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SOLAR ENERGY STORAGE FOR COOLING SYSTEMS IN THE CARIBBEAN

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ABSTRACT

Diurnal and seasonal solar energy storage using sensible heat and latent heat storage materials is discussed. In addition, the application of various solar energy storage materials in cooling installations is shown by describing some solar-aided dehumidification/cooling and absorption cooling systems, and a comprehensive description of both kinds of systems is given. Also presented is a system which uses a thermochemical heat pump for cooling and heating and an innovative liquid sorbent system which employs a dehumidification/cooling concept coupled with a salt-gradient pond. Schematic diagrams of the coupling method are shown. Furthermore, the operation of a solar pond is briefly described along with a retrofit absorption cooling system which uses cold water stored in a decommissioned nuclear reactor pool of 416,000 liters (110,000 gallons) capacity located in the CEER facility in Mayaguez. Finally, a new technology appropriate for the Caribbean climate is demonstrated as an example of the use of local resources using locally built fiberglass parabolic trough collectors.

INTRODUCTION

Energy storage as an area of primary importance for solar energy conversion has been the topic of studies for some time (1-10). Attention has focused on a variety of storage devices and media which could satisfy a wide spectrum of thermal, physical, engineering and economic requirements. Different kinds of storage systems, for example, sensible heat storage [10-19] latent heat storage.

(20-27), thermochemical energy storage [28], photochemical energy storage (29), aquifer energy storage (30), compressed air energy storage [31], kinetic energy storage in flywheels, electric energy storage in batteries and fuel cells, or storage of energy in the form of hydrogen fuel have been investigated. In Puerto Rico, a 22 m^2 (240 ft^2) shallow solar pond system is being designed by CHER for hot water generation and storage for a high school in Mayaguez. CHER has also developed a salt gradient pond computer design. Some applications of natural salt-gradient ponds in the Dominican Republic and on the island of Anguilla in the Caribbean are also being considered for solar energy storage. For example, a 2023 m^2 (0.5 acre or 21,780 ft^2) salt-gradient pond located in San Juan, Puerto Rico will collect up to 1.27×10^3 kJ/yr (1.2 x 10■ Btu/yr). Oceans play the role of the largest natural reservoirs of solar energy storage. The most important application of this stored energy for the Caribbean is for use in OTEC (Ocean Thermal Energy Conversion) plants for the production of electric energy. Puerto Rico has been active in developing this technology and

CHER has played a major role in the biofouling and corrosion studies that have been made in the last several years.

For cooling, energy can be stored as cold (temperature below ambient) for direct use or in the form of medium (ambient to 93°C (200°F)) and high temperature storage (93°C (200°F) to 216°C (600°F)) which can be used for absorption air conditioning and Rankine cycle systems. A variety of storage materials and means have to be used to satisfy such a broad range of temperature and thermal energy requirements. The kind of storage media chosen is also influenced by the end use of the energy and by the process employed to meet that application. For photovoltaic energy conversion processes, storage in the form of electric batteries appears to be the most appropriate. In the case of some photochemical reactions, the reacting agents form the storage media.

Alternatively, hydrogen can be produced electrically or thermally for use as fuel. Water seems to be the best sensible heat storage liquid since it is inexpensive and has a high specific heat. However, antifreeze must be added to water for energy storage below 0°C (32°F). Paraffin wastes and salt hydrates have been used for solar energy storage with some success. If utilities adopt load management (off-peak or time-of-use rates), a heat pump can be used for both cooling and heating energy storage. The off-peak operation of a heat pump will result in reducing a cooling/heating bill and, consequently, in shortening the payback period for the cost of the solar system. In this paper, attention is focused on cooling systems applicable to the Caribbean or other similar areas of tropical climates in which cooling loads for air-conditioning systems are year-round and represent a major fraction of the electric energy demand in commercial and industrial installations. In particular, a salt-gradient solar pond is an effective low-cost solar energy collection and storage means as a medium-temperature heat supplier for absorption cooling systems. The use of a thermochemical heat pump aided by heat collectors and stored in a salt-gradient pond, and solar-aided absorption air-conditioning system which uses the water pool of a decommissioned nuclear reactor for energy storage, will be described in this paper.

STORAGE FOR COOLING APPLICATIONS

The chiller concept is used in the case of a dehumidification-cooling system. The cold storage can be accomplished with chilled water tanks and water in the temperature range of 0°C (32°F) on the low side (freezing point of water) and approximately 10°C (50°F) on the high side (coil temperature needed for dehumidification). The cooling load profile for the system has to be determined in order to size the cold storage properly. Diurnal cold storage is sometimes integrated into solar space-cooling systems in order to reduce chiller cycling frequency during periods of low demand. It may be used in such systems to permit off-peak operation of a standby electric air conditioner. It improves the annual coefficient of performance by increasing the solar fraction and by reducing the installed tonnage requirement. Candidate technical concepts for diurnal coolness storage include the use of ice, chilled water, saturated aqueous solutions, phase-change materials that melt at 7°C to 10°C (45°F to 50°F), and refrigerant storage. Among the most promising systems is one using Glauber's mixture. This storage has good potential for conventional electric air conditioners because of its small volume and commercial availability. Saturated aqueous solutions with high temperature of solution offer some promise of substantial volume reduction and lower first cost. However, chilled water is the only widely used storage medium in existing solar cooling systems. This type of storage is being used in the solar-aided absorption cooling system at CEER by employing a decommissioned reactor 9002.

The Salt-Gradient Pond as Energy Storage (Figure 1) shows a cross-section of a salt-gradient pond. Typically, the brine in the top layers has 1-2% salt (usually NaCl or MgCl) while that in the bottom layer has as high as 25% salt. Due to this salt gradient, the bottom layers of liquid have a higher density than those on top of the pond. This density gradient allows a corresponding temperature gradient to be established without convection currents.

Occurring which would tend to equalize temperatures, in practice, an upper convecting layer exists because of wind disturbances in a similar way as in a normal pond. If the bottom layer of concentrated brine is withdrawn for the extraction of heat, the non-convecting layer will still remain more or less undisturbed in the salt pond. Thus, only a middle non-convecting layer remains undisturbed in the salt pond during the operation of the pond. The relative thicknesses of these layers are determined by the environmental and operational conditions. The non-convecting layer of brine forms a very good thermal insulator so that relatively high bottom temperatures of up to 93°C (200°F) can be expected in high solar flux areas. In practice, this temperature varies from 49°C to 82°C (120°F to 180°F) depending upon the degree of stability of the salt gradient and other factors (rate of heat withdrawal, ambient air conditions, etc.). During sunny periods, about 40% of the solar energy is transmitted through the brine and is absorbed at the bottom of the pond. The bottom layers are thereby heated because of the salt gradient. The brine serves as a sensible heat storage medium, thereby eliminating the separate thermal storage subsystem that is normally required in many solar energy collecting systems.

Figure 1, Cross-Section view of Salt-Gradient Pond. A salt-gradient pond model was developed at CEFR for solar heat storage and delivery sizing, and overall system performance evaluation. These studies show that the pond's potential is as good in Puerto Rico as in the highest insolation areas of the continental US. Puerto Rico receives large amounts of solar radiation on a horizontal plane 204 kJ/m—day (1800 Btu/ft*day) and the availability of this radiation is very much uniform throughout the year because the island is located near the equator. In addition, several other climatological characteristics make Puerto Rico and the Caribbean region a very good site for solar ponds used as energy storage and

Delivery systems, DEHUMIDIFICATION/COOLING AIDED BY SOLAR COLLECTORS. Interest has increased in recent years in the use of collected solar heat for the cooling of buildings. A variety of techniques has been proposed: a) Vapor-compression refrigeration by using a Rankine-cycle engine driven by solar heat. b) Closed-cycle absorption refrigeration wherein the sorbent generator is driven by solar heat.

c) Dry-sorbent dehumidification followed by adiabatic cooling wherein the dry sorbent is reactivated with solar heat. d) Liquid sorbent dehumidification followed by adiabatic cooling wherein the liquid sorbent is regenerated with solar heat. A cooling system built by H. Robison and W. Griffiths [34,35] uses a solar-aided chemical heat pump cycle as shown in Figure 2.

To be cost-effective, any solar cooling system located in the Caribbean should include a provision for dehumidification as well as for cooling. There are three chemical solutions in common use today as liquid desiccants: Lithium chloride, calcium chloride, and triethylene glycol. The latter is more effective but requires much lower regenerating temperatures. Systems using liquid desiccants have the following advantages: continuous cooling during absorption, heat and mass liquid surface, a low fan power requirement, and the use of liquid-to-liquid regenerative heat exchangers to increase efficiency.

Additionally, this type of system, including the systems which use solid desiccants, does not need compressors, evaporators, condensers, gas-fired generators, vacuum systems or pressure systems. The storage reservoir stores energy in the form of concentrated brine at ambient temperature rather than heat in these types of cooling systems. For a given amount of stored cooling energy, the concentrated brine storage concept requires only about one-tenth the reservoir capacity of a system storing the same amount of cooling energy in the form of heat [38]. The open-cycle chemical heat pump uses a calcium chloride water solution. Calcium chloride has the

The text has the advantage of being chemically stable, non-toxic, odorless, non-flammable, non-viscous, and possessing good heat transfer characteristics. Although it is not as effective a desiccant as lithium chloride, calcium chloride is less costly. The negative feature is that it is corrosive in nature. The system, as shown in Figure 2, can operate in the cooling or heating mode. When the heat pump operates in the cooling mode, which is of interest in the Caribbean Region, outside air (1) is cooled by shallow well water which circulates through the packing. The water sink could be ocean water, river water, cooling tower, fountain, or possibly a salt-gradient pond. The heat of sorption is released when the air passes through the coil type heat exchanger containing well water (2). Dehumidification by a calcium chloride solution removes further latent heat. Humidification of the cool, dry air by water spray (3), results in a final conditioned air temperature adequate for human comfort (4). Operation of the heat pump in either the cooling or heating mode always results in the solution being cooled by heat absorption of water.

The refrigeration system is in as the refrigeration effect. Auxiliary system desiccant is the energy, including solar energy. The system uses solar heating regenerated by solar dehumidification/cooling aided by a solar salt-gradient pond. Solar ponds have been proven as an alternative to flat-plate collectors as a means of pooling solar heat for air-conditioning systems. Research towards this indicated that solar ponds have significant advantages over flat-plate solar collector systems. These advantages include lower cost per unit of delivered heat and ease of operation.

The text should be corrected as follows:

Building higher durability and reliability, the combination of solar radiation collection with solar heat storage, and the enhancement of solar heat under cloudy conditions by collecting diffuse radiations. A salt-gradient pond could be coupled with an open liquid sorption system to provide summer cooling by using the concept suggested by Mr. Robison et al. (35). The sorbent brine and the pond being may consist of the same salt or different salts, or the mixture of salts in the form of the solar pond brine. The low solution system can be coupled by or during the operation of the cooling installation. The primary advantages of this direct method of coupling are: the elimination of the need for sorbent brine-to-pond brine heat exchange equipment, thereby reducing cost and improving performance; the inherent insertion of a means of maintaining a stable density gradient within the solar pond at no additional equipment cost; and the inherent 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 shown in Figure 2. The falling-pond method (32) and the rising-pond method (27) could be used as the modes of operation for a coupled pond. Such a coupled pond cooling system will be charged with a byproduct such as salt and have absorptive properties compatible with the liquid-sorbent air-conditioning process. During the pond operation, water diffuses downward through the non-convective layer and into the lower convective layer. The brine containing this diffused water is withdrawn from the lower convective layer. A portion of the withdrawn brine is transported to the liquid sorbent conditioner, another portion is transported to the liquid sorbent regenerators, and a third portion could be transported to generate industrial process heat. In the regenerator, the hot brine is contacted with a scavenger airstream on a brine-to-air contact surface such as a cooling tower. The scavenger airstream typically...

The text shows how the upper convective layer of the solar pond can be used as a heat sink for the liquid sorbent conditioner to reject the latent heat associated with air dehumidification. Embodiments are shown for both coil-type and packed-type conditioners. Water is withdrawn from the upper convective layer, passed through the coil (coil-type) or sorbent brine-to-coolant heat exchanger (packed-type), wherein it receives the latent heat of condensation associated with the dehumidification process and possibly some sensible heat associated with air cooling. The warm water is returned to the upper convective layer where it is cooled by evaporation to the atmosphere. The cooler and dryer air may be passed through a cold water spray before being directed to the air-conditioned space.

ABSORPTION AIR-CONDITIONING SYSTEM AIDED BY SOLAR EXERGY

The single-stage cold generator currently being installed at the CER Solar Energy 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.

TYPE CONDITIONER, FIGURE 4, SALT-GRADIENT POND AS HEAT SINK

Figure 5 shows a schematic diagram of the absorption air conditioning system being installed. Subsystems such as the absorption unit, cooling tower, chilled water storage, heat exchanger, boiler, and collectors array are shown on the diagram. One side of the heat exchanger is connected to the absorption chiller and to the boiler, the other side is connected to the collectors array. The function of the heat exchanger is to facilitate the exchange of heat between the hot concentrated and the cool diluted Lithium bromide solution. The hot water temperature is 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

The system lies in the range of 615 AN, 103 Fa (2,190,000 Beugnry 15 pet steam). A collector's array arc of over 670 m* (7200 ft) is being used. The field of collectors consists of 43 rows with 7 collectors in each row. Each of these rows is series-connected and all 43 rows are interconnected in parallel. A general view of the field of collectors presently under construction is shown in Figure

6. Each parabolic trough collector is made of fiberglass using boat-building technology adopted by Barcelo (36). Mirrors are used to line the fiberglass shell of the collector to provide the reflecting surface. The focal length of the collector is 37 cm (12.5 in) which provides a concentration ratio of over 30. The absorber pipes, consisting of two copper tubes interconnected at one end, run along the focal line. Absorbers painted jet-black are placed in a double envelope glass tube to minimize heat losses and to increase the collector efficiency. Over 300 collectors were built at the CHER Research Facility in Mayaguez. Some of the fiberglass collector shells are shown in Figure 7. From all indications, the durability of these types of collectors was tested in the corrosive environment of the Caribbean Region during a one year solar exposure of a randomly selected collector with successful results. In order to sustain the cooling cycle, solar heated water will be used to reclaim the refrigerant from the Lithium bromide solution. With a flow rate of 0.25 l/s (4 gm) through each collector row, the water temperature should exceed 93°C (200°F) at the intake to the chiller. A former nuclear laboratory and reactor building, now consisting over 3000 m² (32,000 ft²) of office and laboratory space, will be cooled by the system. The pool of the decommissioned reactor will be used as the cold water storage. With a pool capacity of 416,000 liters (110,000 gallons) of water, it is expected that the temperature increase of the storage water during one day of full load operation of the cooling system will be only 3°C (5°F).

Figure 1 shows a general view of the former reactor pool which will be used for chilled water storage. The optimal size of a storage system for a particular application depends upon the storage medium, the size and efficiency of the collector, the amount and frequency of solar radiation, the amount and profile of the building load, the maximum and minimum allowable storage temperatures, the rate of heat transfer to and from storage, the type of storage (hot water or cold water), and environmental conditions. Cost consideration was a dominant factor for the sale.

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FIGURE 6. FIELD OF COLLECTORS

FIGURE 7. FIBERGLASS SHELLS OF COLLECTORS IN STORAGE

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