Solar Pond

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ABSTRACT
Had you ever mentally conceived of storing the solar thermal power without any sumptuous solar storage contrivances? Can't we engender solar thermal energy in the form of low grade heat of 70-80^{0}c with 20^{0}c ambient temp .Yes this paper suggest a solutions of storing the non conventional energy energy only by constructing a simple pool of brine ,isn't it astounding?. Thus a solar pond is a pool of brine which accommodates as the solar energy amassment and sensible heat storage.The solar ponds made a tremendous progress in the last 30 years . This paper withal mainly reviews the fundamental principles of the solar pond and the quandaries encountered in its operation and its maintenance. Here we withal discuss the factors that enhance the heat storing capacities and withal the factors that influence the technical and the economical viability of the solar ponds.

Keywords
Mass Flux, Heat Flux, SGSP

1. INTRODUCTION
Ecumenical warming could be one of the world's most paramount issues in the 21st century [5].Every year, billions of tons of carbon dioxide have been emitted into the ecumenical atmosphere[1].Global warming mainly occurs due to human activities such as conveyance, engendering electricity and in industries which involves burning fossil fuels[2], which could lead to a consequential decrease in world fossil fuels reserves[3].However, renewable energy technologies have been developeds and introduced as an alternatives sources for energy engenderment; renewable energy technology can engender energy with zero carbon dioxide emissions, illimitable sources and benefits the economy[11]. Solar energy is one of the essential world conventional energy sources. The conversion of the energy can be operated by several techniques such as photovoltaic systems for engendering electricity and solar sultry dihydrogen monoxide for heating dihydrogen monoxide with solar energy. Solar ponds have been suggested to be simple and economical in terms of amassing and storing energy on an immensely colossal scale. There are two types of solar ponds depending on the converting deportments and the non-converting solar ponds [4]. Solar energy is an abundant and renewable energy source. The annual solar energy incident at the ground in India is about 20K times the current electrical energy consumption. The utilization of solar energy in India has been very constrained. This is because solar energy is a dilute energy source (mean daily solar energy incidents in India is 5 kWh/m 2 day) and hence energy must be accumulated over sizably voluminous areas resulting in high initial capital investments; it is withal an intermittent energy source. Hence solar energy systems must incorporate storage in order to take care of energy needs during nights and on nebulous days. This results in further increase in the capital cost of such systems. One way to surmount these quandaries is to utilize a sizably voluminous body of dehydrogenase monoxide for the accumulation and storage of solar energy. This concept is called a solar pond.

2. PRINCIPAL OF SOLAR POND
In a clear natural pond about 30~ solar radiation reaches a depth of 2 metres. This solar radiation is absorbed at the bottom of the pond. The sultrier dihydrogen monoxide at the bottom becomes lighter and hence elevates to the surface. Here it loses heat to the ambient air and, hence, a natural pond does not procure temperatures much above the ambient. If some mechanism can be devised to avert the commixing between the upper and lower layers of a pond, then the temperatures of the lower layers will be higher than of the upper layers. This can be achieved in several ways. The simplest method is to make the lower layer denser than the upper layer by integrating salt in the lower layers. The salt used is generally sodium chloride or magnesium chloride because of their low cost. Ponds utilizing salts to stabilize the lower layers are called 'salinity gradient.

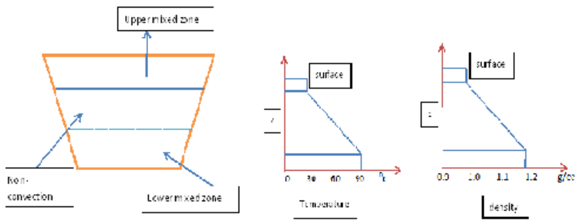

Fig no. 1 solar pond

ponds'. There are other ways to avert commixing between the upper and lower layers.One of them is the utilization of a transparent honeycomb structure which traps stagnant air and hence provides good transparency to solar radiation while cutting down heat loss from the pond. The honeycomb structure is composed of transparent plastic material.Ortabasi & Dyksterhuis (1985) have discussed in detail the performance of a honeycomb-stabilized pond. One can additionally utilize a transparent polymer gel as an expedient of sanctioning solar radiation to enter the pond but cutting down the losses from the pond to the ambient. Wilkins & Lee (1987) have discussed the performance of a gel (cross-linked polyacrylamide) pond. In this review we discuss salinity gradient solar ponds as this technology has made tremendous progress in the last fifteen years. Typical temperature and density profiles in an immensely colossal salinity gradient solar pond are shown in figure 1. We find that there are three distinct zones in a solar pond. The lower commixed zone has the highest temperature and density and is the region where solar radiation is absorbed and stored. The upper commixed zone has the lowest temperature and density. This zone is commixed by surface winds, evaporation and nocturnal cooling. The intermediate zone is called the nonconvective zone (or the gradient zone) because no convection occurs here. Temperature and density decrease from the bottom to the top in this layer, and it acts as a transparent insulator. It sanctions solar radiation to pass through but reduces the heat loss from the sultry lower convective zone to the cold upper convective zone. Heat transfer through this zone is by conduction only. The thicknesses of the upper commixed layer, the non-convective layer and the lower commixed layer are customarily around 0"5, 1 m and 1 m, respectively.

3. STATIC STABILITY

The internal stability of a solar gradient pond is predicated on salt diffusion from the storage zone toward the upper zone of the pond. Diffusion can be defined as the kineticism or migration of an individual component within an amalgamation solution medium. The primary cause of diffusion is the different concentrations or the concentration gradient of a component in a fluid. Such fluids endeavor to become internally stable through equalizing the concentrations, and consequently the molecules peregrinate from the high concentration area to the lower one. If there is no applied pressure or coerced diffusion in a binary or multi-component fluid, the mass flux in the coalescence is primarily dependent on the concentration difference and the temperature gradient. The former is kenned as molecular (mundane) diffusion and the latter may be expressed by thermal diffusion or Soret effect. Lamentably, both molecular and thermal diffusion work against the stability of any salinity gradient solar ponds. Ergo, the salt management is absolutely essential for monitoring and operating a gradient solar pond.

3.1 Static stability Criteria

The salt density gradient resulting from salt concentration difference magnitude in a solar pond is sometimes called a positive gradient, as it contributes to composing the desired shape of the gradient profile inside a non-convecting layer within a solar pond, i.e. the salinity gradient is concentrated downward. On the other hand, the density gradient may engender a inverted profile in the salinity gradient due to the Soret effect; this is not authentically desired and it may be called a negative gradient. These counter effects of positive and negative density gradient should be investigated to soothsay the static stability in a gradient pond, and if a negative stratification dominates 86 the positive gradient, convection may gradually take place inside the gradient zone; this gradient will then be eradicated or at least the performance of the pond will be reduced. In other words, the net concentration value at any point in a salinity gradient pond must be lower than at any point underneath in order to suppress vertical convection in the gradient zone [7]. This stability condition was first suggested by Weingerger [6], and it has been widely accepted and adopted by the most researchers.

If the molecular diffusion is only considered in a solar pond study, then Fick's law can be expressed as the following:

$$j = K_S \frac{dc}{dx} \qquad (1)$$

The condition can be expressed by the following formula :

$$\alpha \frac{dt}{dx} \le \beta \frac{ds}{dx} \qquad (2)$$

$$(\alpha = -\frac{1}{p}\frac{dp}{dx})_s \qquad (3)$$

$$(\beta = -\frac{1}{p}\frac{dp}{dx})_T \qquad (4)$$

where:

$\frac{dt}{dx}$ = temperature gradient with depth (^oC/m).

$\frac{ds}{dx}$ =salinity gradient with depth (kg/m4).

ρ: density (kg/m3).

α: thermal expansion coefficient (1/^{o}C).

β: salinity expansion coefficient (m3 /kg)

Consequently, the density change with depth must satisfy this equation to indicate that a solar pond is sufficiently stable:

$$\frac{dp}{dx} = \alpha \frac{dt}{dx} + \beta \frac{ds}{dx} > 0 \qquad (5)$$

Alternatively, the above correlation can be expressed by a finite different approach:

$$\frac{\Delta p}{\Delta x} = \alpha \frac{\Delta t}{\Delta x} + \beta \frac{\Delta p_s}{\Delta x} > 0 \qquad (6)$$

$\frac{\Delta p}{\Delta x}$: the net density gradient with depth (kg/m4).

$\frac{\Delta p_s}{\Delta x}$: the density gradient with depth caused by salt concentration (kg/m4)

The stability criterion can be withal viewed by another formula predicated on thermal and saline Rayleigh number. It is a dimensionless number resulted by multiply Grashof number, which expresses the cognation between buoyancy and viscosity in a fluid, by Prandtle number, which describes the relationship between momentum and thermal diffusivities. Thus, the Rayleigh number may be considered as the product of the ratio of buoyancy and viscosity forces and the ratio of momentum diffusivity and thermal diffusivity. Hence;

4. DYNAMIC STABILITY

When the above static stability condition is obtained and the salinity gradient is amply concentrated to suppress vertical convection, the solar pond inclines to be stable. However, there are several external perturbation factors, such as wind, falling particles, rainfall, evaporation, heat loss, etc., which may support the Soret thermal gradient to revolt against the salinity gradient suppression force. This may occur due to the potential energy stored into the inverted temperature profile and, if the transmitted external energy together with the profile potential energy is more vigorous than the viscous damping, then vertical convection will be initiated and will grow with time, leading to the commixing of the solar pond layers. It has been found that heat diffusivity is 100 times more expeditious than salt diffusivity[9],[10] In a laboratory experiment, the internal oscillation was identified as having a minutely diminutive value but then it grew gradually until it was ultimately fortified by convection; shortly afterwards, the saline gradient was debilitated by the mass transfer resulting from this oscillation

The dynamic stability condition equation for a gradient solar pond was introduced by Weinberger [14]. The proposed formula can maintain the gradient adequately to avert any oscillatory kineticism effects developing with time, and this condition may be expressed by the following relationship:

$$(v + \alpha_T)\frac{\delta p}{\delta T}\frac{\delta T}{\delta x} + (V + \alpha_s)\frac{\delta p}{\delta s}\frac{\delta s}{\delta x} \geq 0 \quad (7)$$

α_s are thermal and salinity diffusion coefficient respectively can be rewritten in another suggested.

$$\frac{\delta p}{\delta T} < \left(\frac{p_r+\tau}{p_r+1}\right)\left(\frac{\beta}{\alpha}\right)\left(\frac{\Delta s}{\Delta x}\right) \quad (8)$$

where the Prandtl number (Pr) and the Lewis number ( ) are:

$$p_r = \frac{v}{k_T} \quad (9)$$

$$\tau = \frac{K_S}{K_T} \quad (10)$$

The above equations have been adopted by most investigators, and they been used widely to investigate gradient solar pond stability. Equation is employed to carry out the stability calculation from the top to the bottom of a solar pond, including both convecting and non-convecting zones. In the case of unidimensional instability, Schladow [15] suggested a simplification of the above equation:

$$R_p = \frac{p_r+1}{p_r+\tau} \quad (11)$$

The mathematical analysis of thermohaline (double-diffusive) diffusion in a gradient study may predict the marginal stability, and can be represented in this equation [16]:

$$R_T = \frac{v+k_s}{v+k_t}R_s + \left(1+\frac{K_S}{K_T}\right)\left(1+\frac{K_S}{v}\right)\left(\frac{27\pi^4}{4}\right) \quad (12)$$

The salinity and thermal Rayleigh correlations have an effect much more immensely colossal than the second term in the left hand side of Equation hence, the latter term can be neglected, leading again to the Weinberger dynamic stability criterion in Equation this simplification is commonly surmised. For a typical salinity gradient solar pond, Hull [16] verbally expressed that the Lewis number conventionally varies from 30 to 140, and that the Prandtl number is expected to be between 3 and 10. It was corroborated in the same report that the salt concentration gradient should be far more preponderant than that obtained through the dynamic stability correlation in order to ascertain that the marginal stability is vigorous enough to keep a gradient zone in a fine-tuned position.

4.1 Instability Sources

Albeit the internal demeanors of the three components of a solar pond are not plenarily understood including the gradient zone and boundary erosion, there are several factors believed to cause destabilization issues in an SGSP. The following factors may cause static or dynamic instability issues.

4.2 Mass Flux

In solar gradient pond studies, the dihydrogen monoxide inside a pond is conventionally considered as a binary system (a single solute substance in an aqueous solution). There is a paramount lack of information about the diffusion coefficient of a ternary system not to mention multi-component saline dihydrogen monoxide. However, the stability of the system significantly depends on the mass convey rate. The mass transfer rate per unit area in a uniform temperature binary solution depends on the concentration gradient and the molecular diffusivity. Thus, the upward salt migration from the affluent salty lower zone to the surface layer would contribute to gradient pond destabilization.

4.3 Salt types

The salt type contribution to SGSP stability should be appreciably considered. A typical salt for a gradient pond must have the following essential features to enhance the pond's performance and stability

- The salt solubility value must be high enough to meet the highest level of solutions density require.
- The salt solubility should not change significantly with solar pond temperature variations.
- When the salt is dissolved in water, the solution must be sufficiently transparent to permit solar irradiation to the bottom of the ponds.
- It must be environmentally friendly.
- It must not cause any contaminations to the ground water.
- For cost considerations, it should be cheap and large in quantity , and near to the pond's location.
- The salt molecular diffusivity Ks should be low.

The firmness of salt solubility against solar pond temperature variation with time and with position in the pond (depth) is quite consequential for solar pond stability. Different types of salt exhibit sundry solubility demeanors with temperature transmutation in dihydrogen monoxide, which are summarized , It can be optically discerned that the top three salts in terms of stability with temperature are sodium chloride (NaCl), magnesium chloride (MgCl2) and sodium sulphate (Na2SO4).

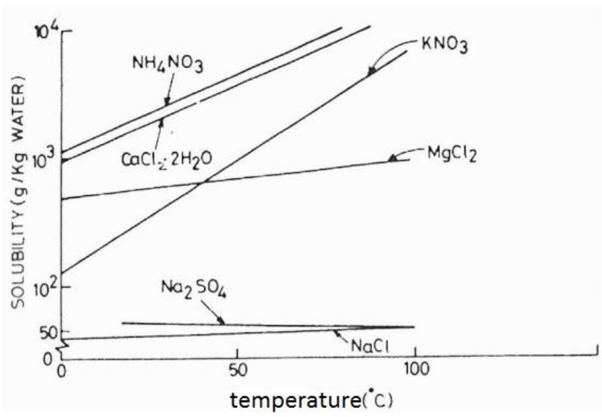

Fig.4.4 solubility of three salt with temperature variation

The salt diffusivity value is another consequential factor in terms of enhancing SGSP stability. Generally, the molecular diffusivity of a salt is a function of salinity and temperature, as the solvent viscosity decreases with elevating temperature. For example, the solubility of sodium chloride (NaCl) at 90oC is 5 times more preponderant that its solubility at 10oC. On the other hand, the molecular diffusivity Ks may vary less than 10% with the salinity percentage variation at between 0 and 20 at a certain temperature. The molecular diffusivities of variants of salt at room temperatures. Hull et al. reported that the diffusivities at other temperatures have not been investigated but it is understood that the diffusion coefficient customarily increases at higher temperatures, which leads to raising the upward salt flux.

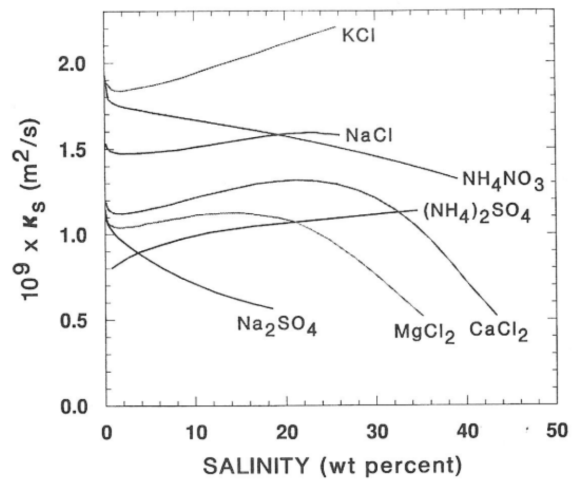

Fig no 4.4 (a). : Salt molecular diffusivities with salinity variations at 25 ^{0}C

According to the above information, it is not surprising that it is verbally expressed that sodium chloride is the most efficacious salt by far for filling and operating solar ponds all over the world. Sodium chloride withal represents the most astronomically immense proportion (77%) of sea and ocean dihydrogen monoxide salts, and it is one of the most stable salts with temperature variation. Moreover, the transparency of sodium chloride brine is appreciably high, and it is one of the most frugal salts in the world. This salt has the ability to be dissolved in dihydrogen monoxide up to 27-30% afore reaching saturation, which is relatively low, The astronomical majority of the US SGSPs have been utilizing sodium chloride.

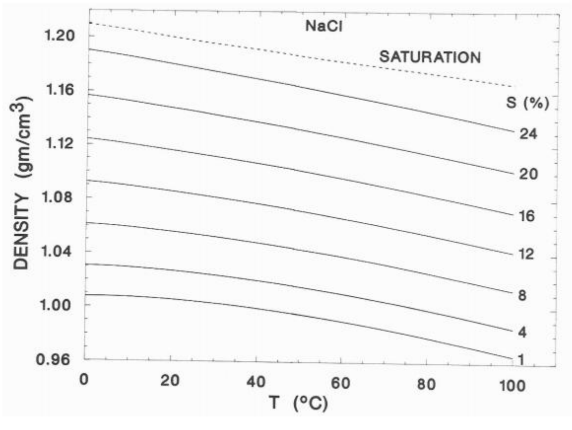

Fig no.4.6(b) : Density-temperature variation for NaCl solution.

However, another commonly used salt in salinity ponds is magnesium chloride(MgCl2), which is considered the second most immensely colossal salt constituent of sea and ocean dihydrogen monoxide, albeit it is the most immensely colossal proportion of salt in the Dead Sea (as well as in some saltworks brines). This salt is exceptionally stable during operation; it additionally exhibits great solubility in engendering brine with high density, as it is able to dissolve between 35 and 40% according to the solution temperature. This salt has been utilizeds in two ponds in Israel and an astronomically immense pond in the USA [33, 81, 123]. In comparison with sodium chloride, magnesium chloride is able to engender higher salinity brine, and is more stable during the solar pond's operation. However, it is much more extravagant than sodium chloride.

The brine most widely used in Israeli gradient ponds is Dead Sea brine, as it is costless and can be drawn directly from the Sea. The Dead Sea is unlike other seas and oceans as magnesium chloride represents the major salt in percentage terms, at about 13%, while NaCl stand for only 8%. MgCl2 is the most dense brine in the world; its average density is about 1230kg/m3 .

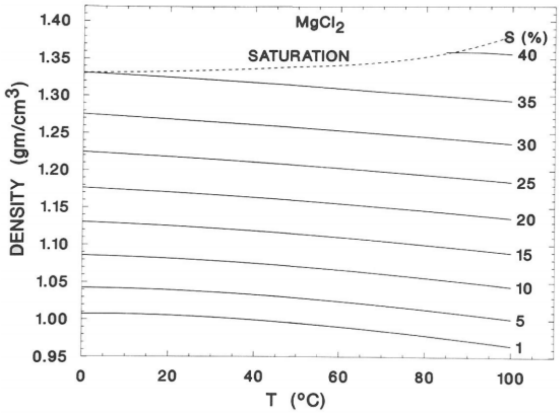

Fig no. 4.4(c): Density-temperature variation for MgCl2 solution

5. HEAT FLUX

Heat convey from a solar pond to the circumventing area affects the saline dihydrogen monoxide density, which in turns affects the stability of the gradient pond, as expounded above. The heat within a dihydrogen monoxide medium is influenced by radiation, convection and evaporation. The latter represents the primary mechanism of solar pond heat losses and represents the main process in concentrating the upper layer of a pond. Surface dihydrogen monoxide cooling, by either evaporation or any other processes, and concentrating the upper zone solution increase the density of the dihydrogen monoxide. This incrementation in dihydrogen monoxide density correspondingly results in a elevate in convection kineticism, which may affect the stability of the gradient zone and its upper boundary. It may withal erode the upper zone and raise the upper-middle zone boundary. This is what was reported by in an investigation that followed a considerable period of surface layer evaporation in the Ohio State University solar pond. It was found that the gradient had expanded upwards by 10cm, representing an impuissant gradient extension.

The heat flux from the lower zone at high temperatures may lead to the boiling point being reached; consequently, one of the worst instability cases will occur because the gradient zone with all boundaries may be entirely eradicated. This solar gradient pond disaster has been observed in a few ponds and it seems that the presence of air bubbles was the main factor in these ponds becoming commixed.

5.1 Heat Extraction System

The potential for a gradient pond to become unstable due to the brine withdrawal process from the lower convecting saline region is logically to be expected. Harsh suction and/or reinjection procedures through a turbulent flow mechanism coupled with an improper diffuser system design would definitely increase the middle zone erosion risk. This happened in the 400m2 OSU and the 2000m2 Miamisburg

Ohio solar ponds, where uneven returning flow was the reason given for gradient erosion in the former pond, while the problem was caused as a result of the high suction rates in the latter SGSP.

Authentically, many solar pond monitoring cases have attested that brine withdrawal for heat extraction is not a quandary if a congruously designed system is employed. The withdrawal point should be several centimetres just below the top of the storage convecting zone, and the returned more arctic brine should be re-injected at a lower level of this bottom zone. It is additionally recommended that the returned fluid temperature should be well below the storage zone temperature, otherwise a rapid erosion may be caused to the gradient zone above in such cases [33]; albeit there was not a given reason, it can be interpreted that this system is recommended to satiate the natural convection phenomenon, as the more gelid pumped molecules, which are heavier, would incline to flow toward the bottom. A high suction rate of 1000w/m2 for obtaining energy was utilized in the 40,000m2 Israeli solar gradient ponds with an opportune diffuser setup, and there was some conspicuous erosion. Another example of such precise operational investigations was reported on the 156m2 Wooster SGSP, which had a heat energy extraction rate of 112w/m2.

6. EVAPORATION

As mentioned above, the evaporation effect on a solar pond's stability and performance is prodigiously consequential. Customarily, the greatest proportion of lost heat from a solar pond heat occurs as a result of evaporation, and this heat loss cools the pond, categorically the surface layer. Thus recorded temperatures are conventionally less than the ambient temperature; the evaporation equations were given in the antecedent chapter. Daily evaporation lessens the amount of dihydrogen monoxide in the upper zone, and consequently the salt concentration increases. Both losses of heat and dihydrogen monoxide are not desired in any SGSP operation, as these will act as instability factors, as discussed above. Consequently, some fresh dihydrogen monoxide must be integrated to compensate for the evaporated dihydrogen monoxide and to maintain the gradient stability. The required amount of fresh dihydrogen monoxide is directly dependant on the evaporation rate, which in turn is conventionally affected by the prevailing weather conditions. According to different Israeli SGS ponds, it is reported that each 1m2 of pond area needs about 1.8m3 every year of fresh dihydrogen monoxide for this purport; the average salinity in the upper zone elevates to around 2% (at most) in this timeframe.

7. WIND

The air current blowing parallel to the top surface of a dihydrogen monoxide body engenders wind shear; the dihydrogen monoxide becomes wavy (according to the wind speed) and the dihydrogen monoxide then resists this action. In fact, the mechanism of the wind-dihydrogen monoxide interaction is quite involute. Van Dorn in 1953 carried out several experiments in an artificial pond to investigate the effect of wind accentuate on the pond, finding that the effects of friction drag for a body of dihydrogen monoxide are directly proportional to the square of the wind speed and to air density. It was withal descried that this drag action is not engendered unless the wind is blowing at higher than a certain speed.

In a comparison with other findings regarding wind shear estimations, Van Dorn concluded that the differences were a result of the height at which the wind speeds were quantified. Francis in 1954 found that the drag coefficient is only constant as long as the wind speed is not higher than (proximately) 4.12m/s, but that with more expeditious winds, it becomes a function of wind speed.

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