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OUTDOOR PERFORMANCE RESULTS FOR N. B. S. "ROUND ROBIN" COLLECTOR NO. 1

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16. Abstract

The efficiency of a PPG flat-plate solar collector was evaluated utilizing an outdoor solar collector test facility at the NASA-Lewis Research Center, as part of the National Bureau of Standards "round robin" collector test program. Data was recorded and reported in accordance with the format set forth by the N.B.S. The correlation equation for collector thermal efficiency η, curve fit of the data was: $\eta = 0.666 - 1.003(\text{Btu/hr-ft}^2\text{-}^\circ\text{F})\theta$, where the parameter θ is the difference between the average fluid temperature and the ambient temperature, all divided by the total flux impinging on the collector.

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INTRODUCTION

One part of solar energy research at NASA Lewis Research Center has been the determination of flat-plate solar collector efficiency under real-sun conditions.

This report presents efficiency data obtained from a PPG flat-plate solar collector tested outdoors as part of the N.B.S. "Round-Robin" collector test program. The proposed N.B.S. standards for collector testing (ref. 1) were used as a guideline, wherever possible, in acquiring and reporting the data.

EXPERIMENTAL APPARATUS

The outdoor solar collector test facility used is shown in figure 1. This facility consists of two collector test stands, each with the capability to simultaneously test five flat-plate solar collectors. The mechanical components of the flow loop (pump, water tank, etc.) are enclosed in the instrument shed which is located in the center of each stand.

Coolant Flow Loop

The liquid used as a coolant is a 50-50 mixture, by weight, of ethylene glycol and water. Corrosion inhibitors are present in the ethylene glycol (ref. 2).

Figure 2 shows a schematic of the flow loop of one of the collector test stands. Note that each collector has an independent flow-loop which is in parallel with the other four collector flow loops. An expansion tank is provided to allow for changes in fluid volume.

The coolant is circulated by a 1/4 horsepower pump, with a surge tank connected at its outlet. Coolant is stored in a commercially available 80-gallon water tank which has two 5500-watt immersion heaters. In general, the tank heaters are used to maintain a constant storage temperature.

The air liquid heat exchanger is used to regulate the inlet temperature to the collectors. In the event that the inlet manifold temperature

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increases above the "set" temperature, an automatic controller operates a series of valves which route the hot fluid to the heat exchanger, where the excess heat is dumped.

Flow control for each individual collector is achieved by the adjustment of a remotely operated valve. Also, since a constant pressure is required in the collector inlet manifold, a collector bypass line is provided.

For those collectors with aluminum absorber plates, an aluminum screen is placed in the flow path just upstream of the inlet to the collector.

Filtration of the water-glycol mixture is provided by a 25 micron filter, located just downstream of the pump.

INSTRUMENTATION

The following measurements are recorded for each collector:

(1) Coolant flow rate

(2) Coolant temperature at the inlet to the collector

(3) Coolant temperature at the outlet to the collector

(4) Absorber plate temperature

(5) Coolant pressure at inlet to the collector

(6) Pressure differential across the collector

The coolant flow rate through each collector is measured with a turbine-type flowmeter. The flowmeters were calibrated for a 50-50 mixture of ethylene glycol and water by the vendor.

In order to make a "gross" check on flowmeter output, the capability to "grab-sample" the fluid has been incorporated into the coolant flow loop. By withdrawing a sample of fluid from a collector flow loop, and knowing the time interval over which the sample was taken and the fluid temperature, it is then possible to compute the fluid flow rate. Checks of this nature are periodically performed on each flowmeter.

Collector temperatures are measured with chromel-constantan thermocouples (ISA-type E). The inlet and outlet thermocouples were made from the same spool of wire, and were calibrated in an oil bath. Then the inlet and outlet thermocouples were matched so that their combined error is within $\pm 0.5^{\circ}$ F.

A check is performed on the inlet and outlet thermocouples prior to installation of a collector on the test stand, and also after removal. This is done by immersing both the inlet and outlet thermocouples in an ice bath and then in a boiling water bath.

Solar radiation is measured in the plane of the collectors, and in the horizontal plane. There is a pyranometer on each test stand which is oriented at the collector tilt angle. Solar instruments located on a nearby roof also measure the total insolation (horizontal surface), the diffuse insolation (horizontal surface), and the normally incident direct radiation.

Each of the four pyranometers is checked in the solar simulator (ref. 3) every six months, at a high flux ($\approx$300 Btu/hr-ft^2), and at a low flux ($\approx$100 Btu/hr-ft^2). The four pyranometer outputs are compared to each other and also to a standard pyranometer (same brand name and type). The standard is not used outdoors but is stored in a "light tight" container. It is used only as a reference. The desiccant charge in each pyranometer is routinely checked, and changed if necessary.

Solar instruments in the horizontal plane are used as a check on the solar instruments in the plane of the collectors. The output of the pyranometers on each test stand are also compared to each other. Agreement within $\pm$3 percent is typical.

In addition to the collector and insolation data, the following weather data are recorded: air temperature, wind speed and direction, and relative humidity.

Data Acquisition

The outputs of the various types of instrumentation pass through signal conditioners and then into a matrix-type patchboard. The signals are then routed to a high speed integrating voltmeter which scans each instrumentation channel and digitizes the millivolt signal for storage on magnetic tape. Sufficient capacity exists for the on-line retrieval of the millivolt outputs of each channel. Also, an on-line access to a computer allows for output in engineering units.

RESULTS AND DISCUSSION

Figure 3 is a plot of the efficiency of the PPG collector. The efficiency is plotted on the ordinate, while the parameter $\left(\frac{\text{avg fluid temp - ambient temp}}{\text{total solar flux on collector}}\right)$ is plotted on the abscissa. The data presented were determined using methods described in reference 1.

The straight line through the data represents a first-order curve fit. The equation for the curve fit line was found to be: $\eta = 0.666 - \left(1.003 \frac{hr\text{-}ft^2\text{-}{}^\circ F}{Btu}\right) \cdot \theta$ where $\theta = \frac{(T_{in} + T_{out})/2 - T_{amb}}{I}$. The intercept value of 0.666 corresponds to the product $(F' \cdot \alpha \cdot \tau)$, while the slope value of $-1.003 \frac{hr\text{-}ft^2\text{-}{}^\circ F}{Btu}$ corresponds to the product $(F' \cdot U_L)$. F' is the collector plate efficiency factor, α the collector surface absorptance, τ the transmittance of the covers, and U_L the overall heat loss coefficient (see, for example, ref. 4).

Table I lists some general information pertaining to the collector, and to its installation and operation.

Table II lists various quantities used in determining the efficiencies plotted in figure 3, and also test conditions for each of the sixteen data points. It should be noted that the quantities $\int_{\tau_1}^{\tau_2} (T_{f,e} - T_{f,i}) d\tau$ and $\int_{\tau_1}^{\tau_2} I \, d\tau$ were not continuously integrated during the test. Rather, data was recorded at four minute intervals, and the trapezoidal integration rule was then applied to four of these respective instantaneous values.

CONCLUSIONS

A two-gloss black paint flat-plate solar collector manufactured by the Pittsburgh Plate Glass Company was tested outdoors, as part of the N.B.S. "Round Robin" collector test program. Results were then evaluated and presented in accordance with the guidelines set forth in N.B.S. Technical Note 899 - "Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices."

By plotting efficiency against the parameter $\left[\frac{(T_{in} + T_{out})/2 - T_{amb}}{I}\right]$ the following correlating equation was determined from a first order curve fit of the test data:

$$\eta = 0.666 - 1.003 \frac{hr\text{-}ft^2\text{-}{}^\circ F}{Btu} \cdot \theta$$

where

$$\theta = \frac{(T_{in} + T_{out})/2 - T_{amb}}{I}$$

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1. Hill, James E.; et al.: Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices. NBS TN 899, Nat. Bureau Stand., 1976.

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3. Yass, Kenneth; and Curtis, Henry B.: Low-Cost, Air Mass 2 Solar Simulator. NASA TM X-3059, 1974.

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TABLE I. - GENERAL INFORMATION

Item tested	Flat-plate solar collector
Manufacturer	Pittsburgh Plate Glass
Gross dimensions	$75\frac{5}{16}$ by $34\frac{1}{4}$ in.
Gross area	18.15 ft^2
Absorber area	18.09 ft^2
Glazing	Two covers - glass (Herculite) Total solar transmittance = 0.85 Room temperature normal emittance = 0.86
Absorber plate	Aluminum plate, tube sheet construction, black paint coating $\alpha_s = 0.94$, $\epsilon_h = 0.92$
Transfer fluid	50/50 mixture of ethylene-glycol and water
Normal operating temperature	120° - 200° F
Minimum transfer fluid flow rate	259 lb/hr
Maximum transfer fluid flow rate	264 lb/hr
Maximum operating pressure	18 psig (at collector inlet)
Collector mounting	A wooden box was constructed using 2- by 4-inch boards for sides and a sheet of plywood for the backing. The collector was placed in the box, and this assembly was then attached to the collector test frame. The test frame was fixed at one tilt angle during the testing, but could be oriented at a variety of tilt angles to allow for the seasonal changes in the sun's angle of declination.
Location of test	Cleveland, Ohio at NASA-Lewis Research Center, located adjacent to Cleveland Hopkins Airport Latitude = 41° 24' Longitude = 81° 51' W Altitude = 777 ft above sea level

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TABLE II. - EFFICIENCY TEST DATA FOR N.B.S.-ROUND ROBIN COLLECTOR NO. 1.

Data point	Solar time, hr	Mass flowrate, lb/hr	Specific heat, Btu/lb-°F	$\int_{\tau_1}^{\tau_2}(T_{f,e} - T_{f,k})d\tau$,[a] °F-hr	$\int_{\tau_1}^{\tau_2} I\,d\tau$,[a] Btu/ft²	ΔP, psid	Tilt angle, deg	Azimuth angle, deg	Incident angle, deg	$\overline{T_{in}}$, °F	Percent I_{diff}	$\overline{W_{ind}}$, mph	η	θ, °F-hr-ft²/Btu
1	11:28/11:44	264	0.815	3.92	83.10	0.4	55	0	16.3-14.8	76.6	9.5	8.3	0.562	0.099
2	11:48/12:04	264	0.815	3.91	83.00	0.4	55	0	14.6-14.3	77.4	9.4	8.9	0.561	0.099
3	12:08/12:24	263	0.815	3.93	83.76	0.4	55	0	14.4-15.4	78.4	9.3	7.8	0.556	0.098
4	12:28/12:44	264	0.816	3.90	82.70	0.4	55	0	15.8-17.9	79.1	9.3	10.1	0.562	0.102
5	11:15/11:31	264	0.841	3.07	78.87	0.3	24	0	11.5-8.2	131.2	10.6	5.8	0.477	0.208
6	11:35/11:51	264	0.842	3.16	81.06	0.3	24	0	7.4-5.0	132.5	9.4	4.2	0.479	0.206
7	12:07/12:23	266	0.843	3.20	82.78	0.3	24	0	4.9-7.1	134.7	13.3	5.7	0.479	0.205
8	12:27/12:43	266	0.844	2.85	79.16	0.3	24	0	7.3-11.1	135.7	15.4	5.6	0.447	0.213
9	11:19/11:35	261	0.861	2.28	79.69	0.2	24	0	9.9-6.2	171.3	16.1	4.6	0.355	0.306
10	11:39/11:55	261	0.861	2.31	80.26	0.2	24	0	5.4-2.4	171.6	15.2	5.2	0.357	0.306
11	11:59/12:15	261	0.862	2.35	80.72	0.2	24	0	2.1-4.1	171.7	15.0	6.9	0.361	0.298
12	12:19/12:35	261	0.862	2.23	80.96	0.2	24	0	5.0-8.5	171.9	15.4	5.5	0.342	0.297
13	11:29/11:45	259	0.877	1.53	79.04	0.2	24	0	7.3-3.5	204.1	15.8	4.6	0.243	0.425
14	11:49/12:05	259	0.877	1.59	79.20	0.2	24	0	2.6-1.3	203.4	16.1	6.2	0.251	0.422
15	12:09/12:25	259	0.877	1.42	76.85	0.2	24	0	2.2-6.0	203.7	17.8	4.7	0.231	0.434
16	12:29/12:45	259	0.877	1.38	77.21	0.2	24	0	6.9-10.8	203.5	19.6	6.8	0.224	0.432

[a]Evaluated by trapezoidal integration rule.

FIGURE 1. - OUTDOOR COLLECTOR TEST FACILITY

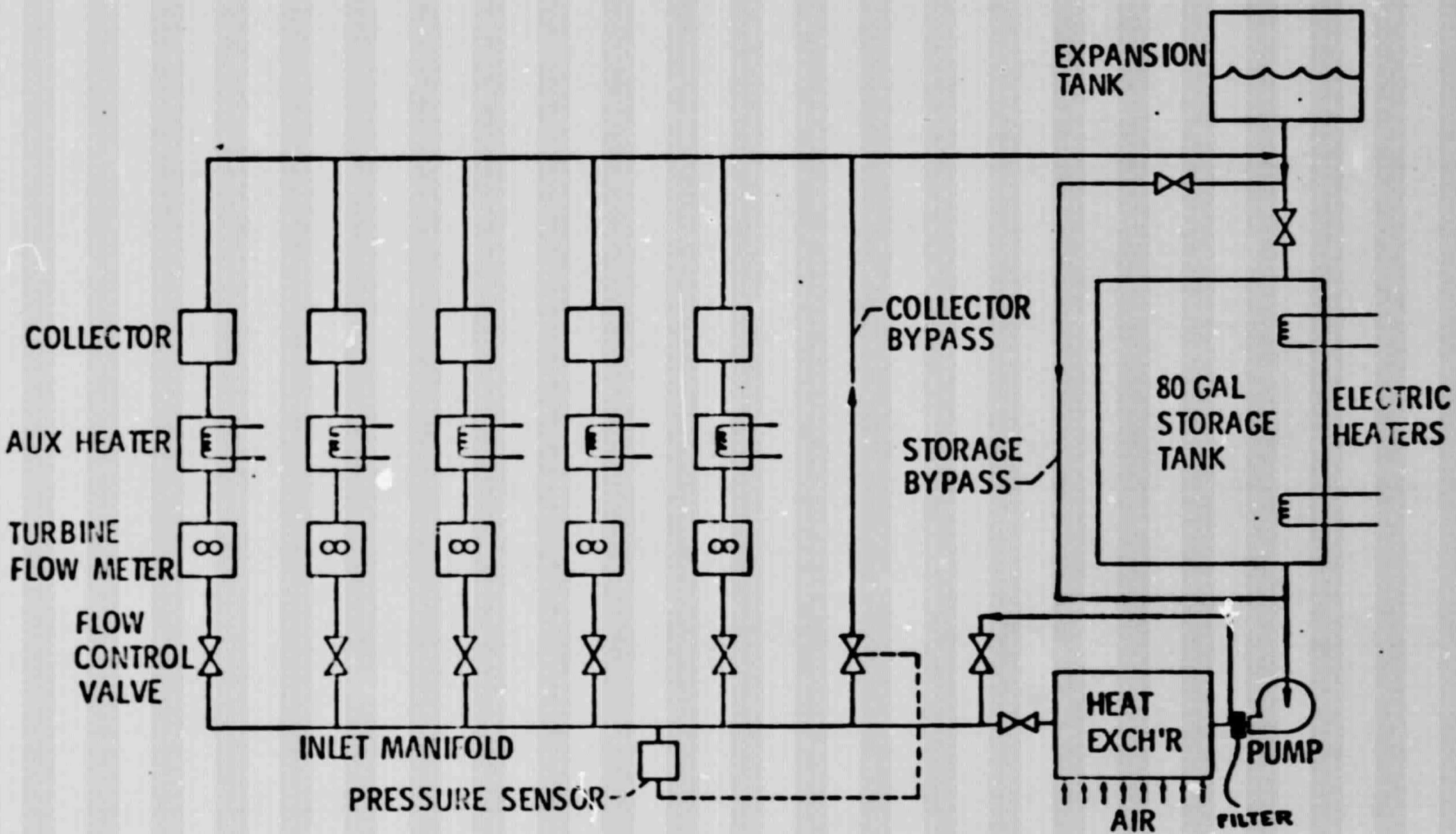

Figure 2. - Schematic of outdoor collector facility.

FIG. 3

EFFICIENCY CURVE FOR ROUND-ROBIN

COLLECTOR #I