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SOLAR ENERGY STORAGE FOR COOLING

SYSTEMS IN THE CARIBBEAN

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ABSTRACT

Diurnal and seasonal solar cnergy storage using sensible heat and latent peat ?storage materials is discussed. In addition, the application of various solar enerey storage materials in cooling installations is shown by describing seme solar-aided debunid! Sication/ cooling and absorption cooling systens, and a comprehensive description of both kinds of systens is given. Also prosented is a aystem which uses a thermochemical heat pump for cooling and heating and an innovative Liquid sorbent system which employs a_dehunidi fication/ cooling concent coupled with 2 salt~gradient pond, Schematic diagrams Of the coupling method are shown. Furtherrore, the operation of a solar pond is briefly descrised alow with a retrofit absorption cooling system which uses cold water stored in a docermissioned nuclear reactor Pool of 416,000 2iters (110,000 eallons) capacity located in the CEER facility in'Yayaquez. Finally, a new technology appropriate for the

Caribbean clinate is derenstrated as an example of the use of local resources using locally built fiberglase parabolic trough collectors,

"DYTROOUCTION

Rrergy storage as an area of primary importance for solar energy conversion has been the topic of studies for sone time (1-10). Attention has focussed on a variety of storage devices and media which could satisfy a wide spectrin of themal, physical, engineering and economic requirements. Different kinds of storage ?systers, for example, sensible heat storage [10-19] latent heat storage (20-27), therrochenical energy storage [28], photochemical eneray storage (29), aoquifer energy storage (30], cimpressed air energy storage [31), Kinetic energy storage in fiywwels, electric energy storage ih batteries and fuel cells, or storage of energy in the form of hydeoyen fuel have bocn investigated.

In Puerto Rico, a 22 n° (240 £7) shallow solar pond system is being Gesicned by CHER for hot water generation and storage for a high school in Mayaguez. CER has also developed a salt grasient pond corputer design. Sone applications of ratural salt~gradient ponds in the Dominican Republic and on the island of Anguilla in the Caribbean also being considered Sor solar energy storage. For example, a 2023 m (0.5 acre or 21,780 £t%) salt~oradygnt pond located 4p san Juan, Puerto

Rico will collect up to 1.27 x 10 ka/yr (1.2 x 10° Btu/yr). Oceans Play the role of the largest natural reservoirs of solar energy? storace. ?The most inportant application of this stored energy for the Caribbean is for use in OTHE plants for the production of electric eneray. Puerto Rico has been active in developing this technology and CHER has played a

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major role in the biofouling ant corrosion studies that have been made in the last coveral years.

For cooling, energy can be stored as cold (temperature below anbient) for direct tse or in the fom o° nedium (ambient to 93°C (200°F)) and hich tenperature storage (93°C (202F) to 216°C (600F)) which can be: jused for absorption air conlitioning and Rankine cycle systens.

A warlety of storage miterials and means have to be used to satisty such a broac range of ?enperature and thermal enersy requirements. The kind of storace nedia chosen is also influenced by the end use of the ?energy and by the process employed to meet. that applice conversion processes, storage in the form of

the most appropriate. For photovoltaic

fencrgy storage in olectric batteries appears? to be the

proper solution, In the case of som photochenica! reactions, the

Zeacting agents form the storace media, Altematively, hydrogen can

be produced electrically or thema!ly for use as fuel,

Water seems to be the best sensible hoat storage Liquid since it is

jmempensive and has 2 high specific heat. Antifreeze, however, must

?be added to water for energy storage below OC (32°F). Paraffin wastes

and sait tydrates have been used for solar energy storage with some

suocess. 3f utilities adopt load managenent (ofepeak or tine-of- any

es), a heat pump can be uscd for both cooling and heating energy

storage. The off-peak operation of a heat pup will result ik

getucing a coolinc/heating bill and, consecuently, in? shortening the

aybock perice for the cost of the solar systan.

in teks paper attontion is focussad on cooling systens applicable to the Caribbean or other similar areas of tropical climates in which gooling loads for air-conditioning systems are year-round and represent a major fraction of the electric eneray demant in commercial and industrial installations. In particular, a salt-gradient solar Pond is an effective low-cost solar energy? collection and storage Reans as a sedium tenperature heat supplier for absorption cocling systems {32093}. The use of a thermoctemical heat panp aided by heat collects: and stored in a cat-gradient pond [335) aude sols aided absorp ion air-conditioning cystem which uses the water pool oa Gecomsissioned muclear reactor for anerey storage [36] will be described in this paper.

?STORAGE FOR COOLING APPLICATIONS

?The storage of thermal energy is an important aspect of solar enerwy Gooversion. the range of technologies which can be used for shis Burpose is brond; however, this poper will focus prisarily on cooling systene.

For cold storage, the lower tomerature limits of the storage are imposed by the chiller perfomance or the winter anbient enviroment in the cave of temperate clinates. The upper limits are determined by a combination of factors such as the cooling load, the tyme oF storie,

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the storage container, and the minimum generator inlet temperature required when a chiller concept is used, In the case of a Gehumiditication-cocling systen, the cold storage can be accomplished with chilled water tanke and ?water in the terperature range of O°C (32°F) on the low side (freezing point of water) and approximately jor (50°F) on the high side (coil temperature neaded for Gehunidification). The cooling load profile for the system has to be determined in ordar to size the cold storage properly.

Diumal cold storage is sometines integrated into solar space?cooling systems in order to reduce chiller cycling frequency during periods Of low demand. Tt may be usod in such systons to permit? off-peak Operation of a standby electric air conditioner. Tt inprowes the annual coefficient of perfomance by increasing the solar fraction and by ?reducing the installed tonnace requirement, Candidate technical Goncepts for diurnal coolness storage include the use of ice, chilled water, ?saturated aqueous solutions, phase-change materials that mele at 7°C to 10°C (45°F to 50°F), enc Ferrigerant storage. Among the most promising systans is cne using Glauber?s mixture, oe storaye has a good potentia for conventional electric ?air conditioners because of its swall volume and comercial availability. Saturated aqueous, solutions with hich terperature of solution Offer some promise of substantial volume reduction and lower first ?cost, Chilled water, bewever, is the only widely used storage medium in existing "solar gwoling systers. This ?type of storage is being used in the solar sided absorption cooling syster at CEER by employing a decommissioned reactor 9002.

SALT-GRADIEN? POND AS ENERGY STORAGE

Figure 1 shows a cross section of a salt-gradient pond. Typically, the brine in the top laycrs has 1-28 salt (usually Neel or Mycl) while that in the bottom layer has as high as 25¢ salt, Due to this sale Gradient, the bottom layors of licuid have a higher density than these on top of the pond. This density gradient allows a corresponding semperature gradient? to be established without convection currents occurring which would tend to equalize temperatures, In practiwn. 1 upper convecting layer exists becatse of wind disturbances v0 Similar way as in a nomal pond. If the bottom layer of concentrate! brine is withdram for the extraction of heat, the nonconvecting Jayer will still remain more or less undisturbed in the salt pond.

Thus only a middle non-convecting layer remains undisturbed if the salt pond during the operation of the pond, tho relative thicknesses of these layers are determined by the unvirormental and operations! ?conditions.

?The non-convecting layer of brine foms a very good thermal insulator 0 that relatively high botton terperatures of up to 93°C (20°F) can be cwpected in high solar flux areas, In practice this temperature varies from 49°C to 82°C (120°F to 180°P) depending upon the degree of stability of the salt gradient and otter factors (rate of heat, withdrawal, anbient air conditions, etc.). During sunny periods about 408 of the ?solar energy is transmitted through the brine anc ig absorbed

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at the bottom of the pond. The bottom layers are thereby heated because of the salt cradient. The brine serves as a sensible heat storage medium, thereby eliminating the separate thermal storage subsystem that is nomally required in mary solar energy collecting systens.

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EXTRACTION RETURN

FIGURE 1, CROSS-SECTION VIEW OF SALI-GRADIENT POND

A salt-gradient pond rodel was developed at CEFR for solar heat Storage and delivery sizing, and overall systen performance evaluation, ?These studies shows that the pond potential is'ss god in Puerto Rico as in the hichest insolation areas of the contanental BS jqhusrto Rico receiues largo amounts, of solar radiation ona borizontal plane 204 kI/n?day (1800 Btu/#t*day) and the availability Of this radiation is very mich uniform throughout the year bec she island iccatson near the ewator. In addition several ott ¢limatological characteristics make Puerto Rico and the Caribbean teoicn a very good site for solar ponds use as energy storage and celivury systens,

DERLMIDIFICATTON/COOLING AIDED BY SOLAR COLLECTORS.

Interest has increased in recent years in the use of collected solar eat for the cooling of buildings, A variety of techniques has been Proposed:

a) Vapor-conpression refrigeration by using a Rankine-cycle engine

?driven by solar hea!

b) _Closed-cycle absorption refrigeration wherein the sorbent generator is driven by solar heat;

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c} Dey-sorbent dehumidification followed by adiabatic cooling wherein the dry sorbent is reactivated with solar heat;

}_ Liguid sorbent dchumiditication followed by adiabatic cooling wherein the liguid sorbent is recenorated with solar heat.

A cooling system built by H, Robison and W, Griffiths [34,35] uses a solarvaided chemical ?heat pump cycle as shown in Figure 2. To be cost effective, any solar cooling systen located in the Caribbean should incluie a provision for demmidification as well as for cooling,
There are three chemical solutions in comon use today as. liquid desicoants: Lithium chloride, calcium chloride and triethylene glycol.
The latter is more effective bu: requires mich lower? regenerating temperatures, Systens using liquid cesiccants have the following advantages: continuous cooling during disorption, heat and mass

Liguid surtace, a low fan power reqquirerent, end the

use of liguic~tomliguié regerorative heat exchangers 20? increase

efficiency, Miditionally this type of system, incluiing the systens

which use solid dessicants, do not need compressors, evaporators,

Sondensers, gas-fired generators, vacuum systers oF pressure systens,

The storage reservoir stores eneray in the forn of concentrated brine

at ambient tenperature vather than heat in these types of cooling

gystens. For @ given amount of stored cooling energy the concentrated

brine storage concept requires only about one-tenth the reservoir

capacity of a syster storing the sane anunt of cooling energy in the

form of heat 381,

The coen-eycle chemical heat pimp uses a calcium chloride water

solution. ?Calcium chloride has the advantage of being chemically

stable, ?non-toxic, odorless, non-flammable, non-viscous, ard

possessing good heat transfer characteristics. Although it is not as

effective a Gossicant as the lichiun chloride, the calcium chloride is

jess costly. The negative foature is that it is corrosive in natures

?The system as shown in Figure 2 can operate in the cooling o: the

heating mode. when the heat pump operates in the cooling mosey which

is of interest. in the Caribbean Region, outside air (1) is coslas by

shallow well water which circulates through the packing. ah

water sink could be ocean water, viver water, cooling tower, fun i

or possibly a salt-gradient por. The heat? of sorption is reseed when ?the ?air passes ?through the coil type heat exchanger containing

well water (2). Dehunidification by a calcium chloride solution

xenoves further latent hoat. tumdificaticn of the cool, dxy alr by

water spray (3), results in a final conditioned air temperature adequate

for human comfort (4).

Queration of the teat pop in cither the cuoling or heating mode

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Stoosptien of water. "To recumrentiate Sols alkene Bobet eee

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?ident solar energy.

OER, ?Ter system uses sold

boing regencroted by solar

DERLMIDIFICATION/COOLING AIDE BY 2. SOLAR SAUI-COADIENT POND

Solar ponds have boen provec as an altemative +o flat-plate

gollectors as a means of poi ing solar heat for air-condst

gystams. Researcl: towate os indicated! ?Swat solar ponds have significant advantages over oo atqplate solar? collector

gyatens. Those acvancaces Elst cost per unit of

delivered heat tas leas" of flat-plate collectors)

easy 0 build, higher durebility ani relsability, the combination Of

solar radiation collection with solar Meat storage, and the enteapnent

Of solar heat under clou'y conti=ions by collecting diffuse radiations

A salt-aredient pond cuuld be wmple? with an open Ligvié sorption

syster to provide sume: cooling ly using the ?soncept suggested By

Hit. Robisor e= al. (35)

?The sorbent brine and tie pond beino sey consiat of the same salt or Gitterent saits, oF tre mixture ci salts in the form of the solar pond brine. The 32: he Towa somtion rystem can be coupled

ly or eeting operation of the cooling instatlation.

The prinary advantaces of th: irect method of coupling are: the elinihation o* tae wed for sorbent Brine to pon! brine heat exchange equipment, thereby reducing cess and improving perfomance; the inherent ?insomertion of a neans O° maintasning 2 stable density graciont within the soler pond et no additional equinment cost; ant fhe Amheren: ability to use the lower convective layer for energy storage in the form of concentrated brine, An example of the means of accomplishing the direct coupling through the falling pond's operation is (shom in Figure 2. ?tho falling-pond method [32) en tae Eisingcpond nethod (27) Could Te used ae the mode Of the opera?

a coupled pond.

Such @ coupled pond cooting sytem will be charged with a by

?such

as fally and have ?cbsomptive properties compatible. with the

Higuid-edtbent aix-conditionine process. During the pond poration,

water diffuses dowward thrown the non-convective layer ?ane into.

?the lower convective 2ayer. ot brine containing this ciffuse water

is withdraw from the lower cowective layer, A portion of the

withdrawn brine is transported to the liquid sorbent conditioner,

arother portion is transported t= the loud sorbont regenerators a

thizd portion could be transported to generate industria) process heat.

In he regenerator the hot brine is contacted with a scavenger

girstrean on a brine-to-air contact surface such asa cooling tow?

HU, Te scavenver airstrear typice!ly consists of outside anbicn

air, building exhiust air, or a mimure of the tw. ?The hot brine,

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having @ water vapor pressure very mich greater than the water vazor pressure of the scavenger airstream, is concentrated by the evaporation of water into the scavenger airstrean. ?The brine this Concentrated in the regenerator is mixed with the diluted brine withdrawn fron the conditioner and is transported to. the lowe convective layer of the solar nond. The concentration of the brine yetumed to the solar pond is higher than the concentration of the dower-convective layer, allowing it to absorb the water diffusing Gomward in the solar pond,

The Liguid sorbent regenerator serves here the dual purpose of providing a means of brine concentration for the Liquid sorbent. conditioner, and providing a means of maintaining a stable density Gradiont within the solar pond. An evaporative pond intereonmected with the salt-gradient pond can also be used as a liquid sorbent regenerator via surface evaporation process. The lower convective layer of the. thus serves as an energy storage reservoir for both sensible heat (brine temperature) and latent absorption (brine concentration) «

The Liguid sorbent conditioner requires a heat sink during the cooling @peration for rejection of the latent heat associated with ai Gehunidification. ?This heat sink can be a cooling tower water, weil water, ocean water, river water or, as is proposed here, the? upper convective layer of"a salt-gradiert pond.

It is ?now shat the terperature of a natural body of water is typically within a few cegrees cf the wet-bulb tenperature of the atmosphere, Furthermore, it is expected that the temperature of the yeper convective layer would approach the anbient wet-bulb temperature. Figure 4 shows how the upper convective layer othe solar pond can be used as a heat sink for the Licusd sorbent conditioner to reject. the later heat associated with air dehumidifcation, Enbodinents are sham for? both coil?type and Backed-type conditioners. Water is withirewn from the upper convective layer, passed through the coil (coil-type) or sorbent brine-to-coolant heat exchanger ipacked-type), wherein it receives she latent ?heat of condensation associated with the dehumidificati-n Process and possibly same sensible heat associated with air cooling.

?Te warm water is retumed to the upper convective layer where its evoled by evaporation to the atmosphere. The cooler and dryer air ray be Passed through a cold water spray before being directed to th: air conditoned space.

ABSORPTION AIR-CONDITIONING SYSTEM AIDED BY SOLAR EXERGY

?The Single Stage Cold Generator currently being installed at the CER Solar ergy Facility in Mayaguez is designed to use hot water at 93°C (200°F). ?Working fluids in ?the machine are Lithium bromide, which Plays the role of the absorbent, and water which plays the role of the refrigerant. The hot water is? used to reclaim refrigerant from the Lithium bromide solution to sustain the refrigeration cycle.

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col. = TYPE

CONDITIONER,

FIGURE 4, SALD-GRIDIENT POND AS HEAT STK

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Figure 5 shows a schonatic diagran of the abscrption air conditioning system being installed. Subsystenc such as ?he absorption unit, cooling tower, chiles water ?storage, ?wet exchanger, boiler, a! obllectors array are show cn the diagtan, One side of the neat uxchanger is connected to the absorption chilter and to the boiler, the cther side ie connected to the collectors arriy. The function of ?the heat exchanger is to facilitate the exchange o* heat between the hot concentrated and he cool diluted Lithium bromide solution, The hot water temperature i= maintained at 93°C (200°F) at the intake of the chiller either by the solar collectors array or by the boiler, The boiler capacity oF the system Ls in the range of 615 AN, 103 Fa (2,190,000 Beugnry 15 pet steam). A collectors array arcs of over 670 m* (7200 ft) is being Used. ?The field of collectors consists of 43 rovs with 7 collectors in each row. Hach of these rows is series connected and all 43 rows are parallelly interconnected. ceneral view of the field of collectors Bresently under construction is shawn in Figure 6.

Each parabolic trough collector is nade of fiberglass by using @ boat building technology adopted by #. Barcelo (36). Mirrors are used to Line ?the fiberglass shell of Ue collector to ?provice the reftesting Surface. The focal length of ?ys collector is ?3? an (12-5 an) which Brovides a concentration ratio of over 30, The absorber? pipes, consisting of two copper tubes interconnected at one che, ran along the fecal Line, Absorbers painted :let-black are placed in Gousle envelope: Glass tubes to minimize heat Iesces and to incranse the collector efficiency. Over 300 collectors were built at the CHER Research Facility in Neyaguez. sce of the fiberglass collector shells are shawn in Figure 7. ?From ?all indications, the durability of these type OF gollectors was tested in the corrosive envirorment of the Caribbean Region during a one year solar exgnsure of a randomiy selected collector: with successful results,

Im order to sustain the cooling cycle, solar heated water will be used fe reclaim the refrigerant fron the Lithium bromide solution. with a flow rate of 0.25 1/s (4 gm) through each collector row, the water temperature should exceed 93°C (200°P) at the intake to the chi lrcr

A former nyclear laboratory and reactor building, now consist over 3000 m® (32,000 £t*) of office and laboratory space, will be covled bby the systen. The pool of the 2 16 deconissioned reactor will? be used a8 Une cold water storage. With a poo! capacity oF 416,000 liters {210,000 gallons) of water, it is capected that the temperature increase of the storage water during one day of full load operation of the geoling systen will be only 3°C (S*F). Figure @ shows a general View of ?the fomer reactor pool which will be used for chilled water storace.

The optim size of a storage system for a particular application depends upon the storage medium, the size ani efficiency of the collector, the amount ani frequency of solar radiation, the amount avd profile of the building load, the maximm and minimim allowanie Storage tenperatures, the rate of heat transfer to and from steraue, the type Of storage thot water or cold. water), and enonceue conditions, Cost consideration was a dominant factor for the sold

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FIGURE 6. FIELD OF COLLECTORS

FIGURE 7. PIRERGLASS SHELLS OF COLLECTUSS mM STORNGE

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