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STANDARDIZED SOLAR SIMULATOR TESTS OF FLAT PLATE SOLAR COLLECTORS

I - SOLTEX COLLECTOR WITH TWO TRANSPARENT COVERS

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16. Abstract

A Soltex flat plate solar collector was tested with a solar simulator for inlet temperatures of 77^{o} to 201^{o} F, flux levels of 240 and 350 Btu/hr-ft^2, a coolant flow rate of 10.5 lb/hr-ft^2, and incident angles of 0^{o}, 41.5^{o}, and 65.2^{o}. Collector performance is correlated in terms of inlet temperature, flux level, and incident angle.

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INTRODUCTION

An area presently being investigated by the NASA Lewis Research Center in its efforts to aid in the utilization of alternate energy sources, is the use of solar energy for the heating and cooling of buildings. An important part of the solar heating and cooling effort at the Lewis Research Center is the investigation of flat-plate collectors which have the potential to be efficient, economical, and reliable. Efficient collectors will be an important consideration in the realization of effective solar cooling systems.

The approach being taken at the Lewis Research Center for determining collector performance is to test collectors under simulated (indoor) and actual (outdoor) conditions. This paper reports the test results of a collector made by the Soltex Corporation, Houston, Texas. Previous test results on other collectors are reported in reference 1.

COLLECTOR DESCRIPTION

This collector consists of a copper absorber sheet (area = 10.04 ft^2) with 11 copper tubes (7/8 in. o.d.) spaced 3 inches apart and soldered to the sheet. The absorber plate has a selective coating of copper oxide. The collector has an inner glazing material of tempered glass and an outer cover of acrylic plastic. The area of each glazing material is 10.78 square feet. There is an air space of 1/2 inch between absorber plate and the successive sheets of glazing. Inlet and outlet headers ($1\frac{5}{8}$ in. o.d.) are provided for fluid distribution. Insulation placed in back of the absorber plate to prevent conduction losses is 3 inches thick. A photograph showing the collector on the test stand is shown in figure 1.

EXPERIMENTAL METHOD

Experimental Apparatus

A drawing of the facility is presented in figure 2. The primary components of the facility are the energy source (solar simulator), the liquid flow loop, and the instrumentation and data acquisition equipment. The test apparatus is described in more detail in reference 1.

Coolant Flow Loop

The flow loop consists of storage and expansion tanks, pump, heater, test collector, and the required piping. The hot fluid storage tank is a commercially available water heater for home use. The tank has two electrical immersion heaters, 5 kilowatts each, and has a capacity of 80 gallons. The pump is a gear type unit driven by a 1/4 horsepower electric motor through a variable speed drive.

A heat exchanger using city water as a coolant is used to control the temperature of the collector coolant fluid at the collector inlet.

A 50/50 by weight mixture of ethylene-glycol and water is used in the liquid loop. The specific gravity of the mixture is checked with a precision grade hydrometer. To suppress vapor formation, the entire flow loop is pressurized to approximately 15 psig by appyling a regulated inert gas pressure to the top of the expansion tank.

Instrumentation and Data Acquisition

The parameters needed to evaluate collector performance are: liquid flow rate, liquid inlet and outlet temperatures, the simulated solar flux, wind speed, and the ambient temperature. The flow rate is determined with a calibrated turbine-type flowmeter that has an accuracy better than 1 percent of the indicated flow. The collector inlet and outlet temperatures are measured with ISA type E thermocouples (chromel-constantan). The error in absolute temperature measurement is less than 1° F and the differential temperature error between the inlet and outlet thermocouples is less than 0.2° F.

The ambient temperature is measured with an ISA type E thermocouple mounted in a radiation shield. The simulated solar flux is measured with a water-cooled Gardon type radiometer having a sapphire window. The radiometer was calibrated with a National Bureau of Standards irradiance standard.

The millivolt-level electrical outputs of the measuring instruments are recorded on magnetic tape by the use of a high speed data acquisition system. The information from the tape is sent to a digital computer for data reduction and computation.

Test Procedure

The collectors are mounted on the test stand and positioned so that the radiant flux is either normal to or at different angles to the collector. Variation of the incident angle is accomplished by rotating the test stand about the vertical axis. The present tests were run at incident angles of 0°, 41.5°, and 65.2° and a tilt angle of 57°. The flow rate is adjusted to a value corresponding to 10 pounds per hour per square foot of collector absorber area. Before the simulator is turned on, the collector is given time to achieve thermal equilibrium at the inlet temperature chosen (1 hr or more). After thermal equilibrium is established for a given inlet temperature, the simulator is turned on and the desired radiant flux is obtained by adjusting the lamp voltage. After steady-state conditions occur, usually in 10 to 15 minutes, data are recorded. The radiant flux is then readjusted to a second value at the same collector inlet temperature, steady-state conditions obtained, and data again recorded. The collector inlet temperature is then set to another value, and the procedure repeated.

COLLECTOR TEST RESULTS

The experimental efficiency of the collector was calculated using the following equation:

$$\eta = \frac{GC_p(T_0 - T_1)}{q_{dr}} \tag{1}$$

The efficiency was determined for a constant flow rate of approximately 10 pounds per hour per square foot and for conditions of inlet temperature ranging between 76° to 201° F, a simulated heat flux ranging between 150 to 350 Btu per hour per square foot, wind speed of 7 miles per hour, and an ambient temperature of 80° F. A tabulation of collector efficiency for different inlet temperatures and simulator flux levels is given in table I.

Performance Curve

The performance data of table I are plotted in figure 3 in forms of the inlet temperature, the ambient temperature, and the radiant flux. The equation of the curve shown in figure 3 which is a best fit for the experimental points is as follows:

$$\eta = 0.574 - 0.837\ \theta + 0.141\ \theta^2 \qquad (2)$$

where

$$\theta = \frac{(T_1 - T_a)}{q_{dr}}$$

Incident Angle Modifier

The intercept of equation (2) (η at $\theta = 0$) is a function of the angle of incidence. Values of this intercept were obtained experimentally with the simulator at a condition where the inlet temperature is essentially equal to the ambient temperature ($\theta \simeq 0$). As explained in reference 1, values of the intercept of the correlating lines of figure 3 (eq. (2)) obtained at several incident angles allows for modification of equation (2) for incident angles other than zero incidence. Equation (2) may be modified as follows:

$$\eta = K_{\alpha\tau} 0.574 - 0.837\ \theta + 0.141\ \theta^2 \qquad (3)$$

where

$$K_{\alpha\tau} = \frac{(\alpha\tau)_{\theta_i}}{(\alpha\tau)_{\theta_i=0}} = \frac{\eta_{\theta_i, T_1=T_a}}{\eta_{\theta_i=0, T_1=T_a}}$$

As indicated in reference 1, use of the efficiency data for conditions when the inlet temperature equals the ambient temperature (table I) permits a correlation of the incident angle modifier ($K_{\alpha\tau}$) in terms of the incident angle. This correlation is shown in figure 4. The equation of the correlating line for figure 4 is:

$$K_{\alpha\tau} = 1.0 - 0.18\left(\frac{1}{\cos\ \theta_i} - 1.0\right) \qquad (4)$$

Equations (4) and (3) permit a calculation of collector performance.

Reference 2 presents an approach by which modifications of the simulator performance data may be made for the conditions of flow, ambient temperature, etc., which depart from the conditions encountered in the solar simulator facility.

SYMBOLS

C_p fluid heat capacity, Btu/(lb)($^{\circ}$F)

G flow rate of collector fluid, lb/hr-sq ft of absorber surface

$K_{\alpha\tau}$ incident angle modifier, dimensionless

P pressure, lb/in.^{2}

q_{dr} incident direct solar radiation in plane of collector, Btu/hr-ft^2

T_a ambient temperature, $^{\circ}$F

T_1 fluid inlet temperature, $^{\circ}$F

T_0 fluid outlet temperature, $^{\circ}$F

α collector surface absorptance, dimensionless

η collector efficiency, dimensionless

θ_i solar incident angle, deg

τ glazing transmittance, dimensionless

REFERENCES

1. Simon, F. F.: Status of the NASA-Lewis Flat-Plate Collector Tests with a Solar Simulator. Presented at the National Science Foundation, Workshop on Solar Collectors for Heating and Cooling of Buildings, New York, N.Y., Nov. 21-23, 1974.

2. Simon, F. F.; and Buyco, E. H.: Outdoor Flat-Plate Collector Performance Prediction from Solar Simulator Test Data. Presented at AIAA 10th Thermophysics Conf., Denver, Colorado, May 27-29, 1975.

TABLE I. - BASIC EXPERIMENTAL DATA

θ_i	Flow, gal/min	G, lb/hr-ft^2	T_1, ^{o}F	T_0, ^{o}F	T_a, ^{o}F	q_{dr}, Btu/hr-ft^2	η, percent	P_1, lb/in.^{2} (gage)	ΔP, lb/in.^{2}
0	0.200	10.5	76.9	92.9	80.0	236	58.3	4.0	0.16
	.200	10.5	76.6	92.9	80.0	238	58.6	4.0	.16
	.200	10.5	76.1	99.7	79.4	348	58.3	4.0	.15
	.201	10.5	76.2	99.8	79.9	348	58.4	4.0	.15
	.203	10.6	111.1	123.5	80.1	234	46.9	4.1	.088
	.203	10.6	111.2	123.6	80.2	236	46.4	4.1	.085
	.203	10.6	111.5	131.7	80.5	353	51.0	4.1	.082
	.203	10.6	111.5	131.9	80.7	352	51.4	4.1	.083
	.203	10.6	111.7	131.9	80.5	351	51.2	4.1	.081
	.196	10.1	160.5	177.2	80 1	354	40.8	5.9	.036
	.193	9.9	201.4	206.6	79.9	240	18.7	19.7	.028
	.191	9.8	199.7	212.9	80.6	364	31.1	19.4	.050
41.5	.201	10.6	77.4	93.0	78.2	266	51.0	5.0	.17
65.2	.201	10.6	77.2	85.3	74.6	152	46.5	5.1	.18

Figure 1. - Collector on Test Stand

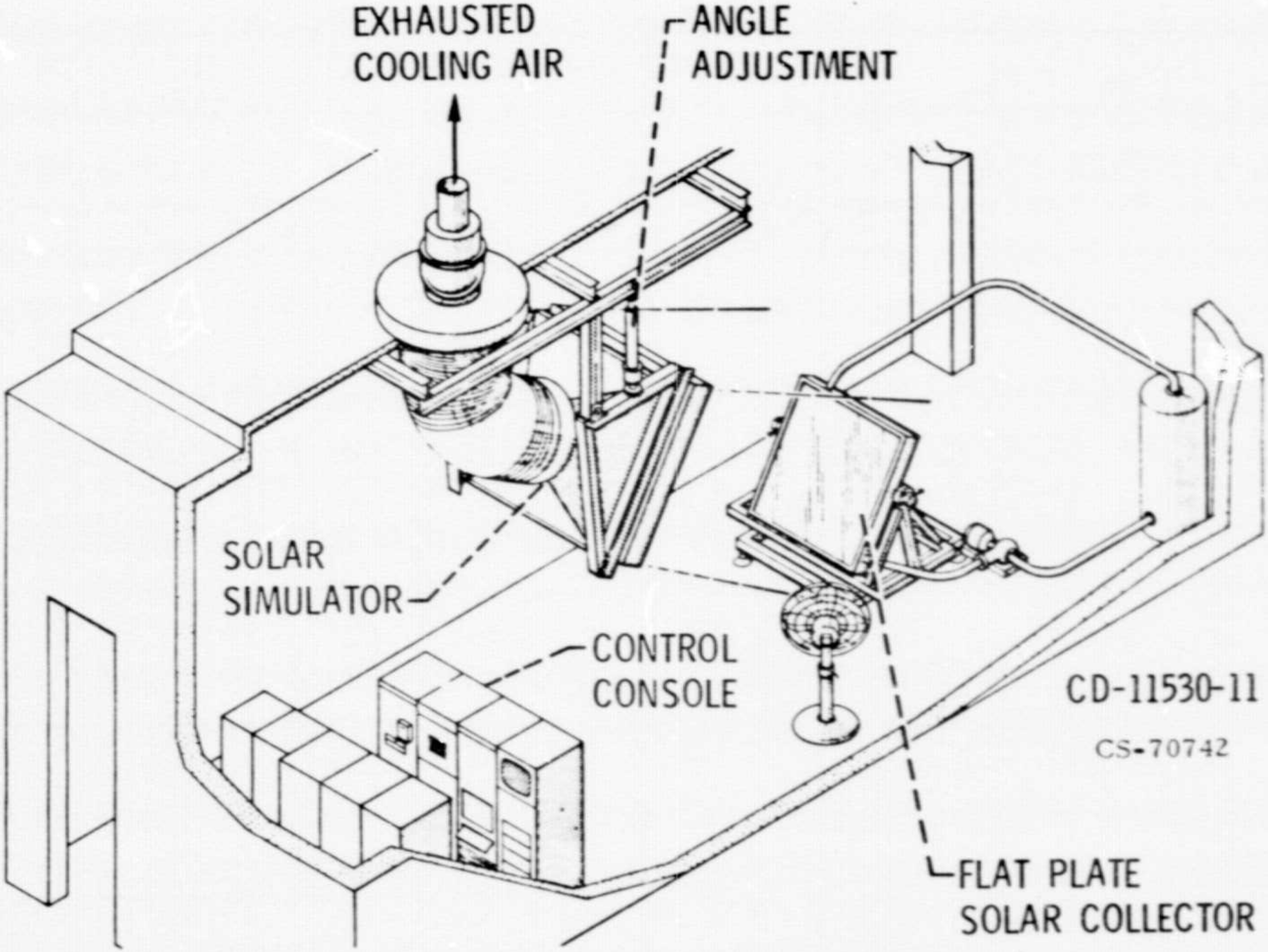

Figure 2. - Indoor test facility.

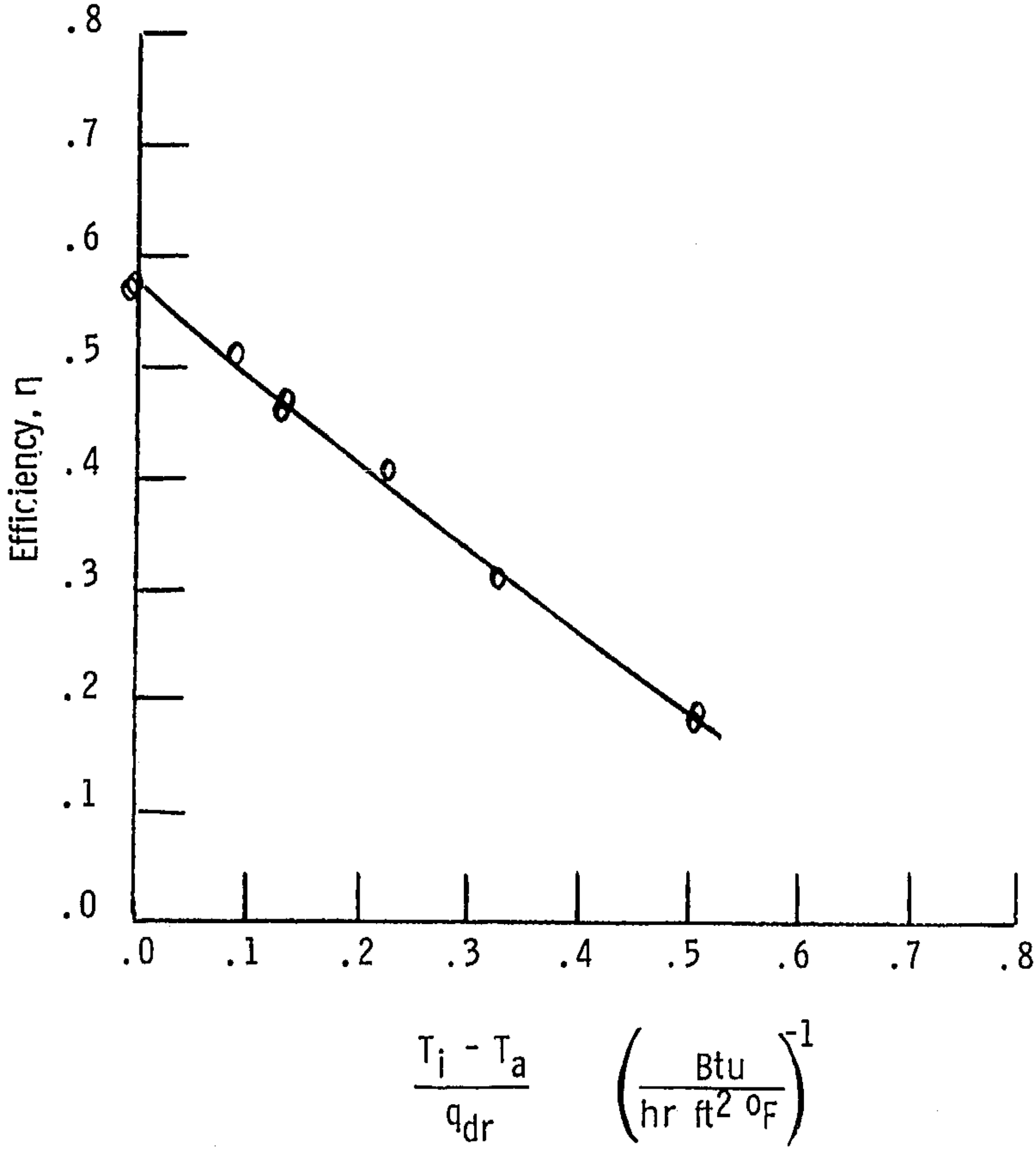

Figure 3. - Collector Performance Correlation

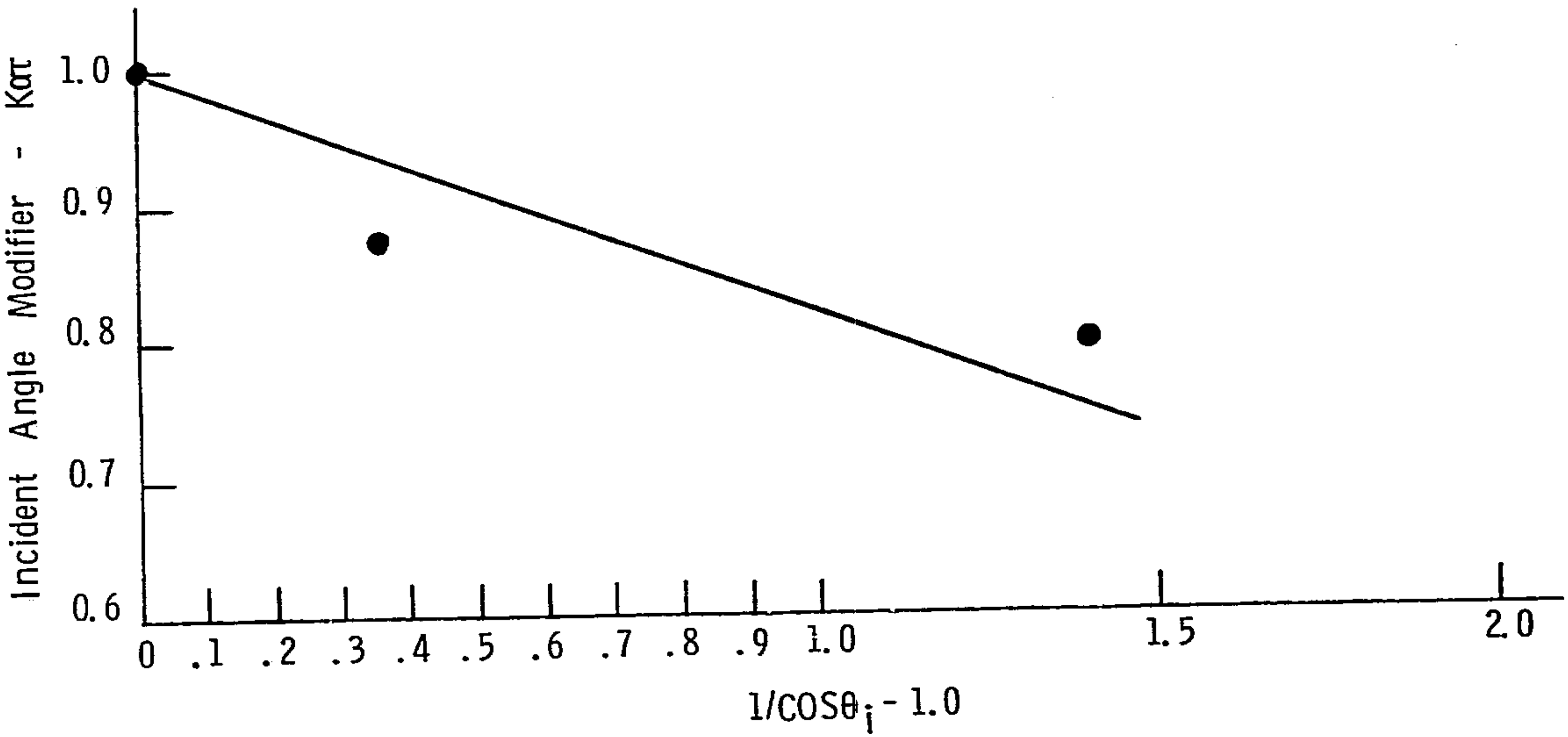

Figure 4.- Correlation of Incident Angle Modifier