistor and another baffle plate. From this apparatus, the air flow enters the blower inlet and continues the cycle.

2.2 Instrumentation

2.2.1 Temperature Measurements

The inlet temperature is continuously measured during each run using an Omega UNI-CURVE thermistor in one leg of a bridge circuit. The fixed legs of the bridge are adjusted through the use of coarse and fine potentiometers in series and optional parallel fixed resistors, thus allowing each bridge to be set up for any temperature range desired. The output from the bridge is recorded on a potentiometric strip chart recorder. The strip chart recorder is calibrated using an attenuator so that the signal is recorded directly as a temperature with an accuracy of greater than 0.5°C .

The outlet temperature is also continuously measured during each run using an Omega UNI-CURVE thermistor in one leg of a bridge circuit. The output is recorded directly as a voltage signal on a calibrated potentiometric strip chart recorder. The average output voltage for each test run is used later in the data reduction program to solve the bridge equation for the resistance of the thermistor which can then be converted into a temperature reading. This temperature reading also has an accuracy of better than 0.5°C .

"Delta T" measurements are made using a twelve junction thermopile installed in the inlet and outlet instrumentation sections. The junctions of the thermo-

pile are located at the centers of equal cross-sectional areas. The thermopile is joined to the readout instrumentation by thermocouple grade copper wire. The output is recorded directly in volts on a potentiometric strip chart recorder. This voltage value was used later in the data reduction program to calculate a 'delta T' value. This value has an accuracy of $\pm 0.1^{\circ}\text{C}$. Each value is cross-checked against the corresponding value of the outlet temperature minus the inlet temperature to insure all measurements are indeed valid.

The ambient temperature is also continuously recorded during each test run using an Omega Uni-Curve thermistor in one leg of a bridge circuit. The thermistor is located in a special ventilated instrumentation shelter called a Stevenson shield. The output from the bridge is recorded directly in temperature units on a potentiometric strip chart recorder.

The dry and wet bulb temperatures are recorded each run by measuring the respective resistance of each thermistor on a Hewlett-Packard digital multimeter. Each value is later converted into a temperature reading using temperature resistance tables.

2.2.2 Solar Irradiation Measurements

An Eppley PSP pyranometer located in the same plane as the collector is used to obtain insolation data. The pyranometer output voltage is recorded on a potentiometric strip chart recorder. The value of the insolation is linearly related to this output voltage.

The direct component of the solar insolation is measured using an Eppley pyrliometer which automatically tracks the sun. Its output voltage is measured the same way as the pyranometer's output voltage. In this way it is possible to separate the insolation into two components: direct irradiation and diffuse irradiation.

2.2.3 Air Flow Rate Measurement

The air flow rate is determined from the static pressure drop across the flow metering nozzle measured by a Merriam inclined manometer. Knowing the pressure drop across the nozzle and the density of the air in the nozzle, which can be obtained from wet and dry bulb temperature measurements, the air flow rate can be calculated.

2.3 Test Results

2.3.1 Explanation of Graph

The test results are presented in terms of a "slope-intercept" efficiency plot along with tables of supporting information. The difference between the inlet temperature and the ambient temperature divided by the total amount of solar insolation is plotted on the abscissa, more commonly called the x-axis. The efficiency is plotted on the ordinate. The efficiency is calculated as the ratio of the actual useful amount of energy absorbed by the collector to the total amount of solar energy incident on the collector. In mathematical terms,

$$\eta = \frac{\dot{m} C_p \Delta T}{A I}$$

where:

η = efficiency of collector

$\dot{m}$ = mass flow rate of transfer fluid

C_p = specific heat of transfer fluid

ΔT = temperature difference between inlet and outlet

A = effective area of collector

I = solar irradiation

UNIVERSITY OF CONNECTICUT SOLAR ENERGY EVALUATION CENTER
AIR TEST RESULTS

SUN SYSTEMS

DATE	SOLAR TIME	BARO. PRES. (IN. HG)	WIND (MPH)/DIR.	TOTAL INSOLATION (W/M SQ)	DIFF. RAD. (%)	INC. ANGLE (DEG.)	TEMPERATURES AMB. INLET DELTA (DEGREES C)	FLOW RATE (SCFM)	EFF.	ABS C M SQ/W
2/12/78	10:50	29.56	3.0 NW	973.61	8.6	16.7	23.30 24.44 15.19	119.2	0.517	0.0012
12/78	10:56	29.56	4.0 W	976.39	8.5	15.3	23.26 24.50 15.34	119.2	0.521	0.0013
12/78	1: 5	29.52	4.0 N	980.56	8.0	15.5	24.69 26.76 15.63	119.1	0.528	0.0021
12/78	1:11	29.52	1.5 NNE	972.22	8.0	16.9	25.38 26.83 15.55	119.0	0.529	0.0015
12/78	11:30	29.56	5.0 NW	1019.44	8.2	7.7	23.56 44.82 11.47	114.4	0.361	0.0209
12/78	11:36	29.56	8.1 NW	1020.83	8.9	6.5	23.13 44.78 11.70	114.5	0.368	0.0212
12/78	12:17	29.52	1.3 NW	1029.17	7.8	5.1	24.29 44.95 13.14	109.1	0.391	0.0201
12/78	12:23	29.52	2.0 NW	1019.44	7.9	6.3	24.31 45.62 12.85	108.9	0.386	0.0209
13/78	11:55	29.56	1.9 WNW	1005.83	18.2	3.2	27.09 69.36 7.75	113.9	0.251	0.0420
13/78	12: 1	29.56	3.0 NW	1021.25	18.2	3.0	27.06 69.31 7.68	114.3	0.245	0.0414
13/78	12: 7	29.56	4.4 WSW	1017.22	18.2	3.4	27.27 69.38 7.86	114.0	0.252	0.0414
8/13/78	12:14	29.56	7.5 SW	1015.56	18.3	4.5	27.06 69.09 8.16	113.8	0.261	0.0414
8/25/78	11:38	29.65	2.9 SW	1024.03	11.6	5.3	23.87 83.22 4.19	107.7	0.137	0.0580
8/25/78	11:44	29.65	3.1 S	1010.69	11.1	3.9	24.04 83.63 4.08	107.7	0.135	0.0590
25/78	12: 4	29.65	2.6 S	1035.00	12.4	1.3	24.18 83.70 4.96	107.4	0.160	0.0575
25/78	12:10	29.65	2.3 S	1023.89	13.5	2.5	24.30 83.59 4.87	107.3	0.158	0.0579

DESCRIPTION OF TEST COLLECTOR

Manufacturer Sun Systems, Inc.

P.O. Box 347, Milton, Massachusetts 02186

Model _____ Serial No. _____ Type Flat Plate (air)

Aperature:

Dimensions 85 3/4" X 37 5/8" Area 22.405 ft²

Glazing Material "Tuffak" Twinwall Polycarbonate (outer)
_____ (inner)

Gros Dimensions:

Height 88 3/4 "

Width 40 1/2"

Weight 65 lbs.

Fluid Hold-up Volume N/A

Air Spaces:

Plate to Inner Cover 2", Between Covers 7/32"

Absorber Plate:

Materials Aluminum Sheet

Coating Flat Black Paint

Flow Path Bottom to Top

General Description _____

Insulation:

Under Absorber Plate 1 1/2" Rigid Fiberglass

Edge None

Frame:

Perimeter Formed Aluminum Sheet

Mounting None Provided

Plumbing Interface 30" X 4" funnel with a 4" diameter flange at its
end.

Remarks:

TEST RESULTS SUMMARY

(ASHRAE 93-77)

Collector Time Constant 5 min.
(if greater than 5 minutes)

Incident Angle Modifier Coefficient $b_o =$.2986

$$K_{at} = -b_o(1/\cos \theta_i - 1) + 1$$

θ_i = incident angle

Equation of Hottel-Willier Curve (see data plot)

$$\eta = A_o - A_1 X \quad \text{First order least squares fit}$$

$$\eta = B_o - B_1 X - B_2 X^2 \quad \text{2nd order least squares fit}$$

Pre-exposure $A_o =$.5257, $A_1 =$ 6.5550

(if applicable) $B_o =$ na, $B_1 =$ na, $B_2 =$ na

where $X = (T_{IN} - T_{AMB}) / I$ [$^{\circ}\text{C} \cdot \text{M}^2 / \text{WATT}$]

Mnfr SUNSYSTEMS

Mod _____

Aperture 22.405 ft²

Validation *Dr. J. L. ...* 9/12/78

2.0 Experimental Procedure

2.1 Test Facility:

2.1.1 General Description

The solar collector test facility operated by the Mechanical Engineering Department is located on the roof of the Engineering II Building at the University of Connecticut, Storrs campus. Overall the facility consists of three test rigs: two test rigs for measuring the performance of liquid cooled solar collectors and one test rig for measuring the performance of air cooled solar collectors. The testing described in this report pertains to an air cooled solar collector exclusively.

2.1.2 Air-Heating Collector Rig

The test rig consists of a 4 X 11 foot inclined plane and support framework, a closed loop air circulating system and transducers for recording temperatures and pressures. The framework design allows for adjustment of the collector incident angle and is aimed due south. Electronic signal conditioning equipment and strip chart recorders are housed in a separate instrumentation shack.

A schematic diagram describing the fluid circuits, valving, and instrumentation locations is presented in Figure 1. Air is used as the heat transfer fluid. Referring to Figure 1, the main flow loop may be traced as follows: air leaves the blower and enters a section of 4.0 inch diameter duct which leads into the air reconditioning apparatus. This apparatus consists of an aluminum heat exchanger for cooling the air and a wire coil resistance heater for controlling the collector inlet temperature. After leaving here, the air passes over an inlet temperature thermistor placed in the center of the air stream, the inlet portion of a twelve junction thermopile, and an inlet pressure monitoring system consisting of four externally manifolded pressure taps evenly spaced around the duct. From this point the air enters the collector.

UNIVERSITY OF CONNECTICUT
SOLAR ENERGY EVALUATION CENTER
ASHRAE 93-77 PERFORMANCE TEST

MNFR SUNSYSTEMS

MOD 22

FLUID WATER

AIR

APPERATURE 22.405 ft²

VALIDATION

[Signature] 9/12/78

EFFICIENCY (%)

100

80

60

40

20

$^{\circ}\text{C} \cdot \text{M}^2 / \text{WATT}$

.01

.02

.03

.04

.05

.06

.07

.08

$(T_{\text{inlet}} - T_{\text{ambient}}) / I$

$^{\circ}\text{F} \cdot \text{FT}^2 \cdot \text{HR} / \text{BTU}$

0.1

0.2

0.3

0.4

0.5