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RESEARCH SOLAR POND: DESIGN AND INSTRUMENTATION

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ABSTRACT

?The Center for Energy end Environment Research (CEER) of the university of Puerto Rico plans to install a 39 m= (415 ft) research salt-gradient solar pond. The design, construction and instrumentation of this pond is presented. Drawings illustrate the pond's design and instrumentation methodology. ?This pond will operate in conjunction with a much shallower evaporative pond of the sane diameter. ?The research pond installation will be used to study automatic and semiautomatic pond operation with the maintenance of the salinity gradient being a main concern.

?The basic materials of the pond construction and the sensors and equipment used in the instrumentation systen are listed in tabular forn, The measurements of principal pond parameters such as brine temperature, ground temperature and moisture, brine flow through the heat exchanger, brine transmissivity and solar radiation are described. The Scanning system, the data acquisition system, and the pond operation and maintenance are also discussed,

1. anrRopucrron

Salt-gradient solar ponds are large pools of water open to the environment. They are filled with salty water in such a way so that the liguid top layer (upper convective zone) has s salt content of 1-4 percent while the bottom layer (lower convective zone) has a salt content as high as 23-27 percent (see Fig. 1). When exposed to solar radiation, the denser bottom layer heats up to a much higher temperature than the surface layer. The heat accumilated in the lower convective zone is "trapped" by the low salinity nonconvective zone that separates the high density brine at the pond bottom from the upper convective zone. Because heat is stored at the pond bottom, the separate thermal storage normally required in solar installations is not needed.

Since the discovery of natural solar pends [1], interest in the practical use of pond phenomena has led to the Construction

?Summer Student Fellow sponsored by Oak Ridge Associated Universities.

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THERMAL

eneney

extraction

Fig. 1. Cross-Sectional View of Salt-Gradient Pond.

of salt-gradient solar ponds throughout the world, these activities stimulated work on understanding the physical and engineer~ ing problems related to solar pond use [2]. in recent years several laboratory size salt-gradient ponds have been built [3-6].

In our work the design and construction paraneters for a 39,n2 (415 £2) ?research pond were established with the view of building and operating a 0.5 acre (21,760 fe) pond to generate industrial process heat in Puerto Alcs in the forures? Fe rand instrumentation package and data acquisition systen were deoinced to enable the investigation of automatic or sexiauconacic song operation in maintaining the salinity gradient to isprove thos the presently used methods that call? for manval pond operation and gradient control. Although a computer progran for a Ho) Programmable Calculator to determine a pond?s density geadione se available, this manual pond control method is tine congening? and denands the operator's constant attention [1]. the desian aren blens of the data acquisition and instrunentation package are technically similar to those encountered in solar hestixe aad cooling [ey

2. DESIGN

A nunber of theoretical models to predict a salt-gradient golar pond's thermal performance have been developed and studied. A general analytical formulation of the pond's thermal behavior that shows it to be equivalent to that of a flat-plate collector [9,10], the development of a new steady-state analytical method for pond analysis {11,12}, and the use of theoretizal eredise sone for pond sizing in heating applications [12-15] are sone of the approaches that have been taken. A simple method to calculate pond parameters has also been introducted [16], and a number of

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solar pond computer models to predict solar pond thermal behavior in different situations have also been proposed [16-25],

?The thermal efficiency of salt-gradient solar ponds strongly Gepends on both brine transmissivity and heat loss to the cround. The solar pond has to be designed then in such a way as to mini- mize the heat losses from the pond and the wetting of the soil around and underneath the pond. Wetting is basically caused by ground water movement, rainwater, or brine leakage. Keeping these factors in mind, the preliminary design of the pond vas performed by using thé simplified method of M. Edesses et al. (16). ?These calculations were later followed up by a more elaborate computer analysis that employed the model developed by J. B. Davila Acar6n [20]. In addition to the refined steady-state anal-ysis of A, Rable and C. F. Nielson [13] his model also takes into account the edge heat losses, bottom heat losses and the effect of surface mixing on the pond's thermal performance.

Figure 2 shows a conceptual drawing of CEER's research salt~ gradient pond. The drawing indicates the three distinctive

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zones formed in the pond: the upper convective zone, the non=

convective zone and the lower convective zone. The Wpper comvec=

tive zone caused by wind stirring and surface heating and cooling

is kept as thin as possible, 0.1-0.4 m (0.3-1.3 ft) in research

Ponds. The lower convective zone's thickness depends on the use

Of the pond. It is typically 0.5-0.8 m (1.6-2.6 ft) thick, with

thicker zones occurring in ponds used for large heat storage.

?The non-convective zone's thickness depends on a nutber of para-

meters and is usually 0.2-1.0 m (0,6-3.3 ft) in research ponds

3. consTRUCTION

?The 7 m (23 Ft) ai

eter pond structure will be constructed

by using two 1.2m (4 #

high, commercially available pool

franes one of the other (see Fig. 3). The high sun angle

in Puerto Rico can cause overheating of sloping sidewalls that

significantly increases heat loss via thermal convection along

the walls and promotes upward salt transport by convective mix-
ing. This problem was cevere in a production pond built in Alice Springs in Worthern Australia [26]. Thus, the CEER research pond walls and their supports, made of galvanized steel coated with a Tust-resistant acrylic enamel finish, will be vertical. ?The pool comes with its own 14-gauge vinyl liner with electronically welded

Soil from the excavation piled around the entire pool will form a berm about 0.9-1.2 m (3-4 ft) high. Since the brine depth is about 1.8 m (6 ft), this leaves 30 cm (1 ft] at the top of the structure for overflow or the adjustment of zone thickness, and 30 em (1 ft) at the bottom for sand and thermal insulation

A layer of sand a few centimeters thick will smooth the bottom ground irregularities and protect the Liner from sharp stones in

the ground.

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ro feduce heat losses from the pond, 10 cn (4 in) thick sty-

rofoan thermal insulation is used on the side walle of the pond

and 5 om (2 in) thick urethane board is used on the bottom. the

wall thermal insulation extends 0.9-1,2 m (3-4 ft) beneath the

Fond bottom to reduce edge heat losses that can anount to up to

30 percent of the heat collected. A vapor barrier will be ine

stalled between the wall thermal insulation and the soll.) the

primary liner used in the research pond is the Shelter-Rite hypa-

Jon XR-SSP, custom cut and factory welded to fit the pond shay

the secondary back-up liner used is a 30 mil thick PVe lines, The research pond will be operating in conjunction with an evaporative pond of the sane dianeter as the research pond, bet with a depth of only 1.2m (4 ft). ?The evaporative pond wile have a single layer hypalon XR-5SP liner and thermally insulated walls. To reduce thermal interferance between the ponds, they will be built at a distance ecual to the pond diameter from eich other. The highest ground available on the site was selected fer the ponds? construction to reduce heat losses through rain water accumulation in the soil around the ponds. Soil thermal condece fivity at the pond site is expected to be up to 2-5 Watts/mec, ?The pond construction is planned for FY 1984. Table I lists some of the materials selected for the construction.

Table I, Description of Selected Materials.

Material | Model/Type luantity Company

?ound Water Poo! xin Sears Roebuck

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Styrofoan Board | 1.2 = x 2.4 m Conds

To'em thick so | Seyagder, pr,

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thermocouple with Porseiny? | 300m] Snes zee

wire neu ation Camtord, con,

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INSTRUMENTATION

The most important physica! parameters of @ salt-gradient solar pond are the temperature end salinity gradients. an accurate and efficient system mast be designed to monitor these two Parameters. Since the CEER pond will be used for research, an elaborate instrumentation system was designed, The system will measure temperature and salinity gradients in the pond, solar radiation at the sucface and at aay depth, the heat losses to the ground, and the amount of hes! energy extracted; it will also detect the presence of leaks in thw pond liners.

The measurement of solar satiation ee the surface and at various depths of the pond allo tne cs_culat-on of the solar energy absorbed and provides a: son Of the brine clarity.
This measurement with thone cv Sprough the sides and bottom, of energy renoved by "os A, and of temperature and salinity gradients will a:tow the heat Salance and pond efficiency to be calculated.

A weather station sear the pond will measure ambient temper-

ature, humidity, insolation and wind velocity. This data will be

used to calculate the heat losses from the surface of the ponds

4.1, Measurements

?The sensors beiny used in t

meters are listed in Table 11.

heasurement of the pond para~

Platinum resistance thermoneters,

Selected for measuring the brine tempera-

ture. The system? instrumentation design calle for nine RTDs with temperature gradient neasursmort capability every 7-5 cm (3 in}s ?They will monitor the non-convective zone temperature distribytion by scanning hourly. RTD probes will also moditor the operation of the diffuser. T type copper-constantan thermocouples in Teflon Jackets will be installed in the heat exchanger piping to monitor the brine inflow and outflow tenyeratures during heat extraction from the pond. ?A pump (creferably bress ov plastic) rated at

20 liters/min?at zero head end di-ven by 4 1/2 h.p. electric motor Will circulate the brine in che hoat oxchasder. A shell and tube heat exchanger with cast iven shell and conjec-nickel alloy tubes will be used. ? type copper-constantan taernocouples will also be used to measure the ground tenperature around the pond, ?The design calls for measurement at tervals of 1.3 m (4-5 ft) hori= zontally and from .3 to 0.9 m (1 te 3 ft) vectically under the pond bottom. Altogether thirty-saven strategically located ther- mocouples will be used (sce Fig. 4). The uncerground thermo- couples will be scanned daily and the signals will be converted to temperature readings by a dats logyer. Pigure 5 shows the technique of installing the underground thermocouples.

A leak detection syste was designed and integrated into the pond installation. This system consits of a series of T type copper-constantan thermocouples with Iefloa jackets located be- tween the liners. The sand belwoun the lunes is sloped so that the leaking brine will accumulate jn the center where a sump pump

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Fig. 4. Location of Underground Thermocouples.

can evacuate it. Although electric conductivity probes could be used ina leak detection system, they require an Ave. brides eine S2Ek Se mgasure conductivity ane such a circuit is hoe coupatibie EER our data acquisition systom. For the same teason, on olere tric resistance grid could not be used for leak detection in iene

Flow measurement. A commercially avatiable flowmeter or the flowmeter described By s. M. Gieman et al. [27] will measere the

tes, in the heat exchanger loop. PVC piping will be used with the heat exchanger and the diffuser, the flow in the nest exthan= Ser loop will be measured and processed hourly by the data loguers

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les.

During the operation of the diffuser, the flowmeter signals from the diffuser line will be read sunually hourly at the pond site.

Soil moisture ne Five bouyoucos ympsum soil blocks enbedded in the cand Feiwoen the liners and in the soil under the pond and around the pond will measure soil moisteres A Pouyoucos soil moisture meter will be read manually every 24 hours. | A salinity probe can be used with this meter to neasure salinity valvos up to 1000 p:

here is no ideal method to mea-pond or to monitor the density

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ensity

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gradient. Hydrometers aru the easiest instruments to ase to-check.

fhe density, but the isnsity detcrmination oreecas is, tee eoneek:

ing and subject vo eross. ?According to fF. Laycand» (28) he

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through the probe. The Poin. ?9 the pond in the

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Pond tenperature are nod- Pron a jrash, An butomatie method for sconning ?lesteie covets values is described by

R. P. Pynn et al, (231

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the data to the Apple II microcomputer system in the duta acquisi-

tion room via short haul calling and answering modems. The

Apple II microcomputer will be equipped with an interface card

S232 to accept signals from the micrologger. The list of selec=

ted equipment is given in Table tv.

Table IV. Description of Selected Equipment

Instrument Modei/Type No.| Company

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Conductance Meter Model 32 1} tific

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Bouyoucos Moisture

Arthur i. Thoma:

Meter Model IPK25 1 Philadelphia, Pa,

i ? Digites WT Series U:

Solar Data printer Digital necoraer | 1 &

| ?e Mosel 6240 Dayton, ohio

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Solar Data integrator | model 411 1} oratory ine.

a Kewport, Reis

apple Computer

Microcomputer Appie 1 1] Apple, Computer

Monitors tabs Monitors tabs

Data Logger Model 9300 +) san Diego, Ca.

Flow Technology|

Slave unit 200 Channels 1] ine.

Phoenix, Az.

?[Canpbeifseten-|

Mode prt 1020 | 2| tific, Inc.

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Model sc95A 1] tiie, ine.

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5. DATA SCANNING SYSTEM

Figure 6 shows the two-dimensional scanning system of tenper= ature, electrical conductivity (density) and brine transmissivity. A horizontal cable that stretches across the pond is supported by gteel pipes that are driven into the ground and held in position by guy lines. A small measurenent probe attached to the cable can be moved buck and forth across the pond to scan pond paras meters by using the combination of pulleys and electric motors shown in the f.gure. This underwater robe containa an liD plati- num thernoneter for temperature measuronent, an electric coniuc-

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Fig. 6. Two-Dimensional Scanning system.

tivity ce11, and an Epply underwater radiometer. igure 7 shows ghe pulley and underwater probe arrangenent. ?the scanning sseten would also include fixed RIDs, underground thermocouples adie tional electric conductivity cells, flowmeters and neather station instruments. The scanning would have to be done at the raseece rate needed by any one of the sensors, in this case the fised Tree ay ine Fest Of the data will be discarded by the data scquisi- Elon system (Apple 11 microcomputer) until its scanning tine te attained, i.e. the scanning might take place hourly but undere ground thermocouple data will be saved only every 24 hours,

For a typical scanning oper.

the measuring probe could be set

at the bottom of the pond. The

would then begin raising the pro!

Mize the effect of thermal inert

sition system will then do the =

?The scanning intervals can be do

could be as snort as 30 seconds.

ation, the horizontal position of

manually and the probe positioned

electric motor. (ora manual winch)

be at a rate slow enough to minis

{a (0.3 cn/sec). ?the data acqul-

ignal scanning of each sensors

fdemined according to nesdse. and

The data logger interfaced with

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Pig.

Genera? View of Pulley and Underwater Probe.

the Apple 11 microcomputer wilt monitor ehe

gengory will be scanned ag an electric moro: pulls them through

the water, mictoconputer will be slaced in a leop to

await the data logger's scannine signals. he main advantages of

a twomdinensional cable and police, data scanning svstes are ite

versatility, fairly low cost end va y adeptability to small

size research ponds. A drawback Ui

zontal cable has a ten

conditions.

ning process. ?the

under moderate wind

fan alternative to the above system is the one-dimensional

Scanning system shown in Fisure 2. Az shown sn the figure, che Measuring unit is made of S cm (2 in) diameser PVC pipes, ?the system construction is simple and the cost icw, but the unit can only scan on the circumference c! she pond by moving on the pond irene. Figure 9 shows details of che measuring unis construct lone This system can be used in conjunction with a fixed oF floating measuring platform, more or less sanually oper

automatically operated cable aad valley system,

ted, or with an

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Fig. 8. One-Demensional scanning System.

PATA ACQUISITION SYSTEM

A microprocessor should serve as the nucleus of a dedicated gata acquisition and monitoring system. Through its parallel input/output ports it can perform several operations such as con- trol data acquisition via pre-programmed scanning, process ace, make decisions, execute maintenance instructions, and provide seedback between implemented instructions and data which resulted from their implenentation. ?The main advantage of a microprocessor system is its versatility; this feature will be considered in fee ture research on the automation of pond maintenance and operation.

However, since a data logger was available, it was decided to use it as the system nucleus in association with an apple II ai= grocomputer. A Monitor Labs 9300 data logger combined with an Apple It microcomputer fulfills the function of a daca sequicition system in our case. The data loguer has forty channels assigned

---Page Break---

Fig. 9. Detailed View of measuring Unit.

for thermocouple signal input, the twenty channels for R?D input; gighty more channels could be?added. The Monitor Labs 9300 dota jogger accepts two independent scanning rates, is eauipped with {ime averaging features and has an internal clock and printer, A200 channel-capacity Monitor Labe slave unit works in tanien with the data logger. The Apple IT microcomputer has 48% mnory and is equipped with a disk drive, a video monitor and an intoct face card to the data logger. with tho Monitor Labseapple it interface, the microcomputer initiates the scanning process of the data logger and stores the data received. once stored, software Programs can provide data analysis and gradient modification

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instructions. Figure 10 shows the data

room with the

Monitor Labs 9300 dats logger in the forecs

Some disadvantages are inherent in this

tem because the Apple microcomputer car

ger, it can only init

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puter can not override the pre-set sequen

Most purposes all the channels must be re

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7. OPERATION ANC

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Fig. 11. Detailed view of Diffuser.

maintaining the non~convective zone (yradient zone) thickness constant by injecting fresh water at the zone surface to replace evaporative losses, and by injecting concentrated brine near the pond bottom to replace the salt. The salt slowly diffuses uprard through the solar pond gradient one at an average annual rate of about 10 kg/m? (2 lb/ft). during the diffusion process the up= Per convective zone slowly gains more salt and the lower canvece tive zone loses salt. Because of the high rainfall rate at the pond site will reduce surface water evaporation losses, it may be hecessary to pump surface brine into the evaporation pond, and to introduce only small amounts of fresh water onto the surface to built up the Upper convective zone thickness to the design level. Concentrated Trine from the bottom of the evaporative pond oF free salt in the amount up to 120 kg (264 lb) per month may have te be introduced to the bottom of the research pond to replace the salt that has migrated upwara through the diffusion process ang been discerded with the surface brine. ?The salr-gratient maintenance in a pond will be a continuous process.

Te combat evaporation losses usually a surface wash in the

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amount of 1.0 to 2.0 cm/m? (0.037 to 0.074 in/ft#) of fresh water Per day is sufficient depending on the evaporation rate and rainfall on that Gay. Any device used on the pond surface for controlling the upper convective zone must also be effective in reducing evaporation that may be instrumental in causing mixing by convective overturn [31]. One way to control the evaporation rate is to install windbreaks that would act to reduce both surface wind stirring and evaporation. Surface oil filme are also being tried in research size ponds on an experimental basis.

Wave suppressing devices will not be used because it is anticipated that wind action will not havea negative effect on the operation of a pond of this emall size.

Brine clarity in a salt-gradient solar pond is important because radiation falling on the pond must be able to penetrate through the pond's upper convective and gradient zones to the lower convective zone. Chemical treatment of solar pond brine assures the pond's high transmissivity by controlling the bacter~ is, algae and minerals content in the pond. Controlling the pi level through chemical treatment also minimizes corrosion of

Pumps. heat exchangers, and piping. about 0.5 kg (1.1 lbs) per week of chlorine in thé form of sodium hyperchloric and hydro-chloric acids will be used to minimize bacteria growth in the pond by keeping the pil level ¢-6.5. Weekly brine samples will be taken and pil will be measured by using a pil meter. A diffuser loop will be used to adjust pil at a specific depth of the pond. A small quantity of copper sulphate (~1 kg) will be put in the Pond at the beginning of its operation to control algae growth.

Since mostly dirt, especially sand, will fall to the leve of the lower convective zone ané stay there, a cand filter sim Jer to the one used in swimming pools will be used. The filter loop will be equipped with a by-pass valve to permit periodic flushing with fresh water. For the research activities described above about 1?.5 tons of dodium chloride will be used in the re~ search pond and $ tons of salt in the evaporation pond. Calcium chloride or a mixture of various salts [32] will be used to in-vestigate the concept of pond coupled dehumidi fication cooling [33].

8. concLusios

The design, construction, instrumentation and operation/ maintenance of a research salt-gradient solar pond has been des~ eribed to provide a basis for studying pond automation and scal- ing up. It is apparent that the automation of pond operation and maintenance has not been addressed adequately and needs to he studied as an important part of calt-aradient solar pond develop- ent and application. The use of a dedicated microprocessor should be planned for future pond automation research to obtain data on @ pond-nicroprocessor integrated

ACKNONLEGMENTS

The authows acknowledge the fruitful comments of Dr. J. Re Mull of Argonno National Laborat:

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