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SOLAR ENERGY PROGRAM

Final Report

AN INVESTIGATION OF POROUS-MEDIUM SOLAR-POND FEASIBILITY

Ty A. Newell

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ABSTRACT

A feasibility study of a porous medium solar pond has been completed. In general, the results show that a partially transparent bed of glass and water will not perform well as a solar pond non-convecting zone. Effective thermal conductivities for the glass/water bed are high, indicating significant convective motion. In addition, radiation transmission through several glass/water interfaces is low. Useful radiation transmission models for partially transparent porous mediums have been formulated and are presented. Finally, a numerical simulation of a porous medium in a solar pond storage zone has shown that significant performance increases can be obtained.

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1. INTRODUCTION

An investigation on the feasibility of porous medium solar ponds has been completed. The overall investigation consisted of three main topics. These topics were:

1. Determination of a porous medium's heat transfer characteristics relative to solar pond operation,
2. Evaluation of radiation transmission through a partially transparent porous medium, and
3. Numerical simulation of solar pond performance.

The basis for the investigation was that a relatively inexpensive material (e.g. glass) could be distributed within a pond such that convective heat losses to the environment would be suppressed. Radiation transmission through a glass/water medium is reduced, however, as the number of glass/water interfaces increases. Thus, a competing effect is realized since increasing pond insulation reduces pond radiation transmission. As discussed in the following sections, radiation transmission is degraded too much and pond performance will generally be low. While these results imply that the proposed configuration is undesirable, a new concept was developed from these results. The new concept proposes a means of significantly increasing solar pond performance by stratifying the storage zone of a solar pond with a porous medium. This strategy has been simulated numerically and shows that significant improvement in pond performance can be obtained.

2. POROUS MEDIUM HEAT TRANSFER INVESTIGATION

In general, a solar pond has two characteristic features. A layer of water near the surface of the pond is stagnated by some method in order to act as a layer of insulation. This layer must also be relatively transparent to allow incident solar radiation to pass through to the lower layer of water. The second characteristic feature of solar ponds is the lower layer which acts as a thermal energy storage tank. Solar radiation passing through the upper pond layer is absorbed and stored in the lower region.

Formation of the stagnated water layer near the pond surface is critical. This layer must have good insulating quality and be inexpensive. The present proposal suggested using a porous medium of glass and water to suppress convection. Because no data or studies of a similar nature have been performed previously, detailed experimental and theoretical studies were required.

Convection suppression occurs in a porous medium due to two effects. First, the solid particles cause additional shear stress. Second, mechanical blocking of convective currents occurs in the porous medium passages. In order to have an effective insulation, the fluid component must be stagnated. Significant factors of this stagnation are the temperature conditions imposed, the pore size, and the fluid properties. These factors can be stated in terms of a factor called the Rayleigh number which is basically a ratio of the destabilizing potential of the system to the system's dispersive capability of the destabilizing component. A rough calculation would suggest a porous medium with cavities of approximately one centimeter dimension as being adequate to suppress fluid motion. Because the current proposal assumed irregular cavity shapes (glass bottles or randomly broken glass pieces), an accurate estimate for stagnation could not be made on an a priori basis.

An experiment to determine specific heat transfer characteristics of a glass/water system has been developed. The experiment consisted of a well-insulated canister which had an electric heating element at one end and a cooling water jacket at the other end. The canister could have either bottom or top heating orientations. Top heating orientation provided a base case test in which water stagnation should occur. Results from the top heating experiments indicated that the glass/water system was stagnant. Effective system thermal conductivities could be determined and the values correlated well with glass/water conductivities calculated from component volumetric fractions.

Bottom heated experiments were used in order to simulate conditions similar to those expected to occur in a porous medium solar pond. A wide range of volumetric ratios of glass and water were tested. The results indicated, however, that a glass/water medium could not be effectively stagnated while retaining good radiation characteristics. Effective thermal conductivity calculations showed values many times greater than corresponding top heated experiments. The high effective thermal conductivity values indicate that significant convective motion was occurring.

A detailed description of the heat transfer investigation is described in the thesis by D. Ketchum (enclosed with this report). In addition to the experimental heat transfer results, Ketchum numerically simulated a solar pond's performance with high effective thermal conductivities in the upper layer. His results show significantly decreased pond performance. These simulation results do not include the radiation transmission degradation which would lower pond performance even more.

3. SOLAR RADIATION TRANSMISSION THROUGH A GLASS/WATER MEDIUM

The previous section described the limited success of stagnating water with randomly oriented glass. Concurrent with the heat transfer study of the glass/water system, an investigation of glass/water radiation transmission characteristics was performed. The radiation study consisted of experimental and theoretical aspects.

Experimental studies of radiation transmission through glass/water systems were performed with simulated and actual solar radiation conditions. A metal halide vapor lamp was used for solar radiation simulation. The simulated results showed that characterization of radiation transmission based on volume fractions of the glass/water system were reasonable. Because the indoor radiation lamp could not be matched to actual solar radiation spectral distribution, an outdoor test facility was constructed. The outdoor facility was operated under a variety of conditions. Glass/water ratios, solar beam to diffuse radiation fractions and varying solar incidence angles were tested. In general, the results showed significant degradation of radiation transmission and, coupled with the heat transfer results of the previous section, indicate that a porous medium solar pond is not feasible in this configuration.

A significant aspect of the radiation results is that solar radiation transmission through a randomly ordered glass/water medium has been successfully modeled. Actual radiation transmission through such a system is complicated. A structured glass/water system was hypothesized for a theoretical model which would have similar characteristics as the randomly ordered system. Comparison of results between theoretical and experimental systems show good agreement.

A semi-empirical model was also formulated for glass/water systems. This model showed excellent agreement with experimental results and is a valuable tool for other research involving glass/water systems. Also, extension of the semi-empirical model to systems other than glass/water can be made through determination of a constant.

A detailed description of the radiation transmission studies is included in the thesis by M. Witte (enclosed with this report). In addition, APPENDIX A consists of a paper derived from this work and presented at the 1983 American Solar Energy Society Conference held in Minneapolis, Minnesota.

4. PERFORMANCE PREDICTIONS FOR A SOLAR POND WITH A STAGNATED STORAGE ZONE

The porous medium solar pond investigation has resulted in a new configuration which can significantly increase solar pond performance. Stagnation of the storage zone of a solar pond using a porous medium can improve solar pond performance due to three effects:

1. Ground losses are minimized,
2. Available temperatures for process use are increased, and
3. Energy extraction from the porous medium is efficient.

The experimental study of heat transfer across a randomly ordered porous bed indicated that top heating would result in fluid stagnation. If a solar pond is constructed such that the storage zone is filled with a non-transparent porous medium (e.g. rock), then radiation absorption will occur at the top of the rock bed. This region would be the hot spot of a solar pond and would be the level at which energy extraction should occur. Because thermal energy must propagate through the stagnated water/rock region, ground losses are minimized. When energy extraction rates occur such that the region above the rock bed becomes cooler than the adjacent rock bed region, convection circulation will occur which brings warmer water to the energy extraction level.

A numerical simulation of solar ponds with stagnated storage zones has shown that pond performance can be increased from 5 to 100 percent over conventional ponds with low process temperature requirements and deep ground water levels are at the low end of performance increase. Ponds with high process temperature requirements and shallow ground water levels are increased more significantly.

An additional feature of a stagnated solar pond with a porous medium is that less salt is required due to significant displacement of storage zone

volume by rock. This may result in investment savings depending on local availabilities of rock and salt.

APPENDICES B and C contain a more detailed description of solar pond storage zone stagnation. The paper in APPENDIX B has been accepted for publication in the ASME Journal of Solar Energy Engineering. This paper describes general aspects and considerations of storage zone stratification. The second paper in APPENDIX C was presented at the 1983 American Solar Energy Society Conference. This paper describes the effects of storage zone stratification in relation to seasonal variation of process loads.

5. CONCLUSIONS

The porous medium solar pond investigation has examined three topics. Two of the topics, heat transfer and radiation transmission characteristics, have indicated that a glass/water porous medium is not feasible. Potential porous medium structures may be conceived which are feasible. For example, teflon has an index of refraction similar to that of water and would have much better radiation transmission qualities. Also, some other fluid which is floated on the water (e.g. oil) could be used with the porous medium for better stagnation properties (i.e. higher viscosity). Either of these suggestions, however, would significantly increase pond cost and, therefore, be economically unfeasible.

The third area of investigation is one which should be pursued in more detail. The significant performance increases predicted for a stratified storage zone and the probable minimal investment costs for such a configuration justify its future study.