SOLAR POND TECHNOLOGY

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Abstract: Had you ever thought of storing the solar thermal power without any expensive solar storage devices? .Can't we generate solar thermal energy in the form of low grade heat of 70-80.c with 20.c ambient temp .Yes this paper suggests a solution of storing the solar energy only by constructing a simple pool of salt water ,isn't it amazing?. Thus a solar pond is a pool of salt water which serves as the solar energy collection and sensible heat storage.

The solar ponds made a tremendous progress in the last thirty years . This paper also mainly reviews the basic principles of the solar pond and the problems encountered in its operation and its maintenance. Here we also discuss the factors that enhance the heat storing capacities and also the factors that influence the technical and the economical viability of the solar ponds.

Keywords: solar ponds, solar energy collection, renewable energy, solar energy storage, economical viability.

INTRODUCTION:

Energy is an important input in all sectors of any country's economic growth**.** The standard of living of a given country can be directly related to per capita energy consumption.

Due to the rapid increase in population and standard of living of human beings, there is problem of energy crisis. The supply of oil will fail to meet the increasing population demand. Hence an alternative energy source had to be chosen to meet the future energy demands.

Currently a number of alternative energy sources and the method of abstracting the energy had been discovered .Among the most widely distributed and clean renewable energy resources ,the solar energy is one of the effective solution to environment pollution and fossil fuel shortage. Solar energy is an abundant and renewable energy source. The annular solar energy incident on the ground in India is about 20,000 times the current electrical energy consumption. Hence a very little amount of solar energy is sufficient to meet the major energy demands , particularly in the tropical lands. But the use of solar energy has been very limited. This is because Solar energy is the time dependent and intermittent energy resource. And also mainly solar energy is the diurnal energy resource. Hence the main challenge laying here is storing the solar energy to meet the energy needs. Hence energies must be collected in large areas with high initial investment .These solar energy storing systems must take care of collecting solar energy at cloud day and during winter times .They should posses the efficacy of storing energy at night times in Oder to supply the energy when required in uniform manner. This may result in further increase in total capital cost of building such systems. One among the best ways to overcome this problem is to use large body of water for collecting and storage of solar energy. This concept is called SOLAR POND.

PRICIPLE OF OPERATION AND DECRIPTION OF A SOLAR POND:

A solar pond is a mass of shallow water about 1 or 2 metres deep with a large collection area ,which acts as a heat trap. It contains dissolved salts to generate a stable density gradient . Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water , the lower layers would heat up, expand and rise to the surface. Because of the relatively low conductivity ,the water acts as an insulator and permits high temperature (over 90°C) to develop in the bottom layers . At the bottom of the pond , a thick durable plastic layers liner is laid. Materials used for liners include butyl rubber, black polyethylene and hypalon reinforced with nylon mesh. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water , the concentration varying from 20 to 30 percent at the bottom to almost zero at the top.

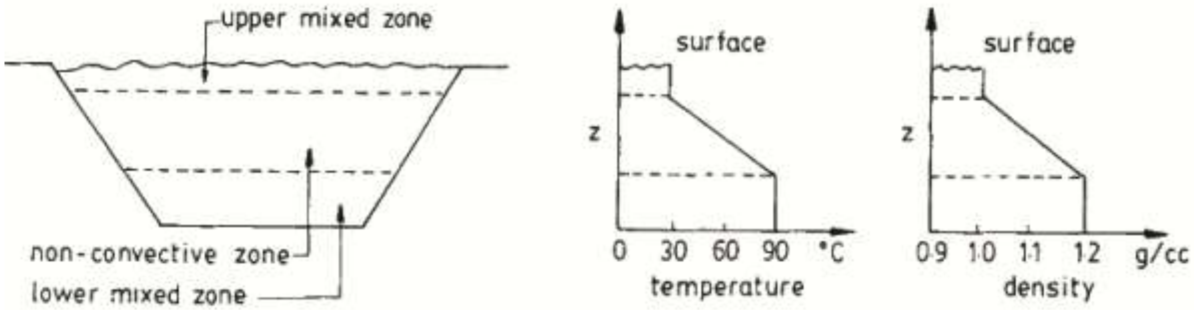

Figure 1. Different zones in a solar pond.

. In the salt-gradient ponds , dissolved salt is used to create layers of water with different densities-the more salt, the denser water .Thus a solar pond has three zones with the following salinity with depth :

1) surface convective zone (0.3-0.5m),with salinity<5% concentration

2)Non-convective zone(1-1.5m , salinity inc with depth

3)storage zone (1.5-2m , salt=20%)

The Non-convective zone is much thicker and occupies more than half the depth of the pond. Both the concentration and the temp increase with the depth in it. It mainly serve as a insulating layer and reduces the heat transfer. A some part of this zone also acts as thermal storage. The lower zone is the storage zone. Both the concentration and temp are constant in this zone. It is the main thermal storage medium. The deeper the zone. The more is the heat stored. The lowest zone traps heat energy for longer periods. The capacity to store heat for long periods is the chief advantage of solar ponds. Even in the cloudy days and in the ice covered regions the energy can be stored , since the salt water near the bottom heats up and expands. However it cannot rise to the because it is denser than the less salty water above. Hence a non convective solar pond is best utilized for storing the solar energy at a reasonable cost.

Performance analysis:

Extraction of thermal energy in the lower layers of the pond can be easily accomplished without disturbing the non-convicting salt gradient zone above. Hot water can be extracted from a solar pond without disturbing the concentration gradient. This is achieved by installing the water outlet at the same height as the water inlet. Hot brine can be withdrawn and cold brine returned in a laminar flow. Pattern because of presence of density gradient. For small or model ponds because of presence of density gradient ,heat exchangers consisting of pipes can be placed in hot lower layers ,but this entails not only the initial installation cost but the continued pumping loses associated with the heat transfer fluid.

The solar pond is separated into three zones for thermodynamic analysis.

The thermal(energy)efficiency :

a)upper convective zone (UCZ) can be expressed as

$$\eta = Qnet / Qin$$

$$Qnet = Qin - Qout = (Qsolar + Qdown) - (Qwa + Qside)$$

Where

Qnet = net heat stored in UCZ

Qsolar = net incident solar radiation absorbed by the UCZ

Qdown = total heat transmitted to the zone from the zone beneath it

Qside = heat loss to the side walls of the pond

Qwa = heat loss to the surroundings from the upper layer

$$\eta ucz = 1 - \frac{(Qwa + Qside)}{(Qsolar + Qdown)}$$

$$Qwa = UwaAucz(Tucz - Tamb)$$

$$Qside = (UsideAside(Tucz - Tside)$$

$$Qdown = \frac{\bar{K}}{X1} Aucz\,(Tdown - Tucz)$$

Where K = thermal conductivity; X1 = thickness of the first layer

$$Qsolar = \beta Aucz\ h1$$

Where

h1 = ratio of energy reaching layer 1 to solar radiation incident on the pond surface

A = area of the pond

ß= incident beam rate entering into the water.

b) The thermal (energy) efficiency for non convective zone (NCZ)

$$Qnet = Qin - Qout = (Qsolar + Qdown) - (Qwa + Qside)$$

$$\eta NCZ = 1 - \frac{(Qwa + Qside)}{(Qsolar + Qdown)}$$

$$Qwa = UwaANCZ\,(TNCZ - Tamb)$$

$$Qside = (UsideAside(TNCZ - Tside)$$

$$Qdown = \frac{K}{X1} ANCZ\,(Tdown - Tncz)$$

K = thermal conductivity; X1 = thickness of the first layer

$$Qsolar = \beta A\ NCZ\ h1$$

Where

h_1 = ratio of energy reaching layer 1 to solar radiation incident on the pond surface

A = area of the pond

ß= incident beam rate entering into the water.

c) The thermal (energy) efficiency for lower convective zone (LCZ)

Qnet= Qin-Qout = (Qsolar + Qdown) -(Qwa+ Qside)

$$\eta LCZ = 1 - \frac{(Qwa + Qside)}{(Qsolar + Qdown)}$$

Qwa = UwaALCZ (TLCZ -Tamb)

Qside = (UsideAside(TLCZ-Tside)

$$Qdown = \frac{K}{X1} ALCZ\ (Tdown - TLCZ)$$

K = thermal conductivity; X1 = thickness of the first layer

Qsolar = ßA LCZh1

Where

h1 = ratio of energy reaching layer 1 to solar radiation incident on the pond

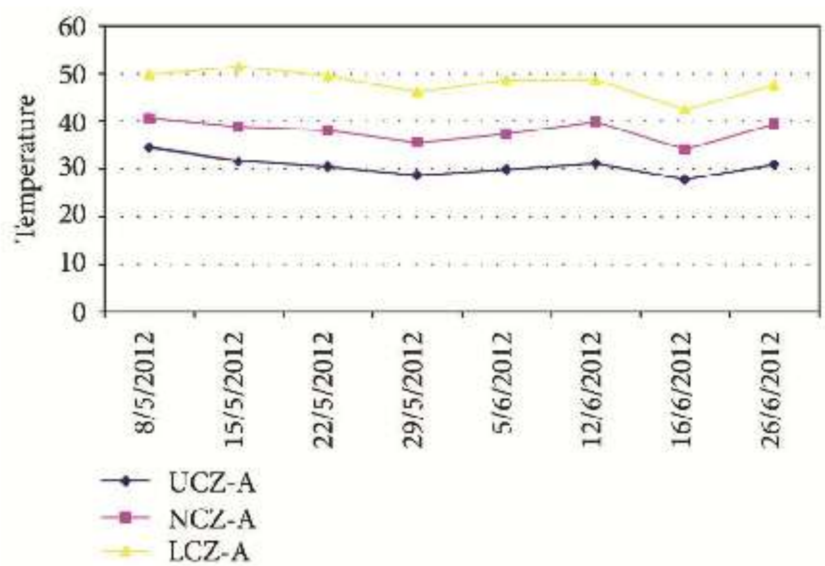

Figure : 3 graph between temperature and duration of time.

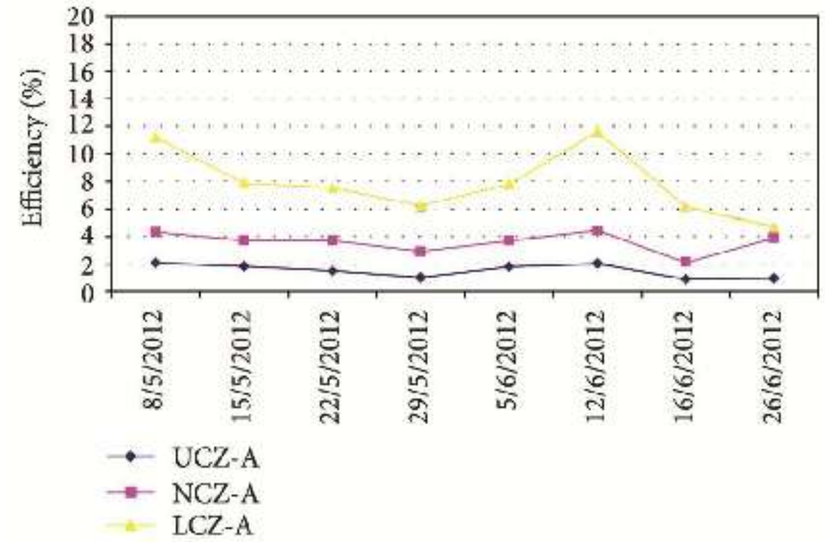

Figure 4; the efficiency graph of a solar pond

The experimental efficiencies values of NCZ are 59% and 44% respectively .Because of lower heat losses in this layer , it has a higher efficiency than UCZ layer

The experimental efficiency values of the LCZ are 52 and 26 respectively. Because most of the energy is stored in this zone, it has higher efficiency than the other two layers

POND CONSTRUCTION

The site is selected for the construction of solar pond should have the following attributes***:***

(a) be close to the point where thermal energy from the pond will be utilized;

(b) be close to a source of water for flushing the surface mixed layer of the pond;

(c)the thermal conductivity of the soil should not be to high;

(d)The water table should not be too close to the surface.

For constructing a non convective solar ponds an insulated and double-glazed covered salt gradient solar pond having a surface area 1.6 m × 1.6 m and a depth of 1 m has been fabricated. The LCZ IS 0.5 m high from the bottom of the pond with high-density brine. Approximately 0.1 m of fresh water on the top makes the UCZ containing light density brine , above which there is gradually decreasing density brine. This region performs the insulation , that is , keeps the stored energy in the bottom zone ,called NCZ. This zone has a height of 0.3 m . the total thickness of the side walls in which a glass wool is used for insulation is 8 c.m.The energy obtained from this system can be stored below the boiling point of brine . under the bottom of the pond a concrete with blocking with filling gravel of 0.12 thickness is fixed . The inner surface which is made by A*l*, is blackened to absorb and store the maximum sun's energy . The bottom surface area is 1.2 m× 1.2m and expanded to an exposed surface area to collect the heat energy in a large amount .The side walls of both the models were exposed at an angle of 110° from the bottom surface .The total thickness of top glazing is 1.4 cm with gap space of 1 cm.The source of water supplying in solar pond is a tank of 300-liter capacity placed at height of 5m from the bottom surface level of the pond. A galvanized iron pipe (DIA – 2M ,L=6M) is directly connected to the bottom of the pond. Below different types of salts ,and the extracted thermal and electrical power are given. Salts like sodium chloride ,magnesium chloride and sodium carbonate are considered and the power extracted from the theses sources are encompassed in the below table. Also the amount of flow rate maintained with different pond area are explicated

Salt Type	Solar pond area (m^2)	Flow rate Cm^3/min	Thermal power M.Wt	Electrical power MWe
Sodium chloride (NaCl)	1811151	$13.6 X 10^5$	400	10
	149	$11 X 10^6$	320	8
	906	$6.9 X 10^6$	200	5
Magnesium chloride ($MgCl_2$)	1811151	$41.3 X 10^5$	400	10
	149	$33.1 X 10^5$	320	8
	906	$20.6 X 10^5$	200	5
Sodiumbicarbonate $NaHCo_3$	1811151	$21.6 X 10^5$	400	10
	149	$17.2 X 10^5$	320	8
	906	$10.7 X 10^5$	200	5

An estimate of the area required for solar pond to minimize heat losses and liner costs ,the pond should be circular. since a circular pond is difficult to construct ,a square pond is normally preferred. In some cases such as the Bangalore solar pond ,the site constrains may force to construct a rectangular pond with large aspect ratio. For large solar ponds the shape will not have a strong influence on cost or heat losses. The depth of the solar pond must be determined depending on specific application. The usual difference of the surface gradient and storage zone of the pond are 0.5,1 and 1m respectively. If a particular site has low winds , one can reduce the thickness of surface layer to 30 cm. If the temperature required for the process for the heat applications is around 40°c then the thickness of the gradient zone can be reduced to 0.5m.Storage zone thickness higher than 1m may be required to take care of long periods of cloudiness.

SALT REPLENISHMENT

On account of the gradient of concentration between the storage and the surface zones , there is a diffusion of salt through the gradient zone. The transport of salt through the gradient zone by diffusion can be expressed as

Qm=[(Sr-Su)D]/b, (1)

Where b=thickness of gradient zone ,D=mass diffusion coefficient , and St ,SU=salinity in lower and upper mixed layers ,respectively.

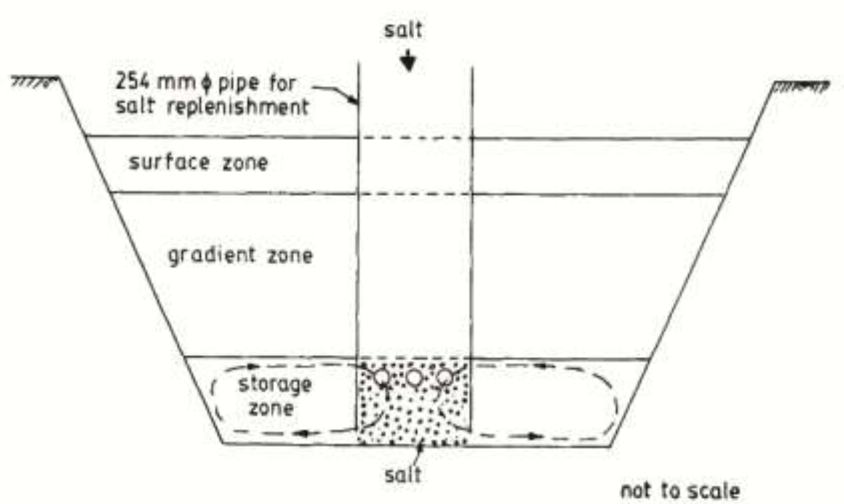

Figure 11. Passive salt replenishment.

If the salinity in the storage zone is 300 kg/cubic metre and In the surface zone is 20kg/cubic m, gradient zone thickness is 1m and diffusion coefficient of salt is 3*10-9 sqm/sec. then the rate of transport of salt by diffusion will be about 30kg/sqm year .In small polar ponds the salt transport can be as high as60 kg/sqm year because of additional salt transport through side wall heating.

If the salt lost from the storage zone is not replenished regularly then there may be an erosion of gradient zone from below or formation of internal convective zones .The normal method of salt replenishment is by pumping the brine in the storage zone through a salt bed; It was shown that for small solar ponds a passive salt replenishment technique is adequate .In the Banglore solar pond about 100 kg of salt is added daily through a chute into the storage zone. The salt that was added dissolved within a day.

ALGAE CONTROL

The thermal efficiency of a solar pond is strongly dependent upon the clarity of the pond which is reduced by the presence of algae or dust. Bits of debris, dust or leaves lighter than water float on the surface and can be skimmed off. Dust and debris much lighter than water will sink to the bottom .The dust accumulated at the bottom of the pond does not adversely affect the absorption of solar radiation at the bottom of the pond. The dust floating in the gradient zone can be settled by adding alum. The growth of algae can be controlled by adding bleaching powder or copper sulphate .If the water used in the pond is alkaline, copper sulphate will not dissolve. Hull(1990)has proved detailed account of the relative merits of various methods of algae control.

ECONOMICS

Solar energy conversion devices have not found widespread application because they require high initial capital investment. The cost of solar pond is much less than that of the conventional flat plate collectors. The cost of solar pond is however, strongly dependent upon site specific factors such as local cost of excavation and salt. The thermal performance of solar pond is also dependent on the site specific factors such as solar irradiation, ground thermal conductivity and water table depth. Hence there is bound to be large variation in the cost of thermal energy produced by solar ponds at different sites.

Considering detailed analysis of the various components of a cost of a solar pond. If the cost of salt and its recycling is excluded , estimated the cost of large solar pond(area>100,000sqm) to be around US $10/sq m(in 1986) and that of small solar pond (area around 100sqm) to be around US $50/sqm.If the cost of salt is $40/tonne the cost of large and small solar ponds are around $45/sqm and $85/sqm respectively. In the estimates, the cost of salt represents 50% of total cost of small solar ponds and more than 75% of total cost of large polar ponds be located close to sites where salt is available at low cost .In India small solar ponds can be constructed at a cost of Rs200 to Rs400/sqm. The following is breakdown of the cost of the solar pond per square metre

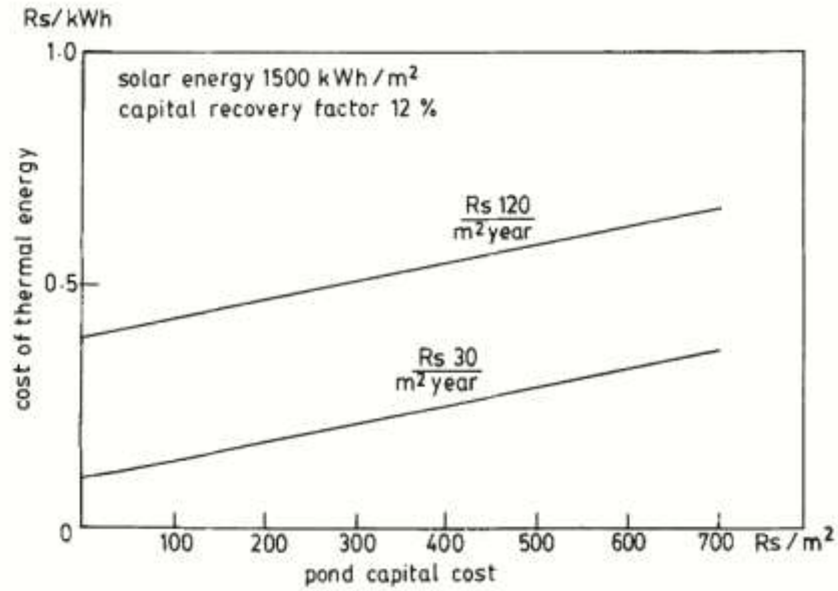

Figure 12. Cost of thermal energy as a function of pond capital cost.

$$C\dot{p}=2.546(C1+C2)+0.675C3+1.3C4+0.456C5+0.0415C6+0.124C_7+0.021C8+0.085C9+C10 \quad (8.1)$$

Where C1= excavation charges, Rs /cubic m ;C2=water charges, Rs/cubic m ;C3=salt cost Rs/tonne;C4=liner cost Rs /sqm;C5=clay,Rs/tonne;C_6=cost of bricks, Rs/1000 bricks; C7= cost of cement, Rs/bag ;C8=cost of sand ,Rs/cubic m ;C9=cost of brick lining, Rs/cubic m;C10=cost of wave suppresser, Rs/ sqm.

The net present value method to estimate the cost of thermal and electrical energy from solar ponds can be estimated as

$$Cth=[CRF*C\dot{p}+Cm]/np*\ Si \quad (8.2)$$

Rs/sqm;Cm=maintainance cost of solar pond,Rs/sqm;np=Thermal efficiency of solar pond,Si=average incident solar energy ,k wh / sqm year.

The variation of the cost of thermal energy from the pond for various values of the capital cost of the pond and the maintenance cost of the pond is shown in above figure.We find that solar ponds produce thermal energy at a cost lower than that obtained from burning fossil fuels or electricity. The estimated the cost of electricity obtained from a solar pond as follows:

$$Ce=[Cr\{Cp+Cpp*Ge/N\}+Cm]/(1-f)Ge \quad (8.3)$$

Where Ce=cost of electricity,Rs/k ;Cr=capital recovery factor;Cp=cost of solar pond,Rs/sqm; Cpp= cost of Rankine cycle power plant Rs/kwhe;Ge=gross electricity generation, kwhe/sqm;N=number of hours of operation per year;Cm=maintenance cost, Rs/sqm;f=fractional parasitic losses.

If we assume that Cr=0.125,CF=Rs 140/sqm, Ge=20 k-Whe/sqm,Cpp=Rs1500/K We ,N=5000h,Cm=Rs7/sqm, and f=0.2,we obtain Ce=Rs2/k .Where we find that the cost of electricity obtained from the solar pond power plant is higher than that obtained from fossil fuel based thermal power plants but is comparable to the cost of electricity from diesel generation sets. From the above analysis we can also infer that the cost of the electricity from the solar pond power plant can be reduced to Rs1/kwh, the capital cost of the solar pond reduces to Rs12/sqm. This is impossible to achieve unless there is a natural site(such as salt lake) which requires no salt digging ,or liner .We can conclude therefore that electricity generation from the solar pond is not economically viable unless the site conditions are extremely favourable.

THE EFFECT OF RAINFALL:

Rainfall can have beneficial or detrimental effects on the operation of a solar pond. If the rainfall is not heavy, it helps to maintain the density of surface layer at low value. During the monsoon, in the Bangalore solar pond, there was no need for flushing the surface layer to maintain the density at low rate .Heavy monsoon rainfall can, however ,penetrate to the gradient zone and dilute it. The analysis of heavy rainfall episodes in Bangalore solar pond indicates that raindrops can penetrate to about 50cm from the surface. Hence it may be desirable to maintain higher surface zone thickness during the rainy season.

SOLAR POND APPLICATIONS:

1.)Heating and Cooling of Buildings: Because of the large heat storage capability in the lower convection zone of the solar pond, it has ideal use for heating even at high latitude stations and for several cloudy days.

2. Production of Power: A solar pond can be used to generate electricity by driving a thermo-electric device or an organic Rankine cycle engine - a turbine powered by evaporating an organic fluid with great promise in those areas where there is sufficient insulation and terrain, and soil conditions allow for construction and operation of large area solar ponds necessary to generate meanings quantities of electrical energy.

3.Industrial Process Heat: Industrial process heat is the thermal energy used directly in the preparation and of treatment of materials and goods manufactured by industry. Several scientists have determined the economics of solar pond for supply of process heat in industries. The heat from solar pond is highly competitive with oils and natural gas.

4. Desalination: The low cost thermal energy can used to desalt or otherwise purify water for drinking or irrigation. The multi-flash desalination plant below 100ºC which can well be achieved by a solar pond. This system will be suitable at places where portable water is in short supply and brackish water is available. It has been estimated that about 4700 m3/day distilled water can be obtained from a pond of 0.31km2 area with a multi-effort distillation unit.

5. Heating animal housing and drying crops on farms:Low grade heat can be used in many ways on farms, which have enough land for solar ponds. Sever small demonstration ponds in Ohio, Iowa and Illinois have been used to heat green houses and hogbarns.

6. Heat for biomass conversion: Site built solar could provide heat to convert biomass to alcohol or methane. While no solar ponds have been used for this purpose, it is an ideal coupling of two renewable-energy technologies.

CONCLUSIONS

Solar pond technology has made tremendous progress in the last fifteen years. An excellent monograph is now available on the science and technology of salinity gradient solar ponds (Hull et al 1989).This technology is cost effective for low temperature process heat needs of industry. The generation of electricity using solar ponds is not economically viable as yet .However , the new concerns regarding the environment and safety of nuclear power plants and nuclear wastes disposal may change the picture totally.

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