Scope of fertiliser solar ponds in Indian agriculture

G.R. Ramakrishna Murthy *, K.P. Pandey

Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur 721302, India

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Abstract

Fertiliser salts are considered in the place of sodium chloride for operating solar ponds. A study was conducted to identify the potentially viable candidate fertiliser salts for Indian conditions. Muriate of potash, a potassic fertiliser, is found to have properties comparable to that of sodium chloride, and can generate energy at cheaper cost than urea. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

The rapid decline of fossil fuels is increasingly emphasising the need to explore nonconventional energy sources to mitigate the impending energy crisis. The necessity to switch over to renewable energy sources assumes still more importance in developing countries like India, where a great deal of foreign exchequer is incurred in importing the conventional fuels. In India, the power demand is likely to grow at the rate of 4 per annum, over the next 15 years, tantamounting to 10,000 MW additional capacity every year. The energy shortage of 14% and a peak power demand deficit of 28% are expected in the rural sector by the year 1997 [2].

Solar energy is one of the most viable propositions to meet the challenge of growing power demand and to combat the problem of dependence on conventional fuels. The annual solar energy incident in India, with an average daily incident solar radiation of $18 \times 10^6$ J m$^{-2}$ and 250–300 sunny days in an year [2], is about 20,000 times the current electrical energy consumption [26]. This suggests that there is a vast potential for solar energy systems. However the solar energy systems have not become popular because of lack of energy storage. Since the energy needs to be utilised when there is sunshine, often the energy demand does not synchronise with the period of energy availability. Furthermore, the utility of solar energy systems can be improved only
when storage facilities are incorporated so that the energy needs during lean periods of sunshine like nights and cloudy days can be met. This underlines the need for energy storage devices/techniques in solar energy.

The solar pond, essentially a large area solar collector, can provide cheap means of collection and storage of energy. Hull [11] opined that solar ponds are especially appropriate for agricultural applications. A study was conducted in a solar pond 1000 m² in size with a simulation of grain drying. Apart from grain drying, solar ponds appear to be ideal for meeting many of low temperature agricultural needs like greenhouse heating, animal shelter heating, process heating [8] and other variety of purposes like generation of electricity, industrial process heating, and desalination [9].

2. Significance of alternate salts in solar ponds

Solar ponds, though represented in different forms like the salt gradient solar pond, solar gel pond and saltless solar pond are generally based on the principle of reducing heat losses by suppressing the convection at the top of the pond. The salt gradient solar pond is a body of saline water in which the concentration increases with depth, from a very low value at the surface to near saturation at the bottom. The stratification of concentration is achieved by dissolving a salt at different salinity levels. Sodium chloride is the salt most widely used to achieve the stratification in a solar pond because it is cheap and extensively available. However, there is a need to switch over to a suitable alternative salt in place of sodium chloride for the following reasons:

1. There is a growing environmental concern related to sodium chloride [10] as it poses problems affecting the groundwater table in the event of a liner leak, as experienced with a solar pond at Hunsur, India [25]. If similar problems occur with fertiliser salts, the loss can be minimised. With a fertiliser salt, the problem is economically manageable because the entire fertiliser is recycled to the farm use in the event of a liner leak [10].
2. Since sodium chloride salt has no alternative use after being used in a solar pond, the disposal of the salt diffused into top layers is difficult. Furthermore, ponds using sodium chloride salt necessitate the construction of an evaporation pond almost equal in size to the solar pond for the recovery of the salt diffused to the top zone of the pond. This renders the system uneconomical [24].
3. Since the solar pond meets the low temperature needs of agricultural processes, the salt should be friendly to the agricultural environment and of use to the agricultural processes after its utilisation in the solar pond. Some of the agricultural processes that have the suitability of using the solar pond heat in direct form are:
   - Soaking of paddy in hot water at a temperature of 90°C for 2–3 h prior to steaming in the paddy parboiling process.
   - Blanching of vegetables in steam to make them germ free and for stabilising colour.
   - Sugarcane sett treatment in hot water at a temperature of 55°C for 2 h for removal of plant pathogens before planting in the main field.
   - Direct consumption of hot water at 40–50°C for domestic purposes.
4. Solar ponds are widely acclaimed as appropriate energy sources for agricultural regions because
of land availability and frequent requirement for low temperature process heat in agricultural applications.

The utility would further be enhanced if the salt has an addition value for the farm. In this context, the fertilisers play an important role, not only being used as a crop nutrient but also as a medium for storing the solar energy in the solar pond. Thus, it is necessary to search for a suitable alternate salt that has the dual advantages of meeting certain criteria such as brine transparency and suitable salinity–density properties as required by a solar pond and of further benefit to agriculture.

3. Established application of solar ponds for agriculture and other operations

3.1. Greenhouse heating

Sokolov and Arbel [22] demonstrated the use of a fresh water solar pond for greenhouse heating purposes. The pond consisted of an excavated area in the earth with a liner and a thin top cover. The water was used as a heat transferring fluid during periods of solar radiation. Energy was delivered to the greenhouse by pumping hot water from the upper layer of the pond through a heat exchanger. The water returned after heat extraction to the bottom of the solar pond. In another study, Arbel and Sokolov [4] studied collector materials with different material properties and concluded that the use of an appropriate material improves the solar pond performance.

Riva [20] studied a 20 m² solar pond for two years before constructing a bigger pond 140–160 m² in area. The energy efficiency was found to be 10–20% during preliminary testing. The energy was intended for air heating in a dryer 40–50 m² in area.

3.2. Process heat in dairy plants

The hot water requirements for sterilisation and pasteurisation in a dairy plant at Bhuj in Kutch district of Gujarat State, India are being met by a solar pond 6000 m² in area [7]. The hot water temperature was in the range of 84–95°C during the pond’s operational period [18].

3.3. Desalination

Desalination involves the process of obtaining fresh water for drinking and irrigation from either brackish or saline water after suitable treatment [17]. A solar pond multi-effect distillation system consists of a set of evaporative condensers and heat exchangers extracting heat from the solar pond. The fresh water is produced through repetitive cycles of evaporation and condensation, using heat at low temperature from the solar ponds.

Tabor [27] showed that a pond 1/3 km² in area could operate a multi-effect distillation unit with an annual mean output of 4000 m³/day at a rate of US $ 0.67/m³. He further remarked that a solar pond desalination plant produces about five times the quantity produced by a simple tray type solar still. A 20,000 m² solar pond in Italy was used for desalination of seawater to produce 120 tonnes of fresh water/day [26].
3.4. Power production

Some of the major solar pond power plants are listed in Table 1. In these plants, the solution from the lower convective zone is pumped to a heat exchanger that acts as evaporator for an organic Rankine cycle. Trieb et al. [28] made a comparative analysis of different solar electricity generation options and found that the solar pond could produce electricity at a cost of 0.254 German Marks (DM)/kWh in comparison to 1.198 German Marks (DM)/kWh for photovoltaic cells.

4. Scope of hot water applications in agriculture

Many of the agricultural operations involve hot water application for different purposes. Some of them include paddy soaking in parboiling, sugarcane sett treatment, vegetable blanching, washing of cans in the dairy industry and domestic hot water consumption.

Traditionally, the parboiling process involves the soaking of rough rice in water at ambient temperature in masonry tanks for 3 days and then steaming of the drained paddy. The method was later improved to soak the paddy in hot water at around 70°C for few hours depending upon the type of parboiling method. This method could eliminate unwanted odours associated with the traditional method and reduce the soaking time from a few days to a few hours [6].

Heat therapy of sugarcane setts before planting is desirable to raise the crop free from seed piece diseases and certain insect pests. Conventionally, the setts are treated in hot water at a temperature of 50°C for 2 h and at 54°C for 4 h in humid hot air [21].

5. Potential of fertilisers as candidate salts in solar ponds

Hull [12] was the first to propose a new idea for using a fertiliser salt in a solar pond, in combination with farm applications, in order to combat environmental concerns. Hull [11] put forth an approach envisaging an integrated solar pond and agricultural field, in which the fertiliser requirement of part of the farm is met by the surface runoff from normal operation and the whole fertiliser inventory is pumped to the field in case of emergence. This augurs well with the current trend of fertiliser application methods where application of liquid fertilisers is very much emphasised as in the case of fertigation through drip irrigation systems. Hull [13] developed a solar

<table>
<thead>
<tr>
<th>Name/site</th>
<th>Power (kW)</th>
<th>Pond area (m²)</th>
<th>Operation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ein Boqek, Israel</td>
<td>150</td>
<td>6250</td>
<td>1979–1986</td>
</tr>
<tr>
<td>Beith Ha’Arava, Israel</td>
<td>5000</td>
<td>250,000</td>
<td>1984–1989</td>
</tr>
<tr>
<td>Alice Springs, Australia</td>
<td>15</td>
<td>1600</td>
<td>1985–1989</td>
</tr>
<tr>
<td>El Paso, United States</td>
<td>70 (electricity)</td>
<td>3350</td>
<td>1986–till date</td>
</tr>
<tr>
<td></td>
<td>330 (process heat)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
pond using a fertiliser grade ammonium sulphate salt in a small cylindrical tank and demonstrated its capability to generate concentration and temperature gradients. It was estimated that for a region receiving an yearly average insolation of 150 W/m², a well-managed 4000 m² solar pond at a favourable location provides \(4 \times 10^{12} \text{ J/yr}\) which can dry up to 10,000 m³ of corn. The idea was further supported by Srinarayan [23] who could evolve an ammonium sulphate solar pond in a small plexi glass tank under real conditions.

Pawar and Chapgaon [19] established a solar pond with urea, a nitrogenous fertiliser used in Indian agriculture. It was estimated that by recycling the runoff into the fertiliser cycle of an agricultural system, the cost of solar pond heat was Rs 1.10/kWh which is substantially less than Rs 2.51/kWh for flat plate collectors. In another study, an analysis of cost of electricity generation using different solar options revealed that solar pond-generated-electricity cost only 14.11 cents/kWh as compared to 66.55 cents/kWh with photovoltaics [28].

Carnalite (KCl·MgCl₂·6H₂O), a chief by product of Arab Potash Company situated in Jordan, was found to have heat storage capability experimentally. Banat et al. [5] evolved a stable salt and temperature gradients with this salt. Jubran et al. [16] in another experiment studied the effect of climatic conditions on the performance of a Carnalite solar pond. The plastic rings used as wind suppressers on top of the pond could improve the temperature along the depth of the solar pond by about 5°C as compared to that of a pond having no wind protection. The rainfall was found to have no effect on gradient stability of the carnalite solar pond having a total depth of 1 m. Doria et al. [8] could develop solar ponds using raw materials required for the production of fertilisers and used the heat gained from the solar ponds for obtaining sodium nitrate from caliche and potassium chloride from silvinita. They concluded that silvinita could be a suitable material to evolve a stable solar pond.

The above discussion suggests that there is a need to adopt a new approach to make solar pond technology popular among the farming community for whom the utility of solar ponds is more pertinent. This assumes furthermore relevance to India, where 70% of the population lives in rural areas with agriculture as the prime occupation. As many as 80,000 villages have not yet been electrified. It is important to meet the energy requirements of this important sector of the Indian economy contributing about 60% to the gross national product.

6. Selection of candidate fertiliser salts

The suitable fertiliser salt for a solar pond used in an agricultural system shall have the following criteria:

1. easy availability of fertiliser salt in the market;
2. good solubility characteristics to achieve higher density gradient with less salt;
3. good brine transparency;
4. ease of maintenance without problems like algae growth and outgassing.

Thus it is essential to study the fertiliser scenario in India and identify appropriate candidate salt(s) for use in solar ponds. Fig. 1 [3] shows the fertiliser consumption pattern in Indian agriculture. Fertilisers are used as single nutrients and as complex forms supplying two or more nutrients.
The annual fertiliser consumption in the Indian farm sector is 28.2 mtonnes of which nitrogenous fertilisers constitute 64.5% followed by 21.5% of complex fertilisers, 9% of phosphatic and 5% of potassic fertilisers. Based on the extent of consumption, it is clear that urea (17067.6×10³ tonnes) among the nitrogenous fertilisers, single super phosphate (2656.6×10³ tonnes) among the phosphatic fertilisers, muriate of potash (MOP) among the potassic fertilisers (1188.3×10³ tonnes) and di ammonium phosphate (3589.6×10³ tonnes) in the complex fertiliser category constitute major fertilisers being used in India.

Selection of fertiliser salt for use in solar ponds among these will be of relevance to Indian agriculture. However, with regard to applicability of these fertilisers in solar ponds, Hull [12] opined that the fertilisers supplying nitrogen and phosphorus abet the algae and other organisms, which affect the transmissivity of the pond. This eliminates the possibility of using di ammonium phosphate in solar ponds. Single super phosphate is also unsuitable for use in solar ponds because of poor brine transparency. Thus urea among the nitrogenous group and MOP among the potassic group can be considered appropriate for use in solar ponds.

7. Results

The salinity–density characteristics of the finally identified fertiliser salts were shown in Fig. 2. To obtain the solubility characteristics known amounts of fertilisers were dissolved in 100 cc³ of water and the resultant density was found out using the pycnometer and weighing balance. The solubility process was continued till the saturation point with each salt. However the saturation could not be achieved with urea even at higher dissolution. Urea displays greater ease for dissolution in water but the density increases at a lesser rate with salinity as compared to sodium chloride, MOP and ammonium sulphate. Sodium chloride and MOP reach saturation at 25 and
35% of salinity, respectively. This strongly suggests the suitability of MOP as the candidate fertiliser salt for solar ponds. Urea, though it has higher solubility which is quite essential for use in solar ponds, cannot be concluded to be better than MOP because, it requires higher salt to obtain the same density as MOP does. Higher salt inventory means increase in installation cost, rendering it economically nonviable for a solar pond.

Apart from solubility, the characteristics like diffusion coefficient and thermal conductivity are the other factors that influence the performance of solar ponds. Fig. 3 shows a comparison among salts with regard to these properties [15]. There is greater similarity in the properties for MOP and sodium chloride. Though the diffusion coefficient of urea is more than that of MOP which means higher and quicker salt transport to the top of the pond, the other merits with MOP are that it develops higher density for the same salinity and the has lower thermal conductivity which means lesser heat conduction losses to the top. Since it is already well established that sodium chloride is suitable for solar ponds, MOP also can be projected as the candidate salt for solar ponds because of its similarity in salinity–density property.
Table 2 shows the projected estimate of performance for comparison among fertiliser salts viz., MOP with sodium chloride. The estimate was based on a few assumptions that the thermal performance of solar ponds is the same in all cases. They differ in only the amount of salt required to maintain the desired density gradient. The cost of MOP is charged only for its period of retention in ponds [10,19]. It is clear from the table that the cost of unit energy (Rupees per kWh) is the least for MOP as compared to sodium chloride. MOP apart from generating energy at

Table 2
Comparative cost estimate

<table>
<thead>
<tr>
<th>Item</th>
<th>MOP</th>
<th>Sodium chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of the salt, Rupees (Rs)*/kg</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>Total salt requirement (kg)</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Initial cost of the salt (Rs)</td>
<td>1200</td>
<td>450</td>
</tr>
<tr>
<td><strong>Annual cost estimates (per m²)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fixed costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost of the salt (Rs)</td>
<td>392.43</td>
<td>1185.81</td>
</tr>
<tr>
<td>Cost of installation (Rs)</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>1192.43</td>
<td>1985.81</td>
</tr>
<tr>
<td><strong>Running costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation and maintenance cost (Rs)</td>
<td>119.24</td>
<td>198.58</td>
</tr>
<tr>
<td>Cost of leasing land (Rs)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Total running cost (Rs)</td>
<td>119.74</td>
<td>198.58</td>
</tr>
<tr>
<td><strong>Annual operating cost using CRF (Rs)</strong></td>
<td>227.08</td>
<td>377.80</td>
</tr>
<tr>
<td>Total power output of solar pond (kWh)</td>
<td>270.6</td>
<td>270.6</td>
</tr>
<tr>
<td><strong>Unit cost of energy (Rs/kWh)</strong></td>
<td>0.84</td>
<td>1.39</td>
</tr>
</tbody>
</table>

(* one US $=46.4 Rupees)
lower cost, also produces fertiliser solution (as a saline top layer) which can be recycled into the cropping system.

8. Conclusions

- The study of fertiliser consumption pattern in India identifies MOP and urea as the potential salts for solar ponds.
- MOP, because of properties similar to that of sodium chloride has the capability to provide energy at a cheaper price and fertiliser to the crops. The future studies shall have to be conducted using this salt rigorously under simulated and prototype conditions before it is introduced on a large scale in solar ponds.

Acknowledgements

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References

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