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DOE/R/510143-1 Semi-Annual Progress Report

LOW COST, BARE PLATE SOLAR AIR COLLECTOR**MASTER**SUMMARY

DOE Grant #DE-FG02-79R510143 has been awarded for the purpose of developing a low cost, bare plate solar collector that is specifically designed to preheat ambient air with solar energy. Two prototype solar collector test systems have been designed, fabricated and assembled at the test facilities of ROM-AIRE Solar Corporation (formerly Solar Energy Products Company) at Avon Lake, Ohio. Each system has been instrumented to provide instantaneous and average thermal performance data by means of a computerized data logger system. This data logger system is currently being made operational. Data collection is scheduled to begin March 1, 1980 and continue until the project completion date of June 17, 1980.

The project is behind schedule between 3 and 4 months because of material delivery delays. Installation of the test systems was delayed about one month because of an aluminum fabricators' strike. The data logger system was delayed nearly four months because of parts shortages for the signal conditioning equipment.

Some preliminary test data have been obtained for both prototype systems. The results showed that ambient air was preheated between 5°F and 10°F with the systems achieving a thermal performance of between 15% and 30% efficiency.

INTRODUCTION

The purpose of this DOE grant is to develop a low cost, bare plate solar collector that is specifically designed to preheat ambient air using solar energy. This type of solar heating system would be installed on flat roofed public buildings that are required, by law, to supply the building occupants with a specified amount of fresh air for ventilation. The ventilation air would be pre-heated by the solar system before being admitted into the building ventilation system.

The basic characteristics of this type of solar heating system are low costs for materials, installation and operation, combined with sufficient thermal performance to make the delivered energy cost effective with the clean hydrocarbon fuels normally used. For this purpose we have utilized thin aluminum sheet as the low cost material and have fabricated and assembled it into simple heat transfer structures that could be easily installed on a flat roof. A blower is used to pull air through the solar collector assembly and deliver it to the ventilation intake.

REA

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The plan being used to carry out this project includes the following tasks:

1. Design of two test collectors
2. Fabrication and installation of two test systems
3. Instrumentation and data processing

Each of these tasks will be discussed in detail to indicate their status at the present time. In addition, some preliminary test results will be presented and the project schedule will be analyzed to determine what has occurred, what some of the problems have been and what must be accomplished to complete the project.

DESIGN OF TEST COLLECTORS

A solar collector is a device that absorbs solar thermal energy, transfers a portion of this energy to a working fluid which is in intimate contact with the absorber plate and loses the remainder to the surroundings. The useful heat produced by the solar collector is equal to the energy absorbed by the absorber surface less the heat losses from the surface to the surroundings, or:

$$Q = A_c [H\tau\alpha - U (T_p - T_a)] \quad (1)$$

where

Q is useful energy delivered by collector, BTU/hr

A_c is total collector area, ft^2

H is the solar energy received on the upper surface of the sloping collector structure, $\text{BTU/HR}\cdot\text{FT}^2$

τ is the fraction of the incoming solar radiation which reaches the absorbing surface

α is fraction of the solar energy reaching the surface which is absorbed

U is the overall heat loss coefficient, $\text{BTU/HR}\cdot\text{FT}^2\cdot^\circ\text{F}$

T_p is average temperature of the upper surface of the absorber plate, $^\circ\text{F}$

T_a is atmospheric temperature, $^\circ\text{F}$

Most commercially available flat plate solar collectors marketed today flow the working fluid, either air or liquid, in back of the absorber surface and have one or more transparent covers, usually glass, mounted in front of the absorber surface. For a representative single glass collector, both τ and α are valued at 0.9 and U is about 1.0. If air is the working fluid and ambient air flows

across the back side of the absorber plate and cools it to within about 20°F of the fluid, then the heat loss to the surroundings is minimal and the amount of useful energy produced by the collector will be approximately the product of τ and α or somewhat less than 81% of the impinging solar radiation, H. Removing the transparent cover converts it into a bare-plate collector and has the effect of increasing τ to 1.0 but also increasing the heat loss coefficient U to as high as 10. The result is that the useful energy produced by the collector is drastically reduced and becomes very dependent on the magnitude of H. Reference 1 indicates that bare-plate collectors of this conventional type of design could achieve peak efficiencies of only about 35%. This analysis makes it apparent that a conventional type of bare-plate collector could probably not be used effectively to heat air because of the low operating efficiency.

The solar air heating system for this project is based on a unique proprietary design for a bare-plate solar collector. It is significantly different from the conventional design but its performance follows the basic principle of equation (1).

Figure 1. Bare Plate Collector Assembly

Figure 1 illustrates the basic structure of the collector and the air flow pattern. A and B are corrugated metal sheets that overlap and are fastened together to form a rigid structure. The arrow indicates the direction of air flow through the collector. The surfaces of A and B are coated on both sides with a black, weather resistive coating to enhance the absorption of solar radiation. The solar energy incident on surfaces A and B is absorbed and converted into thermal energy. Air flow is induced by a blower located inside the structure. The flowing air, indicated by the arrows, passes over the outside of surface A and into the annular

1/ Whillier, Austin; "Black-Painted Solar Air Heaters of Conventional Design", Solar Energy, Vol. 8, No. 1, 1964.

passage created by the overlap of surfaces A and B and enters inside the structure below surface B. High film heat transfer coefficients are generated over the total length of the air stream because of the relatively high velocity of the stream and because of the entrance and exit effects of the annular passage. The heat transfer is also enhanced by the high thermal conductivity of A and B, which would probably be fabricated from aluminum or any similar light weight, low cost, high conductivity metal with the necessary structural strength. Heat is conducted from the absorbing surface in all directions to areas where the air flow cools the surface. This redistribution of heat reduces the tendency for hot spots and effectively reduces the average temperature of the collector surface, thereby reducing radiation losses to the atmosphere. The high thermal conductivity also makes all surfaces, in effect, heat transfer surfaces supplying heat to the incoming air flow, greatly increasing the effective heat transfer surface area compared to the absorption surface area of a conventional bare-plate collector.

In terms of the basic solar collector heat transfer equation (1), this unique design of a bare-plate collector enhances the transfer of useful heat to the flowing air stream by effectively reducing the absolute values of U and T_p . The absorber plate temperature, T_p , is lowered because both the film heat transfer coefficient and the effective heat transfer surface area adjacent to the air stream are increased. The overall heat loss coefficient, U , is reduced because both radiation and convection losses are lower. Lower radiation loss is due to the lower average plate temperature while the lower convection losses are due to the inward flow of air which traps the heat losses and converts them into beneficial heat gains. The overall result is that the useful heat delivered by the collector is increased because the heat losses from the absorber surface to the surroundings are minimized by the flow and heat transfer characteristics of the collector.

The basic characteristics of the bare-plate collector described can be adapted to many different geometric shapes. For this project we have designed a flat plate structure and a pipe structure. Photo 1 is a photograph of the flat plate structure. It consists of overlapping strips of corrugated and embossed aluminum sheet, which is a common roof and siding material. Each strip included seven corrugated surfaces which overlapped adjoining strips in a pattern shown below:

Screws and washers were used to maintain the spacing. Thus the air flows over six surfaces for good heat transfer. When the structure

is tilted from the horizontal it prevents any water from entering during a rainstorm.

Photo 2 is a photograph of the pipe structure. It consists of alternate surfaces of smooth and corrugated aluminum sheet that were fabricated into 5-inch diameter tubes. The tubes overlap as shown below:

Air flow is between the overlapping surfaces of the smooth and corrugated tubes. The diameter of the tubes were determined by estimating the temperature gradients around the circumference of the tube for various diameters, air flow rates and thicknesses of aluminum sheet. For commercially available smooth and corrugated aluminum sheet, a tube diameter of 4 to 6 inches will minimize the temperature gradient between the sun-side and back-side of the tube. The thermal efficiency of the collector should improve when the average surface temperature is minimized.

FABRICATION AND INSTALLATION OF TEST SYSTEMS

The flat plate collector was assembled into a tri-frame structure as shown by the photograph in Photo 3. Each side is 3 feet by 8 feet and the tilt from horizontal is 45°. The floor and sides of the structure are insulation board (R value is 8) covered by sheet metal. The aluminum corrugations were painted a flat black using a durable outdoor paint. Air is pulled through the overlapping corrugations into the tri-frame structure and exhausted through an 8-inch hole on one side. The tri-frame structure will be tested in three positions, one with the collector surfaces facing east and west, a second with the collector surfaces facing north and south, and the third, a repeat of the second but with the north surface covered to prevent air flow.

The pipe collector was assembled into an array as shown by the photograph in Photo 4. Each pipe is 5 inches in diameter and 8 feet long. There are thirty pipes in the array for a total projected surface area exposed to the sun of 100 square feet. Each pipe is connected to a central header duct made of insulation board and covered with sheet metal. Photo 5 illustrates the construction of

the array. Air is pulled through the overlapping surfaces of the pipe into the pipe and then into the central header duct where it flows through the flow nozzle to the blower and then exhausted. The array is positioned so that the pipe surface faces south. The array is mounted onto a wood frame so that it is about two feet above the roof to be above the snow level.

Both test systems are mounted on the flat roof of the Company offices at Avon Lake, Ohio.

INSTRUMENTATION AND DATA PROCESSING

The information necessary to evaluate the bare plate collector system is the thermal performance of the system for a variety of weather conditions. This requires the ability to make a heat balance on the system, both instantaneous and average. For this a pyronometer is used to measure the solar insolation on the system, thermocouples measure the air temperatures into and out of the system and an anemometer and flow nozzle combine to measure the air flow rate. Other variables that affect the system performance are wind speed and direction and the temperature gradients associated with the bare plate structure. Figure 2 is the schematic flow diagram for the system showing the type and location of the instrumentation used. The flow of information is shown schematically in Figure 3. The instruments produce a voltage or millivolt signal that is conducted through junction boxes to the data logger where the signal is digitized and sent to the computer. The computer is programmed to store the information and then retrieve it from storage, do calculations and output the data in the form of a heat balance for the system over various periods of time along with the variables associated with that time period. This information will be correlated for the final report.

TEST RESULTS

Both test systems were in place on the roof by November 1979 but the data processing equipment was not received until the middle of December 1979. Although the systems were not complete, some preliminary data have been obtained. The results of a test made on December 10, 1979 are reported herein as preliminary information.

The data for both systems were recorded at approximately 11:30 a.m. solar time on December 11, 1979. The sky conditions can be described as hazy to clear, the air temperature about 45°F and the wind at about 15 to 20 mph out of the northwest. The tri-frame structure was positioned so that one side faced directly south and air flow was through both the north and south sides. Air flow through both test systems was measured with a portable anemometer by mapping the exhaust duct, calculating the average air velocity through the duct and then calculating the mass flow for the duct dimensions.

The data are:

	<u>Flat Plate</u>	<u>Pipe</u>
Air flow, CFM	358	275
Inlet Air Temp., °F	48.5	48.0
Outlet Air Temp., °F	53.0	55.0
Heat Recovered, BTU/hr	1740	2079
Solar Insolation, BTU/hr, ft ²	276	138
Array Area, Ft ²	23.3	100
Efficiency, %	27	15

Further data will be required before any conclusions can be reached about the performance of the two systems. However, these preliminary data suggest that the flow area and the amount of overlap for the pipe structure may have to be altered to achieve better performance.

TIME SCHEDULE

The schedule submitted in the proposal, which was prepared in 1978, turned out to be optimistic. It predicted that the test systems would be operating by October 1979. In fact both test systems were in place on the roof and ready for operation in November 1979. The one month delay in installing the system was caused chiefly by an aluminum fabricators strike that delay the acquisition of material for the collector assembly. However, the principle delay in getting the systems operating and collection data has been a four month delay in acquiring the data logger and computer equipment. It was necessary to determine the signal characteristics of each instrument used (e.g. the anemometer) before the custom software for the data logger could be specified. In addition, there was some delay in receiving the chips used in the software package. As a result the data processing equipment was not received until the middle of December 1979. Since then, inclement weather has further delayed the installation of the electrical and instrumentation wiring on the roof.

At this time the wiring is within about one week of completion. A computer program is being written to process the data. We anticipate that the system will be operational by March 1. This will provide four months of operating test data before the project is scheduled for completion in June 1980. We believe this will provide sufficient information during a period of varying weather conditions to achieve the objectives of the proposal.

COST SCHEDULE

Through January 1980 we have spent \$35,579 on the project. The costs have been broken down into salaries for professional services, wages for technicians and secretaries and cost for materials and are tabulated monthly:

	<u>Salary</u>	<u>Wages</u>	<u>Materials</u>	<u>Total</u>
Jul '79	3000	-	43	3043
Aug	3000	960	-	3960
Sep	3000	960	311	4271
Oct	3000	1920	2675	7595
Nov	2000	960	255	3215
Dec	1000	960	9543	11503
Jan '80	1000	1920	72	2992
Feb	2000	960	-	2960
Mar	2000	960	-	2960
Apr	1000	-	-	1000
May	1000	-	-	1000
Jun	3000	501	-	3501
	25000	10101	12899	48000

Figure 4 shows the actual spending schedule compared to the proposed budget of the original proposal.

FIGURE 2. TEST SCHEMATIC

FIGURE 3. DATA FLOW SCHEMATIC

FIGURE 4
COST EXPENDITURES

Photo 3. - Flat Plate
Test Assembly

Photo 2. - Pipe
Collector Structure

Photo 1. - Flat Plate
Collector Structure

Photo 4. - Pipe
Test Assembly

Photo 5. - Pipe
Assembly Header

Photo 6. -
Pyrometer

Photo 8. - Junction Box
Data Logger Computer

Photo 7. -
Wind Meter