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# SOLAR PONDS FOR INDUSTRIAL PROCESS HEAT

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## ABSTRACT

Solar ponds offer perhaps the simplest technique for conversion of solar energy to thermal energy, which can be used for industrial process heat. It is unique in its capability in acting both as collector and storage. Further, the cost of solar pond per unit area is less than any active collectors available today. Combination of these economic and technical factors make solar ponds attractive as a fuel saver in IPH applications. This paper presents detailed calculation of solar ponds in two specific applications: providing hot water for aluminum can washing in a manufacturing plant and hot water for washing in a large commercial laundry. With the help of computer codes developed at SERI for other solar IPH systems, it is shown that solar ponds are far more cost effective than any other solar IPH technology for these applications.

## INTRODUCTION

The solar pond is probably the simplest technique for direct thermal conversion of solar energy. It is simultaneously a collector of solar radiation and a large body of thermal storage. Any pond converts insolation to heat, but most natural ponds quickly lose that heat through vertical convection within the pond and evaporation and convection at the surface. The solar pond artificially prevents vertical convection, surface evaporation and convection, or both. Because of its massive thermal storage and of measures taken to retard heat loss, the typical pond takes weeks for a 10°C temperature loss, even in the absence of insolation. Thus, the solar pond converts an intermittent energy source—solar radiation—into a reliable source of thermal energy.

The best established variety of solar pond is the salt gradient solar pond. The salt gradient solar pond has been studied since the early 1960s in Israel [1-3], and one has now been operating in a commercial application for over a year at Miamisburg, Ohio [4]. The salt gradient solar pond contains a "nonconvective layer" of about a meter in thickness in which salt is dissolved in concentrations that increase with depth. Hence, the increased weight of the lower pond

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depths prevents thermal buoyancy convection.

The heated water does not rise, thus heat loss is retarded. Salt gradient solar ponds can achieve temperatures up to the boiling point of the salt solution.

The salt gradient solar pond is commercially ready to aid in meeting many industrial process heat (IPH) requirements. Solar ponds are useful for preheating even in applications where the end use temperature exceeds the typical solar pond temperature. Only about 2.5% of IPH energy in the United States is required at an end use temperature less than 70° C. When preheating to 70° C is considered, 19% of U.S. IPH energy requirements fall within the scope of solar ponds [5]. However, some critical environmental and technical issues need to be resolved before solar ponds can be widely implemented.

## APPLICATIONS SELECTED

To assess the feasibility of solar pond technology for IPH applications and compare the suitability of ponds with more conventional solar technology, two industrial applications as reported in the Solar Energy Research Institute's (SERI) case studies [6,7] were selected for analysis. Through the SERI industrial case study program, complete energy audits of industrial plants are performed and used to provide the basis for solar system sizing and performance analysis. The result is a report on solar system size, performance, cost and life-cycle cost in a number of possible configurations that may include conservation and process redesign. Case studies performed since 1978 include those of a luggage manufacturing plant, commercial laundry, metal container manufacturer, bakery, dairy, paint resin plant, wet corn-milling operation, and an oil recovery operation. Solar systems that have been analyzed include hot air, hot water, and steam systems using flat plate, evacuated tube, Fresnel lens, and parabolic trough collectors. However, the studies did not include appropriate solar pond technology. This paper builds upon the significant achievements of the case study program and presents a comparative analysis of two low temperature hot water applications.

One application focuses upon the hot water requirements for aluminum can washing in a Colo. manufacturing plant where cans are shaped and trimmed from sheet stock, then washed and dried before being sent for bottom coating and printing. On the average, the can processing lines operate 24 h per day, 6.5 days per week, and 50 weeks during the year. Most of the energy used in the plant (supplied by natural gas at $1.93/GJ) is required for can drying. However, approximately 22% of the total energy input goes to a water heater that supplies 60° C (140° F) water to the can washer. Water is heated via steam. The total annual energy requirement for can washing on one process line is $2.3 \times 10^{12}$ joules (2,185 MBtu).

The second application is for hot water used in washing in a large Colo. commercial laundry. Water is heated via steam and effluent heat exchangers. Steam is primarily used in the ironing machines (the largest load in the plant) so that it is conceivable that the required hot water at 82° C (180° F) could be alternatively supplied directly by a solar system. The hot water load constitutes only 8% of the total plant energy demand. The laundry normally operates for one daytime shift, 8 h each day, 6 days per week. Total annual energy to be supplied is $4.3 \times 10^{12}$ joules (4,085 MBtu). Energy is supplied via

natural gas at $1.85/GJ.

## DESIGN OF SOLAR POND IPH SYSTEMS

Solar pond systems were sized to assist the IPH needs of the metal can manufacturer and the commercial laundry. Some salient features involved in solar pond sizing for IPH applications are mentioned here. Details of sizing and performance prediction are given in Refs. 4 and 5. The larger the pond surface area compared to the load, the higher the temperature of the output will be. The deeper the pond, the less the temperature will fluctuate seasonally. In theory, a pond could have been sized to provide 82° C continuous output, as required for the commercial laundry. The incremental surface area and depth required, however, to increase the pond's minimum output temperature from 80° C to 82° C is considerably greater than that required to increase it from 60° C to 62° C. Therefore, there is likely to be an optimal size at which the marginal cost of increasing the pond's area is equal to the cost of backup energy. Hence, the optimal solar pond may use backup, even though it may be feasible to size a solar pond large enough to require no backup.

For the metal can washing application, a solar pond was sized to achieve an annual average temperature of 55° C, with an annual high of 65° C, and an annual low of 45° C. It was assumed that a 5° C loss would be suffered in exchanging heat from the pond. Hence, at its peak temperature of 65° C, the pond will just satisfy without backup the application's requirement for 60° C water. At all other times, it will require backup to boost the temperature. The pond is 5143 $m^2$ (1.27 acres) in surface area and 4.9 m deep. The capital cost of the pond alone is $128,000 if salt is free, $173,000 if salt costs $10 per ton, and $218,000 if salt costs $20 per ton. The costs of the heat exchanger and piping were conservatively assumed to be $8/$m^2$ of pond surface area.

For the laundry application, a solar pond was sized to achieve an annual average temperature of 65° C, with an annual high of 80° C, and an annual low of 50° C. This pond is 3552 $m^2$ (0.88 acre) in surface area and 3.2 m deep. Its capital cost is $76,000 with free salt, $94,000 at a salt cost of $10/ton, and $112,000 at a salt cost of $20/ton. Again, heat exchanger and piping costs were assumed to be $8/$m^2$.

## COMPARISONS WITH "CONVENTIONAL" SOLAR

The simulation codes PROSYS and ECONMAT [6] were used in SERI case studies of the two applications to assess annual performance and costs of alternative "conventional" solar IPH systems. Approximately 20 different collectors were analyzed and the most cost effective collector and system were chosen for each application. Table A shows the cost and performance characteristics of each conventional solar system and of the comparable solar pond system for three assumed salt costs. The annual energy outputs of the solar ponds for the two applications were calculated using the method described in Ref. 8. Note that the configured systems will annually deliver different amounts of energy. A comparison is possible, therefore, only on the basis of annualized energy costs or projected rates of return. It is useful, however, to compare the relative amounts of capital investment required for unit annual energy delivery. The capital capacity cost of the conventional

## Table A. COMPARATIVE COST AND PERFORMANCE OF CONVENTIONAL SOLAR SYSTEMS VERSUS A SOLAR POND SYSTEM

**Metal Can Washing**

| System Type | Area Land Required | Annual Energy Delivered | Collector Subsystem Cost | Balance of Plant[a] | Total Capital Cost | Estimated Annual OMPI |
|---|---|---|---|---|---|---|
| Parabolic Trough Collector Heat Exchange System | 1275 $m^2$ (13,695 $ft^2$) | $2.3 \times 10^{12}$ J (2,200 MBtu) | $193,000 | $197,000 | $390,000 | $ 7,500 |
| Salt Gradient Pond at $20/Ton For Salt | 5143 $m^2$ (55,339 $ft^2$) | $5.8 \times 10^{12}$ J (5,320 MBtu) | $218,000 | $196,600 | $414,600 | $ 8,000 |
| Salt Gradient Pond at $10/Ton For Salt | 5143 $m^2$ (55,339 $ft^2$) | $5.8 \times 10^{12}$ J (5,320 MBtu) | $173,000 | $196,600 | $369,600 | $ 6,000 |
| Salt Gradient Pond at 0/Ton For Salt | 5143 $m^2$ (55,339 $ft^2$) | $5.8 \times 10^{12}$ J (5,320 MBtu) | $128,000 | $196,600 | $324,600 | $ 4,000 |

**Laundry Hot Water**

| System Type | Area Required | Annual Energy Delivered | Collector Subsystem Cost | Balance of Plant[a] | Total Capital Cost | Estimated Annual OMPI |
|---|---|---|---|---|---|---|
| Parabolic Trough Collector, Heat Exchange System | 2087 $m^2$ (22,450 $ft^2$) | $2.96 \times 10^{12}$ J (3,750 MBtu) | $313,000 | $319,800 | $632,800 | $13,500 |
| Salt Gradient Pond at $20/Ton For Salt | 3552 $m^2$ (38,220 $ft^2$) | $3.06 \times 10^{12}$ J (2,907 MBtu) | $112,000 | $112,700 | $224,700 | $ 4,500 |
| Salt Gradient Pond at $10/Ton For Salt | 3552 $m^2$ (38,220 $ft^2$) | $3.06 \times 10^{12}$ J (2,907 MBtu) | $ 94,000 | $112,700 | $206,700 | $ 3,700 |
| Salt Gradient Pond at $0/Ton For Salt | 3552 $m^2$ (38,220 $ft^2$) | $3.06 \times 10^{12}$ J (2,907 MBtu) | $ 76,000 | $112,700 | $188,700 | $ 3,500 |

[a]Includes materials and labor for installation of auxiliary equipment items, such as heat exchangers, plus 60% of direct field costs for indirects, contingency, and fee.

systems (total capital cost divided by annual energy delivered) is approximately $165 per GJ/yr ($173/MBtu/yr). The capital capacity costs of solar pond IPH systems vary between $74 per GJ/yr for expensive salt and $60 per GJ/yr for free salt ($77/MBtu/yr to $62/MBtu/yr). However, approximately twice as much land area is required for the pond as for the conventional trough collectors to deliver the same annual energy.

Installation of a retrofit solar IPH system (no storage is assumed for these systems and full conventional backup is available) is a "service" investment whose costs are offset by savings accrued from reduced fuel consumption. To compare the economic viability of the parabolic trough with the solar pond, a rate of return calculation was performed for each application using the method identified in Dickinson [10].

Equity financing was assumed, with a 20-yr service life, 7-yr depreciation, 50% tax rate, and 20% investment tax credit. No salvage value was taken. Therefore, a multiplier may be determined for various rates of return and the levelized cost of solar energy plotted against rate of return. On the same graph, the levelized cost of the fuel displaced may be plotted for various discount rates. The rate of return from the given project is then found at the intersection of the two curves. Figure 1 shows the rate of return calculation for the metal can washing application and the calculation for the commercial laundry. Two levelized fuel prices are assumed in each case: (1) current quoted price of fuel with an 8% rate of escalation and (2) fuel price of $5.00/GJ ($5.27/MBtu) escalating at 10% per annum. An efficiency of conversion to delivered heat of 85% in metal can washing and 75% in the laundry is assumed.

As can be seen in the charts, installation of any sort of solar IPH system in either application does not offer adequate return on investment when compared to costs of natural gas and a fuel price escalation rate of 8%. However, when compared to natural gas at $5.00/GJ escalating at 10%, the solar pond

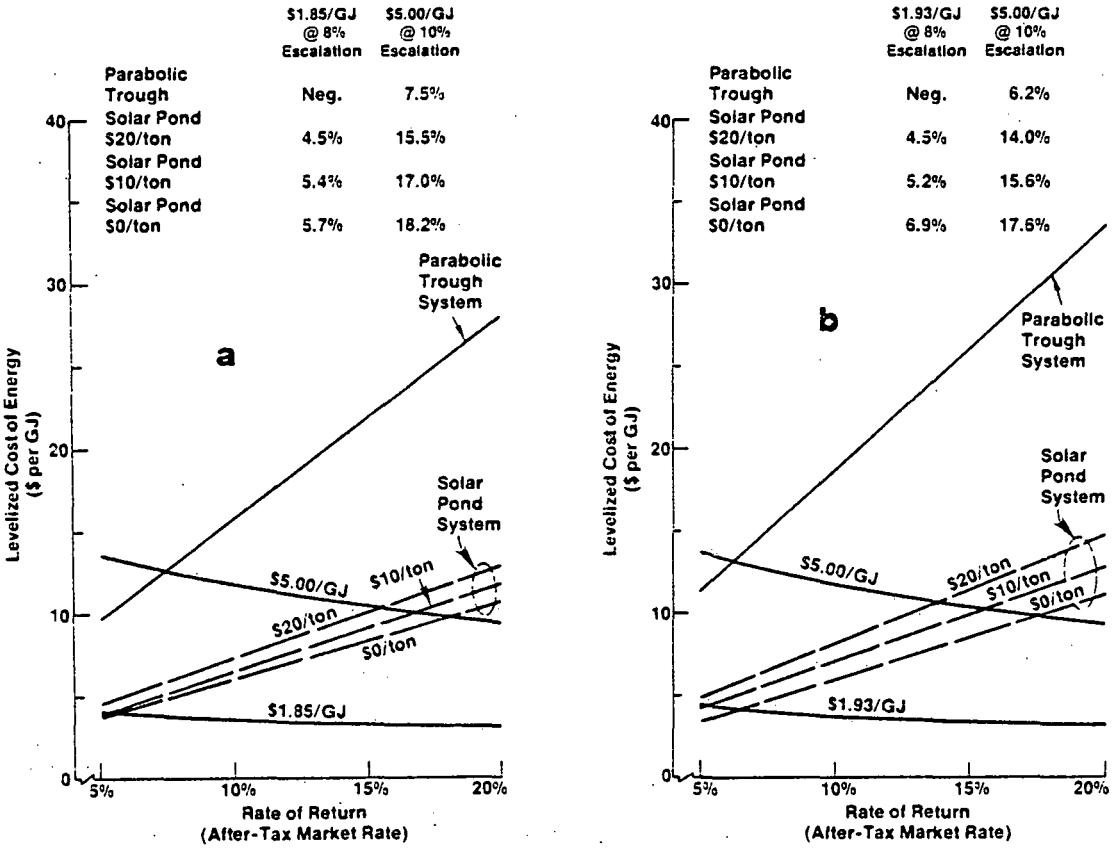


**Figure 1.** EXAMPLE OF A RATE-OF-RETURN CALCULATION FOR (a) A METAL CAN WASHING PROCESS AND (b) A COMMERCIAL LAUNDRY PROCESS

systems usually provide a rate of return in excess of 15%, which is generally sufficient to warrant commitment of funds in general service investments. The alternative conventional parabolic trough systems offer less than half of this rate for the same fuel price scenario. Hence, solar ponds justify serious consideration as economic alternatives for low temperature IPH. In addition, it appears that the return from solar pond systems is not highly sensitive to salt cost.

## CONCLUSIONS

In conclusion, salt gradient solar ponds achieve economic viability as a fuel saver in IPH applications when fossil fuel prices are $5/GJ and are expected to increase 10% per annum. Although the cost of salt for ponds varies widely with location, it does not appear to affect overwhelmingly the pond's economic feasibility. Solar ponds are useful as preheaters for intermediate and high temperature IPH applications as well as for low temperature applications. They are often more economically used as preheaters even when the end use temperature is so low that a large solar pond alone could suffice. For the applications studied in this paper, solar ponds appear to be far more cost effective than any other solar IPH technology. Their economic attractiveness, as well as their simplicity, should make solar ponds a subject

for increasing study and experimentation in IPH applications.

## ACKNOWLEDGEMENTS

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