Estimation of optimum Area of solar Pond (5MW)

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Abstract:- This paper describes the design and development of solar pond having capacity to generate power up to 5 MW with its Estimation of optimum Area of solar Pond. As we know that the sun is the largest source of renewable energy and this energy is abundantly available in all parts of the earth. It is in fact one of the best alternatives to the non-renewable sources of energy. The energy obtained is in the form of low-grade heat of 70 to 80 °C compared to an assumed 29°C ambient temperature that is calculated with help of Rabl and Niselse equation. Since I have taken Gwalior as location of solar pond with **Latitude = 26°.23'(N)**, **Longitude = 78°.17´(E)** rate of radiation is

$H_g = 660 w/m^2$ (For 8 hour) And for 24 hour working

$H_g = \frac{660*8}{24}$=220 w/m^2 .

Key words- Design, Estimation, source, renewable and radiations

1. Introduction

The sun is the largest source of renewable energy and this energy is abundantly available in all parts of the earth. It is in fact one of the best alternatives to the non-renewable sources of energy.

One way to tap solar energy is through the use of solar ponds. Solar ponds are large-scale energy collectors with integral heat storage for supplying thermal energy. It can be use for various applications, such as process heating, water desalination, refrigeration, drying and power generation.

The solar pond works on a very simple principle. It is well-known that water or air is heated they become lighter and rise upward e.g. a hot air balloon. Similarly, in an ordinary pond, the sun's rays heat the water and the heated water from within the pond rises and reaches the top but loses the heat into the atmosphere. The net result is that the pond water remains at the atmospheric temperature. The solar pond restricts this tendency by dissolving salt in the bottom layer of the pond making it too heavy to rise.

A solar pond has three zones. The top zone is the surface zone, or UCZ (Upper Convective Zone), which is at atmospheric temperature and has little salt content. The bottom zone is very hot, 70°– 90° C, and is very salty. It is this zone that collects and stores solar energy in the form of heat, and is, therefore, known as the storage zone or LCZ (Lower Convective Zone). Separating these two zones is the important gradient zone or NCZ (Non-Convective Zone). Here the salt content increases as depth increases, thereby creating a salinity or density gradient. If we consider a particular layer in this zone, water of that layer cannot rise, as the layer of water above has less salt content and is, therefore, lighter. Similarly, the water from this layer cannot fall as the water layer below has a higher salt content and is, therefore, heavier. This gradient zone acts as a transparent insulator permitting sunlight to reach the bottom zone but also entrapping it there. The trapped (solar) energy is then withdrawn from the pond in the form of hot brine from the storage zone.

2. Working principle

When solar radiation strikes the pond, 30% of it is absorbed by the surface at the bottom of the pond. The temperature of the dense salt layer therefore increases. If the pond contained no salt, the bottom layer would be less dense than the top layer as the heated water expands. The less dense layer would then rise up and the layers would mix. But the salt density difference keeps the 'layers' of the solar pond separate. The denser salt water at the bottom prevents the heat being transferred to the top layer of fresh water by natural convection, due to which the temperature of the lower layer may rise to as much as 95deg. C.

In order to extract the energy stored in the bottom layer, hot water is removed continuously from the bottom, passed through a heat exchanger and then returned to the bottom. To generate electricity, heat stored in hot water is piped to an evaporator. Refrigerant in the evaporator is heated and converted into gas. The pressure generated by the gas spins a turbine and electricity is produced by the generator.

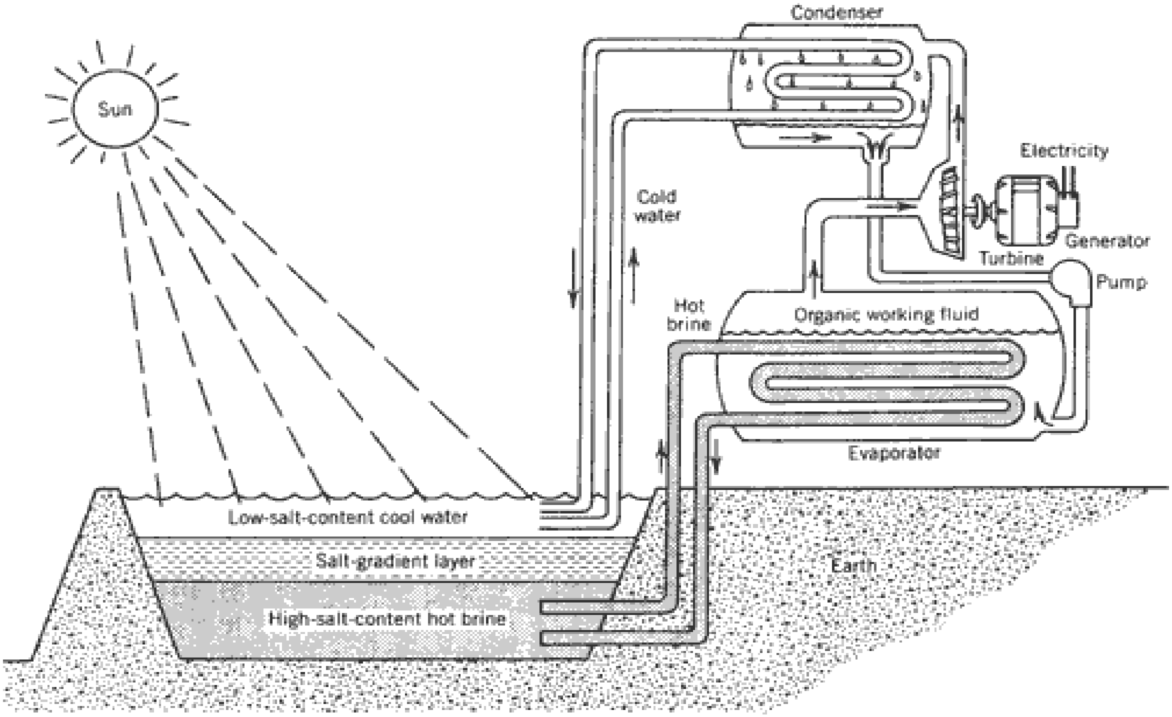


Fig 2.1 Layout of power generation using solar pond

3. Rankine cycle

Rankine cycle is an idealized thermodynamic cycle of heat engine that converts heat into mechanical work. It mostly describes the process by which steam operated heat engines most commonly found in power generation plants generate power. Rankine cycle in work of heat engine generates about 90% of all electric power throughout the world, including virtually all solar thermal power , biomass, coal and nuclear . It is named after William John Macquorn Rankine, a Scottish polymath and Glasgow University professor.

3.1. Components of Rankine cycle

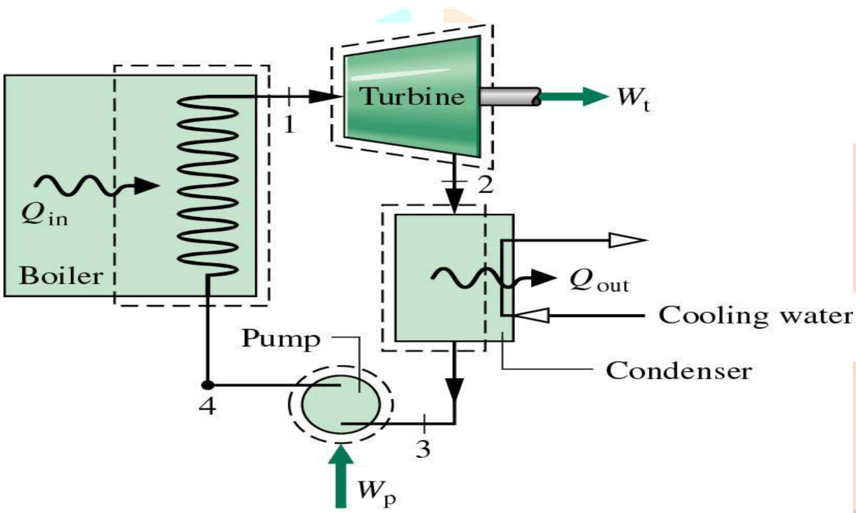


Fig 3.1 Layout of rankine cycle

1. Evaporator
2. Turbine
3. Condenser
4. Pump

3.2 Processes in rankine cycle

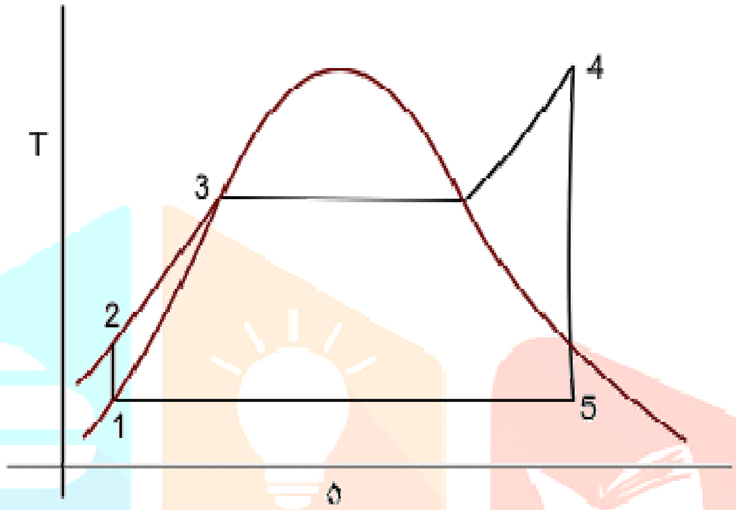


Fig 3.7 T-S diagram for Rankine Cycle

Process 4-5 - isentropic expansion

(Turbine working)

Process 5-1- isothermal heat rejection

(Steam is condensed in condenser)

Process 1-2- isentropic compression

(Pumping of feed water to boiler/evaporator)

Process2-4- isobaric heat addition

(Conversion of feed water into steam)

Tetrafluoroethane, **R-134a**, **Genetron 134a**, **Suva 134a** or **HFC-134a**,

A haloalkane refrigerant with thermodynamic properties similar to R-12 (dichlorodifluoromethane), but with less ozone depletion potential. It has the formula CH_2FCF_3, and a boiling point of −26.3 °C (−15.34 °F) at atmospheric pressure.

BENEFITS OF USING 134a

- It is the first chlorine free refrigerant, that’s why it has zero ozone dipleting potential.
- It has 74% less global warming potential compared to R-12.
- It has a lower suction pressure and larger suction vapour volume.
- Higher thermodynamic efficiency.
- High flamable temperature ,up to 740c.

1. Construction of solar pond

Area of solar pond

Area of solar pond is 706900 m² (optimized from720000 $m^{2)}$ as calculated by Rabl and Neilsen equation.

Thickness of solar pond

Although thickness of solar pond may vary from 1-3.5 m. In this analysis we will take solar pond of thickness 1.5m.

Upper convective zone will be of 100 mm. Non –convective zone which is approx 2/3rd of total depth has maximum thickness i.e. 950mm (2/3rd of depth is 1000mm but to optimize area we reduced it to 950mm). Thickness of lower convective zone will be 450 mm.

Increase in thickness of NCZ increases the effectiveness of solar pond. This is because the NCZ layer plays the role of an insulator and at a certain point less solar radiation can reach the bottom of the pond.

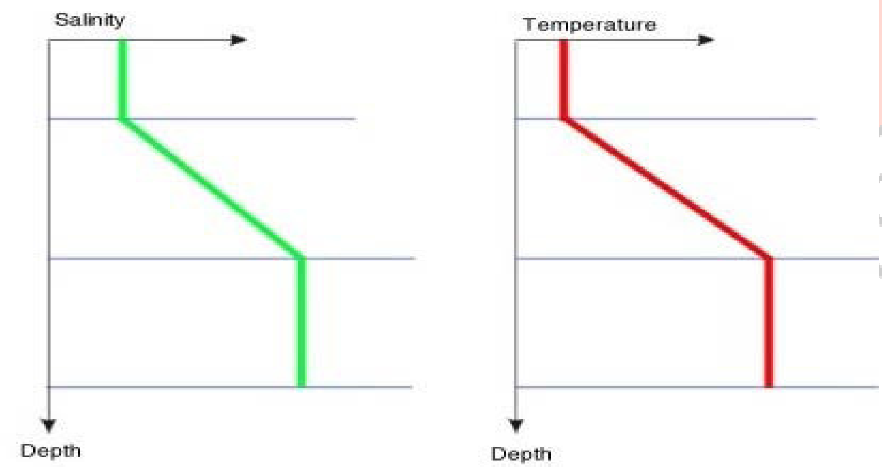


Fig 5.1. Salinity and temperature gradient

2. Estimation of optimum Area of solar Pond for 5 MW

Let power required is 5MW

Now as assuming that temperature of LCZ = 80°C to 90°C

Take temperature of LCZ = 85°C

Assume the temperature of refrigerant at evaporator = 75°C

Saturation pressure of refrigerant corresponding to 75°C (from steam table) p_s = 24.643bar

Condenser having temperature 40°C with p = 10.165bar

Refrigerant temperature after expanding in turbine is 40°C with dry saturated state .

Dryness fraction of refrigerant after expansion (x) = 1

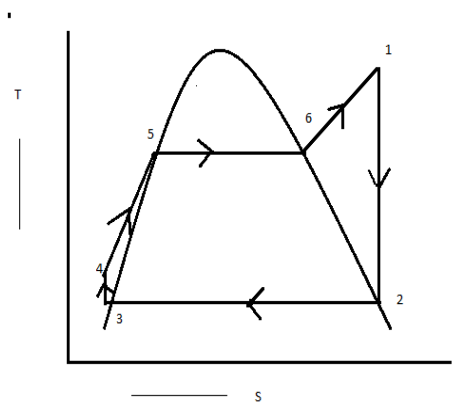


Fig 6.1 T-S diagram rankine cycle

Now, turbine output

$$w_t = m_r(h_1 - h_2)$$

From steam table

Data for evaporator at 75°C, p_s =23.643bar

$T_5 = T_6 = 75°C$

$h_6 = 429.25 kj/kg$

$h_5 = 313.15\ kj/kg$

$s_6 = 1.69155\ kj/kg - k$

$s_5 = 1.35805\ kj/kg - k$

$c_{pg} = 1.7315\ kj/kg - k$

Data for condenser at 40°C, $p_s = 10.165 bar$

$T_2 = T_3 = 40°C$

$h_2 = 419.58\ kj/kg$

$h_3 = 256.35\ kj/kg$

$s_1 = s_2 = 1.7115\ kj/kg - k$

$s_3 = s_4 = 1.1903\ kj/kg - k$

Calculation for mass flow rate at turbine inlet

Take isentropic process 1-2

$s_1 = s_2$

$s_1 = s_6 + c_{pg} \ln (T_1/T_6)$

1.7115 = 1.69155+1.7315ln $(T_1/348)$

$T_1 = 79.0327°C \sim 80°C$

Degree of superheat 5°C

Now

$h_1 = h_6 + c_{pg}\Delta T$

$h_1 = h_6 + c_{pg}(T_1 - T_6)$

$h_1 =$429.25 + 1.7315(80-75)

$h_1 =$ 437.90 kj/kg

$\boldsymbol{w_t = m_r(h_1 - h_2)}$

$m_r = \frac{5*10^5}{437.90-419.58}$

= 272 kg/sec

Now

$s_3 = s_4$, $c_{pf} = 1.9155\ kj/kg - k$

$s_5 = s_4 + c_{pf}\ln\ (T_5/T_4)$

1.35805 = 1.1903 + 1.9155ln (348/T_4)

T_4=45.82°C ~ 46°C

$h_5 = h_4 + c_{pg}\Delta T$

$h_4 = h_5 - c_{pg}(T_5 - T_4)$

$h_4 =$313.5 + 1.9155(75-46)

$h_4 =$257.60 kj/kg

Now, work done by pump

$\boldsymbol{w_p = m_r(h_4 - h_3)}$

w_p = 272(257.60 - 256.35)

w_p= 340.136kw

Heat rejected in condenser

$$Q_c = m_f(h_2 - h_3)$$

Q_c= 44398.56kw

Heat required for boiler

$$Q_b = m_r(h_1 - h_4)$$

Q_b=272(437.90 – 257.60)

Q_b = 49041.6kw

Now,

Load on solar pond = Annual heat required for boiler

Q_l=49041.6*365*24*3600

Q_l= 1.5465*10^{12} $kj/year$

Area of solar pond for required capacity can be calculated from the equation given by **"Rabl and Niselse"**

$$T_{LC} - T_a = \frac{\tau_r H_g}{k}\sum_{j=1}^{4}\frac{A_i}{k_j}\left(1 - e^{-k_i' l_2}\right) - \frac{l_2 Q_l}{kA_p}$$

Where,

$$k_i' = \frac{k_j}{cos\Theta_2}$$

Since pond is located in Gwalior with

Latitude = 26°.23'(N)

Longitude = 78°.17´(E)

$H_g = 660 w/m^2$ (For 8 hour)

And for 24 hour working

$$H_g = \frac{660 * 8}{24}$$

=220 w/m^2

Assume ambient temperature T_a= 30°C

And depth of non convecting zone =.95m

Now

$$cos\theta_1 = cos\varphi \ cos\omega$$

=cos(26°.23´)cos (-30°)

=.7758

Effective angle of incidence θ_1=39.1204°

By snell's law

$$\frac{sin_{\theta_1}}{sin_{\theta_2}} = \frac{h_2}{h_1} = 1.33 \ (takestandard)$$

$\theta_2 = 28.32°$

$cos\theta_2 = .8803$

$$k_i' = \frac{k_j}{.8803}$$

Now, take

$T_{lc} = 85°C T_a = 30°C$

$\tau_r =$ .971824 k = .648 $w/m - k$

From Rabl and Niselse equation

$$85 - 30 = \frac{.9718 * H_g}{.648} \sum_{j=1}^{4} \frac{A_i}{k_j}\left(1 - e^{-\frac{.95k_j}{.8803}}\right) - \frac{.95Q_l}{kA_p}$$

$Q_l = 49041.6 * 10^3 j/sec$

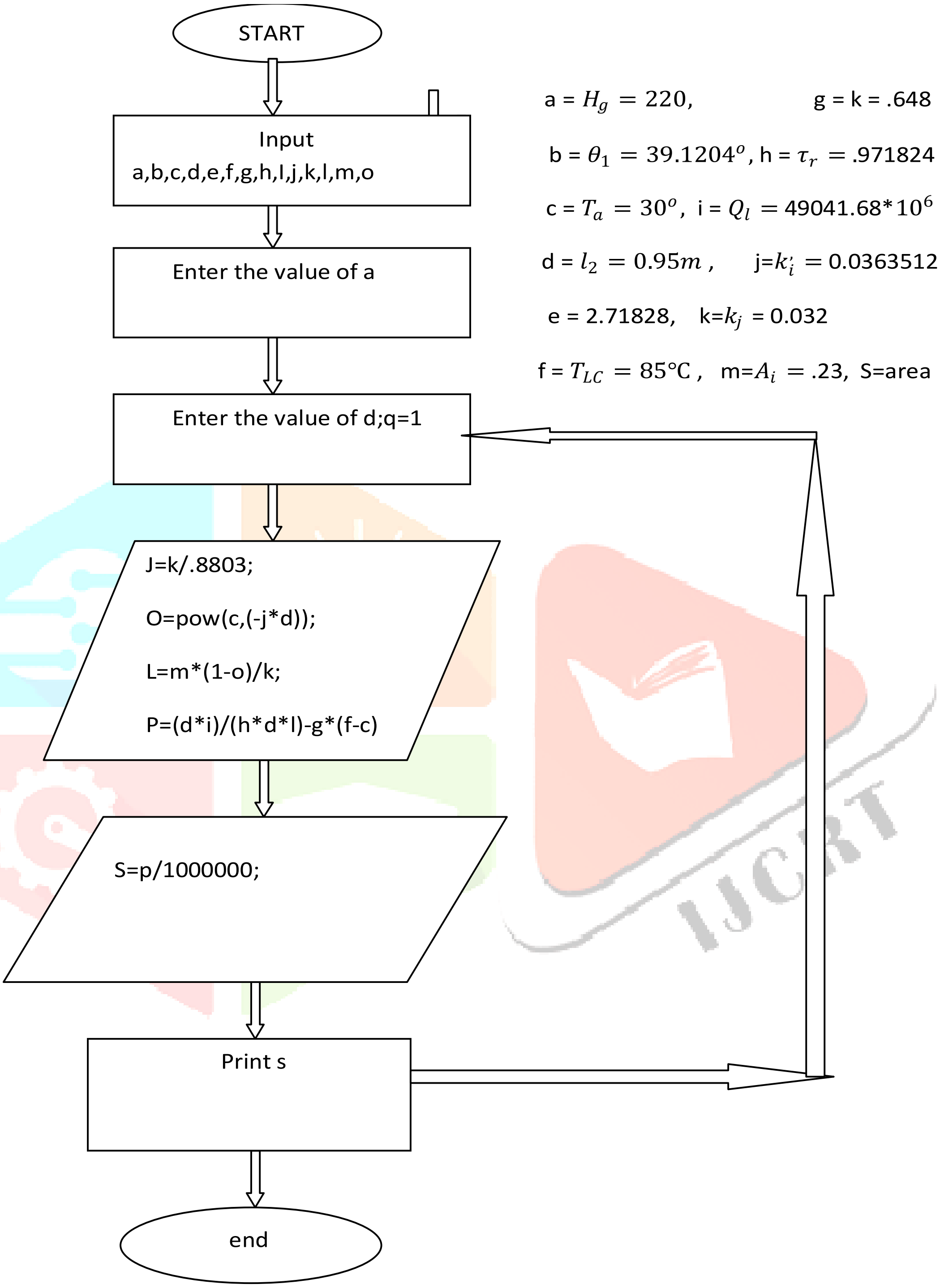
$55 = 156.6997 - \frac{.95*49041.6*10^3}{.648*A_p}$

$A_p = .7069 km^2$

Required area = $.7069 km^2$

The energy obtained is in the form of low-grade heat of 70 to 80 °C compared to an assumed 29°C ambient temperature. According to the second law of thermodynamics (see Carnot-cycle), the maximum theoretical efficiency of a cycle that uses heat from a high temperature reservoir at 80 °C and That a lower temperature of 20°C is 1-(273+29)/(273+80)=14.44%. By comparison, a power plant's heat engine delivering high-grade heat at 800 °C would have a maximum theoretical limit of 73% for converting heat into useful work (and thus would be forced to divest as little as 27% in waste heat to the cold temperature reservoir at 20 °C). The low efficiency of solar ponds is usually justified with the argument that the 'collector', being just a plastic-lined pond, might potentially result in a large-scale system that is of lower overall levelised energy cost than a solar concentrating system.

3. Flowchart for estimation of optimum area


START
Input
a,b,c,d,e,f,g,h,l,j,k,l,m,o
Enter the value of a
Enter the value of d;q=1
J=k/.8803;
O=pow(c,(-j*d));
L=m*(1-o)/k;
P=(d*i)/(h*d*l)-g*(f-c)
S=p/1000000;
Print s
end
a = $H_g = 220$, g = k = .648
b = $\theta_1 = 39.1204^o$, h = τ_r = .971824
c = $T_a = 30^o$, i = Q_l = 49041.68* 10^6
d = $l_2 = 0.95m$, j= k_i' = 0.0363512
e = 2.71828, k= k_j = 0.032
f = T_{LC} = 85°C, m= A_i = .23, S=area

4. Optimum and thermal efficiency of solar pond

$$Q_u = Q_a - Q_e$$

Q_U = Useful heat extracted

Q_a = Heat absorbed due to solar radiation

Q_e = Heat losses

Thermal efficiency

$$\eta = \eta_o - \frac{Q_e}{I}$$

η_o = Optimal efficiency

$$\eta_o = \frac{Q_a}{I}$$

$$Q_a = I\, fra\,(x) NZ$$

$fra\,(x)NCZ = \tau_a$ = 0.36 - .08 ln(x)

= 0.36 - .08 ln(1.3)

$fra\,(x)NCZ$ = 0.364

Q_a = 227 * 0.364 = 82.65 W/m^2

$$Q_e = U_o(T_S - T_a)$$

U_o – Overall heat loss coefficient

T_S – Pond storage temperature = $80\,^0_C$

T_a = Ambient temperature = $29\,^0_C$

If neglect heat losses from bottom and sides of the pond and assume that temperature of upper mixed layer is the same as ambient temperature

Then

$$U_o = \frac{K_w}{b}$$

K_w – Thermal conductivity of water = 0.67 $Wm^{-1}k^{-1}$

b – Thickness of gradient zone = 0.95 m

$$U_o = 0.67/0.95$$

= 0.705 $Wm^{-1}k^{-1}$

$$Q_e = U_o(T_S - T_a)$$

= 0.705 (80 – 29)

= 35.95 W/m^2

$$Q_u = 82.65 - 35.9$$

$$\eta_o = \frac{Q_a}{I}$$

= 82.65 / 227 = 36.4%

$$\eta = \eta_o - \frac{Q_e}{I} = \frac{Q_a}{I}$$

= 46.70 / 227 = 20.57%

Optimal efficiency = 36.4%

Thermal efficiency = 20.57%

5. Cost analysis

Area availability in Gwalior

Land cost of Gwalior is 15-20 lakh /acre and water level is 100-150 ft depth.

Heliostat

Elements of solar pond	Cost in Rs/kw

The main comprehensive conclusion of the report of Sandia National Laboratories "Heliostat Cost Reduction Study" published in June 2007 is that the feasibility of the solar tower thermoelectric power plant goes through get reliable and efficient heliostats at a cost much lower than the different known solutions.

The working group which took part this study, about 30 international experts, pointed out 100 $/m rate (base 2006) as target cost for heliostats at a long term defining a series of R&D projects to achieve it, among others, increasing the size, mega heliostats, reducing the cost of the drive or apply carousel designs.

Later, TITAN TRACKER presented its innovative technology, which allows the complete fulfillment of all these targets for the heliostats, both economical and technical, to facilitate commercial deployment of the CSP central receiver technology.

Fig 13.1 Heliostat

Cost analysis

Structural and improvement	**3 crores**
Heliostat system installation	**5 crores**
Tower/receiver system installation	**50.34 crores**
Steam Gas System	**45 crores**
Thermal system	**3 crores**
Project/Process Contingence	**40 crores**
Indirect engineering	**146.34 crores**

Total estimated cost- 11.085 crores

Land cost 200 crore 60 lacs (50 lacs/acre)

Labour and material cost - 1.5 crores

Total initial cost- 213.95crores

Cost analysis of solar pond (part – 2)

Let land cost = 1 crore 60 lac (10lac/acre)

Labour cost + material and equipment cost = 11.085 crore

Total cost = 12.685 crore

Energy collected by bond = 1.5465*$10^{12}\ kj/year$

Heating value of coal = 27*$10^{3}\ kj/kg$

$$\text{Equivalent amount of coal saved} = \frac{1.5465 * 10^{12}}{27 * 10^{3}} = 5.728 * 10^{7}\ kg/year$$

Let cost of coal = $5.728 * 10^{7} * 5 = 2.864 * 10^{8} Rs$

Let payback period = n

Now by formula,

$$n = \frac{ln\left(\frac{i_f c}{c_f f_E} + 1\right)}{ln\left(1 + i_f\right)}$$

i_f = fuel injection rate = 5%

$C_f f_e$ = cost of fuel saved in I^{th} year

$$n = \frac{ln\left(\frac{0.05 * 12.68 * 10^7}{2.864 * 10^8} + 1\right)}{\ln(1 + .05)} = 6.51\ year$$

6. Conclusion

Today, 85% of primary energy comes from nonrenewable and fossil sources (coal, oil, etc.). These reserves are continually diminishing with increasing consumption and will not exist for future generations.
With sustained GDP growth of around 8 % per annum, India's energy consumption at a conservative estimate will increase @ 5% per annum. At this rate the demand for energy will continue to soar and by 2022 India could emerge as the fourth largest consumer of energy after the US, China and Japan. So we would require an alternative to fulfill the demand for power. The work shows that solar pond is suitable for power generation. The electricity generation in Gwalior using solar pond in connection with organic cycle is rather a good potential wit relatively acceptable cost especially when one consider future fuel prices as well as advances in solar technology.

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He had 5 years wide experience in flied of mechanical engineering subjects.Also tought many interesting subjects (HMT,AM, SOM,THERMAL,CNC AND FLUID ETC).He had also experiences of number of national and international conference.

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