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INDUSTRIAL STEAM GENERATION

BY NON-IMAGING FOCUSING

FINAL REPORT

FEBRUARY, 1979

?PREPARED BY:

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1, Introduction

An innovative solar collector for industrial stean generation has been designed, developed and built by CEER with cooperation and funding from the University of Chicago and Bacardt Corporation. The collector is a linearly segnented compound parabolic concentrator (CPC) with a cylindrical eva~ cuated tube as the receiver. As part of the project, a solar radiation measuring station was installed on the premises of the Bacardi Rum Distitlation Plant in Catafo, Puerto Rico.

This report emphasizes that portion of the project carried out after the First Progress Report of August, 1978.

Me refer the reader to that report for details of the initial phases of the project. In general, that report dealt with the general design ideas and the preliminary analytical studies of these ideas. Some work with an experimental model was also included. This report covers mainly the final design and cons- truction of the collector.

The main design elements that are incorporated in this collector are now summarized. First, it 1s a CPC collector with @ concentration ratio of 5.25, This means it can make use of diffuse as well as direct sunlight. This also means it does not require continuous or even daily tracking of the sun's position. Second, it has an evacuated tubular receiver of a new design. This receiver 1s expected to perform better than other receivers for high temperature collectors. Third, the CPC mirror surface

is segmented and encapsutated in glass tubes. The tubes provide

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Tightweight, low cost structural suport as well as Protection for the mirror surface,

11. Design and Fabrication of Collector components

The major system components of the Iiiearly segmented Compound parabolic collector under consideration are shown in Schematic form in Figs. 1, 2, and 3 which show the evacuated tubular receiver, the segmented encapsulated mirrors and the collector frame. Dimensions given tn these drawings were original design and some were changed in the final design.

A. Evacuated Tubular Receiver

Fig. 4 shows the schematic of the single wall Svacuated receiver tube designed specifically for this Project. A detailed description of this receiver was given in the First Progress Report.

One of the three receiver tubes received from the manufacturer was tested under stagnation conditions and one sun radiation density, The temperature inside the copper tubing was found to be 240°C attesting to the excellent heat absorption and retention qualities of this receiver design.

8. Segmented Mirror

A'major part of our effort since August has gone into developing and busiding the segnented mirror, Figure 5 iMustrates the final design of the mirror units.

Plexiglas plastic (1/8" thick) was chosen as the saterfal for the mirror substrate. Major considerations in this

decision were ease of handling, cutting, and machining, and

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FIGURE -1-

UNIVERSITY OF PUERTO RICO / CEER

FACETED CPC COLLECTOR (EFF crx 5)

(SUPPORT FRAME FOR TUBES MoT SHOWN)

Evacuated

SPACE

SINGLE Wau

Jeuass: roe

CYLINDRICAL ABSORBER + 2a"

WITH ?U- TUBE

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TUBE BLANKS:

(SEALED OFF)

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Smoothness of surface. The plexiglas was cut into strips

7" Yong and 1 15/16" wide,

Finding a suitable reflective film and a method

of Bonding to the plexiglas was a major problem. Much effort

?es Spent in trying to bond 200 Oun-Chrome @, OL-50 metallized

polyester Film (Dunmore Corp., Newtown, Penn.) to the plexigias

with unsatisfactory results. Many different types of bonding

Soents were tried. Finally we learned of a new product manufac-

tured by the 3M Company. This is their "Scothcal? Brand Film

FEK-244, 2 0.004" thick aluminum-on-acrylic film with 86% spectral

reflectance. This film has pressure-sensitive adhesive backing

and satisfactory results were obtained in applying it to the

Plexiglas substrate.

The encapsulation tubes are fluorescent tube

blanks obtained from Corning Glass Works (Fig. 6). These have an outside diameter of 2.08" and a wall thickness of 0.035". We

estimate the diameter tolerance to be + 0.01".

The mirror segments are held inside the glass tubes by spring clips at the ends. In order to prevent undue S29ging of the mirror, it was found necessary to attach three Screw Spacers at equal intervals along its length. A metal heat shield was also attached to prevent damage to the mirror when the glass tube was being closed off.

?After attaching clips, spacers and shields to the Mirror, the assembly was inserted inside a glass tube (Fig. 7).

The mirror mas then checked todetermine whether there was any twist

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Fic. 6 Fluorescent Tuse BLANKs From

Corwinc GLass Works,

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Insertion OF Mirror AssemBLy Into GLass Tuse,

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a.

of one end with respect to the other. This was done by looking at the reflection of a laser beam fron the mirror at different ?points along its length (Fig. 8). Since one end of the mirror

was accessible and since the spacers were not attached to the tubes, any large twists could be removed. The largest allowable amount of twist of one part of the mirror with respect to another was 1°,

Originally it had been planned to close off the glass tubes after they had been evacuated at an elevated temperature and filled with a dry gas. The idea was to eliminate as much moisture as possible from the inside of the tubes. An oven was buflt and it was determined that the mirrors could withstand 100°C without apparent damage. However, when the tubes were evacuated to a pressure of 500 microns of Hg. at 100°C, immediate damage to the adhesive bond resulted. Evacuation alone did not appear to damage the bond and several tubes were made using this procedure. After being connected to a vacuum pump for 30 minutes, they were filled with dry nitrogen at a pressure of ~ 1 atm.. Damage to the adhesive bond of these mirrors did not become apparent until they had been exposed to sunlight for 2 on 3 weeks. Finally it was decided to abandon the evacuation procedure. Tubes were closed off in an air conditioned room. A-room dehumidifier brought the relative humidity down to 50% at 75°C which corresponds to a ratio of moisture to dry air of 1.0% by weight.

Another

important problem encountered in the

Construction of the tubes was the frequent breakage and craking

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of the glass at stress points where it had been worked, Since the temperature of the mirrors could not be raised, it was not Possible to do oven annealing to relieve these stresses. This Problem was alleviated considerably when the evacuation procedure was abandoned. It seems that a large part of the problem was due to differences between the nitrogen pressure inside and atmospheric pressure outside. This resulted in uneven tips which eventually cracked.

©. Collector Frame

Figs 3 and 9 show the collector frame including the tube wells which actually hold the glass tubes.

The basic dual axis tracking frame design developed by the University of Chicago was altered in some important ways. The main beam of the frame which in the Chicago design was an

T-beam was found to be too unstable to torsional forces such as would be exerted on it by the collector weight when tilted. The T-bean was replaced by a rectangular cross section hollow beam which also allowed @ simpler design for fixing the beam to the circular platform.

Four bolts were added to the sides of the main beam. These prevent movement of the circular platform (and thus of the collector) after it has been set at @ particular position.

In order to measure the collector's tilt angles two bubble level with protactor assemblies were installed at

each end of the collector frame. These permit angle measure-

ments with an accuracy of ~ 1/4

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Major efforts on the collector frame went into Gestgning and building the tube wells which are shown in detai? in Fig. 9,

A computer program was developed to calculate the theoretical shape of the reflector surface (See First Progress Reports Appendix &).. Using the results from the program, the {ube wells were precisely machined. Four identical pieces (each was one-half a well) were machined sinut taneously by stacking then. The raw material for the wells were four pieces of 1/2" slustnun, 20" wide and 48" long. The circular holes that hold the tubes have a diameter of 2.09". The straight line distance between circles is 2.11" to allow for the métal bands that grip the tubes. After the, tube holes had been machined, excess materiel was removed to make the structure lighter. The tube holes thus became open semicircles.

F¥g. 10 is a depiction of the support bar and the Structure which holds the receiver tube. These can also be seen in Fig. 9. Two halves of a welt were hetd together by precisely

machined pressure f1t pins and by screws and nuts which joined

then to the support ber. the pressure fit pins assured align

ment to @ high degree of precision. The receiver tube 1s

Supported by a structure that allows space for the mirror tubes

that are close to the receiver.

The mirror tube wells are fastened to cross

Support members of the frame, Six aluminum tubes join the tube

Melis to cach other. These add much rigidity to the structure

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and very little wetght,

The structure for fastening the glass tubes to the wells is shown in Fig. 11. It consists of a stainless steel band which is pulled tight by a screw which rung through a bolt fastened to the frame. The bands are placed so that bands from neighboring tubes do not touch thus reducing the distance between mirror segments.

TIT. Analytical Studies of Collector Orientation

One of the main advantages of a CPC design is the Possibility of doing away with continuous tracking of the sun thus reducing complexity and cost. This is because a CPC can collect radiation incident over an extended range of angles as 1s shown in Fig. 12. Our CPC design is an ideal 6.30 X concentrator truncated to 5.25%. The theoretical half acceptance angle (0,) of the ideal concentrator is 9°. An actual device never has a perfect theoretical shape due to random deviations of its Surface from the "ideal" surface. This changes its acceptance characteristics (see Fig. 12) but this change can be approximated as a reduction in the acceptance angle.

The idea, then, is to orient the collector so that the radiation is incident at an angle less than or equal to the acceptance angle. Yet we want to do this with a minimum amount Of tracking. The optimum collection to tracking ratio ig achieved by orienting the long axis of the collector along the fastewest direction. The angle of interest is then the projected

incidence angle on the plane defined by the zenith and the

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EFFICIENCY

OPTICAL

Fraction of the radiation incident on the aperture

of a CPC at angle @' which reaches absorber. ATT

curves refer to a concentrator in two dimensions

with acceptance half angle 0., assuming perfect

reflectivity. "

???? untruncated idea concentrator

7+ +> truncated ideat concentrator

tr++ untruncated concentrator with

average surface error 4.

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north-south direction. This angle (0,,, measured from the zenith) can be calculated for a particular day and hour by the following formula

tan (0, +a) = tan 8 / cosy

where a is the latitude, 6 is the declination and w is the angular time from noon (w = 2nt/24, t in hours). Fig. 13 is the graph of O., for different days during the year and for Puerto Rico's latitude.

A scheme for orienting the collector can be derived from this graph. One first chooses a half acceptance angle (0.) and a mininum daily collection time (e.g. 7 hours/day). Starting at the summer solstice, one determines the value of 6, at the extremes of the minimum collection time (time=3.5). Call this angle @,. Before and after the solstice the collector would be oriented at an angle 0,-0.. For this configuration, the collector would have a high optical efficiency at any hour

of the day that 0,-20,<8,,<0,. For several days after the

solstice this condition will hold more than 7 hours a day. But there comes a day when it will hold for less than the required

7 hours because it will not hold in the period around noon time.

On this day, the collector orientation should be changed.

Suppose that the value of O,, at the extremes?of the minimum

collection time on this day is @). The collector is then pointed

atan angle @:-@.. This procedure for determining the collector

c

ortentation and the dates for changing it is repeated until a

full year is mapped out. The result is a chart such as the one

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Fie, 13

PROJECTED

SOLAR ELEVATION

(For Latrtupe 18,5)

DAYS FROM.

SoLsTice

° 7 2 3 4 5 6

Time

(OURS AFTER Woon)

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shown in Table 1. For a half acceptance angle of 9° and a minimum required collection time of 7 hrs./day the collector has to be reortented only 10 times a year,

IV. Insolation Measurements

Solar radiation has been recorded at the Bacardf plant in Catafo since July, 1978. Diffuse as well as total insolation have been recorded, Details of the measuring process were given in the First Progress Report.

Results of the computer analysis of data for the months of July, August and September are given in Appendix A. Data for the months of October, November and December shows certain irregularities which are not understood at present. These months are not included in the Appendix.

V. Conclusion

The completion of construction of an innovative experimental solar collector designed for industrial steam generation is the main achievement of our work this year. In addition,

much analytical study of the design has been made and a solar radiation measuring program has been implemented at the proposed industrial site. The analytical studies indicate the possibility of a high efficiency to cost ratio for this collector. Figures

14, 15, 16 and 17 are views of the finished Bacard{ solar collector.

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Fis, 15 Compceten Bacarpi

OF ONE Tupe

Structure,

Coutector. CLose-up View

WELL AND RELATED Support

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Fis,

16 Compceten Bacarpi? CoLLector. CLose-up View

OF ATTACHMENT OF Mirror TuBES To Tupe Wet,

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APPENDIX A

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