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Effectiveness of coagulation for removal of turbidity and biological growth in experimental salt gradient solar pond

A.K. Saxena*, S. Sugandhi, M. Husain*** and S.K. Mahajan******
*Samrat Ashok Technological Institute, Vidisha (M.P.)
**Jawaharlal Institute of Technology, Borawan, Khargone (M.P.)
***SSBT's College of Engineering and Technology, Bambhori, Jalgaon (M.S.)
****31, Jain Mandir Path, Khargone (M.P.)

Abstract

The present paper deals with effectiveness of coagulation for removal of turbidity and biological growth in experimental salt gradient solar pond. The result obtained indicated that coagulation is not able to bring down the turbidity below 1 NTU, while at 10 NTU starting turbidity, the optimum alum dose comes out to be 75 mg/l and it is 60 and 45 mg/l for 5 and 3 NTU respectively. This acquired level of turbidity is within acceptable limits for solar ponds, hence the experimentation with higher dose was not continued.

Keywords: *Coagulation, Non convective zone, Salinity, Salt gradient solar pond, Stratified layer, Turbidity*

Introduction

Energy crises are the principal barrier for the development of modern society. Fossil fuel has played the key role in scientific advancement followed by industrialization and modernization in the past century. At the dawn of new millennium, fossil fuel is alarmingly depleting leading to severe energy crises. Apart from this, fossil fuel has left behind the rigorous environmental havocs including global warming and climatic changes. The rapidly degrading environment has become the prevalent threat to the very existence of human civilization (Pachauri *et al.,* 1998). The solution to both the crises i.e. environmental degradation and energy crises lies in the use of alternative energy sources. Solar energy is the obvious foremost choice due to its plentifulness and environmental friendliness. There are various methods of harnessing solar energy. Salt gradient solar ponds are the most significant amongst various solar energy harnessing methods owing to their reliability, economy and large-scale long-term storage capacity. They store solar energy in the form of heat of water, which finds several direct and indirect applications (Sukhatme, 1994; Duffie *et al.,* 1981). The hot water can also be used to run Rankin's cycle generators and to produce electricity (Amnon, 2004). The technology is globally accepted. Israel is doing pioneer work in the field of solar ponds with a target of switching over to complete dependence on solar ponds for their energy requirements by 2025. Large size solar ponds are working successfully all over the world e.g. (Sukhatme, 1994) 2000 m^2 at Miamisburg (Australia), 3500 m^2 at El Paso, Texas (USA), 225000 m^2 at Bet Ha Arava in Israel is the largest of world at the Dead Sea in Israel has been used to generate 5MW of electrical power. India stepped in to the field of solar ponds with a 1200 m^2 at Bhavnagar in 1973.

Other ponds in India are 100 m^2 at Pondicherry, 240 m^2 at IISc Banglore and 1600 m^2 again at Bhavnagar in 1980, 400 m^2 at Masur, 300 m^2 at Hubli .The largest pond built in India is at Bhuj of 6000 m^2 areas. Presently all over the world scientists are working on various aspects of SGSP; the references cited below highlight few significant recent contributions in this field (Punyasena,2003; Angeli *et al.,* 2004; Jaefarzadeh, 2004; Angeli *et al.,* 2005; Agha *et al.,* 2004; Ouni *et al.,* 2003 and Huseyin *et al.,* 2006). Huanmin *et al.* (2004) has given a glossary of major works in the maintenance of pond.

Salt gradient solar ponds are large body of saline water as shown in the Fig. 1. It has three zones namely upper convective zone, non-convective zone and storage zone. The UCZ is designed to preclude wind born turbulences. It has a minimum salinity of around 2%. The STZ is for storage of hot water. While NCZ has gradient of salinity increasing up to 26% at STZ interface. This prevent convection in the zone hence acts as a lid over STZ. STZ maintains a constant salinity of 26% (Sukhatme, 1994).

The solar radiation penetrates into the depth of pond and warms it up. For the higher efficiency of the pond, good penetration of radiation is required. This insists for transparency (clarity) of the water. However, pond is exposed to atmosphere and continuously receives wind born dust. This adds turbidity to the water. Turbidity has a very drastic effect on radiation penetration and consequently on thermal efficiency (Wang and Yagoobi, 1994,1995 and Husain *et al.,* 2004). Hence a real pond always requires removal of turbidity by coagulation (Kumar *et al.,* 1999). In the present work, an experimental pond is created and salt is dissolved for salinity which imparts to turbidity of water This turbidity is removed by alum dose. Optimum alum dose is worked out to remove turbidity. Optimum time required for removal is also estimated. The experimentation is done for varying levels of starting turbidity.

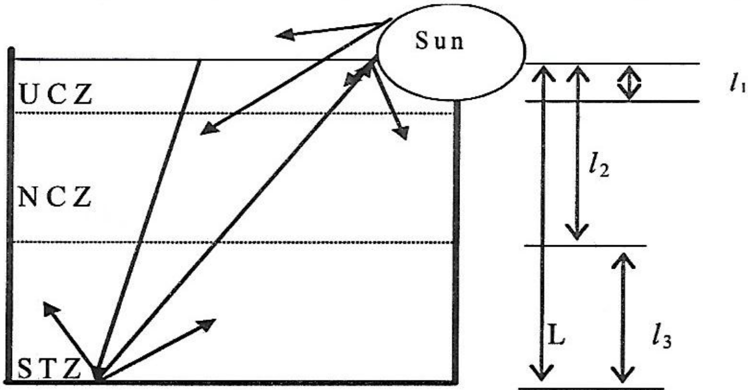


Fig. 1: Schematic diagram of a salt gradient solar pond showing the radiation pathway

Theory

Coagulation of water is a four-stage phenomenon (Sawyer *et al.,* 1978) as described below:

Addition of coagulant → *Rapid mixing* → *Slow mixing* → *Sedimentation*

The rapid and slow mixing is generally done for 30 seconds and 30 minutes respectively. The rapid mixing lead to the uniform mixing of coagulant with water and $Al(OH)_3$ formation. Slow mixing leads to adhesion of $Al(OH)_3$ and colloidal particles to form flocs. Hence it is called as flocculation. Finally sedimentation removes the floc. Sedimentation requires 60 to 90 minutes time. Working of alum is described in following equation (Birdie *et al.,* 1998 and Weber, 1972).

$$Al_2(SO_4)_3.18H_2O + 3CaSO_4 \alpha 2Al(OH)_3 + 3CaSO_4 + 18\ H_2O \quad (1)$$

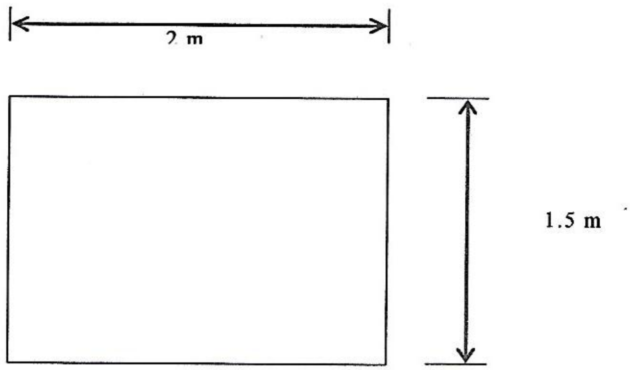
In case of salt gradient solar pond, salinity layers are quite delicate. They are provided to inhibit mixing in the NCZ. Hence rapid and slow mixing in coagulation of pond cannot be carried out. The coagulation is done in two steps only as shown below:

Addition of coagulant in solution form → *Sedimentation.*

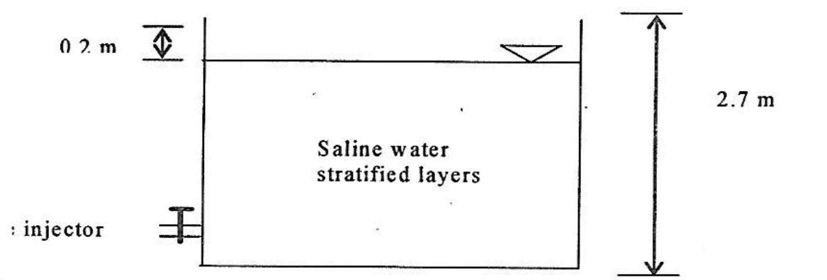
This obviously suggests that the required optimum alum dose shall be unusually higher. Such coagulation is typically termed as still coagulation. Alum is used as a coagulant for present study due to its efficiency, low cost, easy availability and common application by field ponds (Kumar *et al.*, 1999).

Experimentation methodology

A. An experimental laboratory scale pond is created at the laboratory of SATI, Vidisha, MP. Schematic diagram of the pond is shown in Fig 2. It has lateral dimensions 2m x 1.5 m. depth is taken as 2.7 m. freeboard is 0.2 m out of this depth. Hence available effective depth of water is 2.5 m. The tank is made of steel. In a master tank, salt solution (Brine) is prepared and allowed to settle for removal of high turbidity. After a settlement of 24 hours, the supernatant is used in experimental tank. The bottom depth is 1.3 m filled with 26% sodium chloride solution. Then it is filled up to a depth of 2.5 m. with fresh water. Then it is left still for 8 days. The salt slowly diffuses upwards and creates a gradient of salt (Sukhatme, 1994). Meanwhile the bottom zone of experimental tank is fed again with concentrated brine obtained from master tank, to compensate the loss of salt diffused up wards. The feeding is done on 3rd, 5th and 8th day of the start.



Plan of tank used for still coagulation studies



Elevation of tank used for still coagulation studies

Fig 2: Schematic diagram of experimental set up used for coagulation studies.

B. On 9th day, the liquid of experimental tank had a turbidity level of 10 NTU. The tank was ready with salinity layers as shown in Fig 2. Now, tank is dosed with alum solution 15 mg/l. The solution is sprinkled gently over the surface. Then it is allowed to work for 30 minutes. Samples from each 20 cm depth of the NCZ zone of the tank were collected with the help of a long graduated glass tube. The samples were analyzed for residual turbidity in laboratory using Nephelo-Turbidity Meter. Samples were again collected at 60 and 120 minutes and turbidity was measured. The experiment was repeated with higher dose of alum with an interval of 15 mg/l up to 75 mg/l. A dose of 75 mg/l has yielded a residual turbidity of 1 NTU, which is in permissible limits. Hence further increment in the dose is not done.

C. The experimental tank was cleaned and washed. Again in master tank salt solution was prepared. It was dosed and mixed with alum 2 mg/l to reduce the turbidity to 5 NTU. The turbidity was reduced to 8 NTU. Again alum solution was added and turbidity was measured. By hit and try we have obtained a turbidity level of 5 NTU. The steps described in **A** and **B** were performed again. Again experimental tank was prepared with layers (**A**) and alum dosing was done gradually (**B**). At a dose of 60 mg/l, residual turbidity of 1 NTU is obtained.

D. Steps described in **C** were repeated such that starting turbidity of the master tank was kept as 3 NTU. The required dose for obtaining 1 NTU turbidity in experimental pond was 45 mg/l for this case. Normally field ponds are having low turbidity (< 10 NTU). Higher turbidity is uncommon in ponds because of regular maintenance. Hence in the present work, experiment was done with low turbid water.

Results and Discussion

The results are presented in table from Table. 1 to 12. Following salient observations can be made out of these results:

a. The required alum dose for removal of turbidity is very high compared to the case of traditional coagulation (Birdie *et al.,* 1998). The required dose is in the range of 50 to 75 mg/l, while the initial turbidity is quite low, in the range of 3 to 10 NTU.

b. The time required for removal of turbidity is also significantly high. This may also be attributed to the same reason as described above.

c. The reason behind higher dose of coagulant may be attributed to the fact that in the present case, complete coagulation process has not been carried out. The coagulation is done for still water in which flocculation has not been enhanced by mixing.

d. The minimum turbidity achieved is around 1 NTU. Within the observation range, the coagulation has not been able to bring down the turbidity below 1 NTU. With 10 NTU starting turbidity, the optimum alum does comes out to be 75 mg/l. The same for 5 and 3 NTU respectively is 60 and 45 mg/l. This acquired level of turbidity is within acceptable limits for solar ponds. Hence the experimentation with still higher dosing is not continued.

e. The turbidity has formed a downward increasing profile after alum dosing. This is obviously because settlement of colloidal mass is sluggish. The changes in turbidity are relatively faster in the beginning and get slow down after two hours. This is in confirmation to the first order sedimentation kinetics (Sawyer *et al.,* 1978).

f. The higher turbidity has required higher alum dose to yield final minimum turbidity.

Table 1. Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 15 mg/l **Initial turbidity: 10 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	8	7	7
0.4	8	7.5	7
0.6	8.5	7.5	7.5
0.8	9	8.5	8
1.0	9.5	9	8

Table 2.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 30 mg/l **Initial turbidity: 10 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	6	5	4.5
0.4	6.5	5.5	4.5
0.6	7	6	5
0.8	7.5	6.5	5
1.0	8	6.5	5.5

Table 3.Removal of turbidity with respect to alum dose in experimental saltgradient solar pond.

Alum dose: 45 mg/l **Initial turbidity: 10 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	4	3	2.5
0.4	4.5	3.5	2.5
0.6	5	3.5	2.5
0.8	5.5	3.5	3
1.0	6	4	3

Table 4.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 60 mg/l **Initial turbidity: 10 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	2.5	2	1.8
0.4	3	2.5	1.8
0.6	3.5	2.5	1.9
0.8	3.5	2.5	2
1.0	4	2.5	2

Table 5.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 75 mg/l **Initial turbidity: 10 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute NTU
0.2	1.5	1.2	1.0
0.4	1.6	1.3	1.0
0.6	1.7	1.35	1.1
0.8	1.8	1.4	1.1
1.0	1.8	1.5	1.2

Table 6.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 15 mg/l **Initial turbidity: 5 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	4	3.5	3.2
0.4	4.5	3.6	3.3
0.6	4.6	3.8	3.3
0.8	4.7	3.8	3.3
1.0	4.8	3.9	3.4

Table 7.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 30 mg/l **Initial turbidity: 5 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	3.5	3	2.6
0.4	3.7	3.1	2.6
0.6	3.8	3.1	2.6
0.8	3.8	3.1	2.7
1.0	4	3.2	2.7

Table 8.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 45 mg/l **Initial turbidity: 5 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	2.5	1.9	1.6
0.4	2.7	2	1.6
0.6	2.8	2	1.7
0.8	2.9	2.1	1.7
1.0	3	2.1	1.8

Table 9.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 60 mg/l **Initial turbidity: 5 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	1.2	1.1	1
0.4	1.2	1	1
0.6	1.4	1	1
0.8	1.4	1.1	1.1
1.0	1.5	1.1	1.1

Table 10.Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 15 mg/l **Initial turbidity: 3NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	2.4	1.9	1.8
0.4	2.6	2	1.8
0.6	2.8	2	1.8
0.8	2.9	2	1.9
1.0	3	2.1	1.9

Table 11. Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 30 mg/l **Initial turbidity: 3 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	1.8	1.6	1.4
0.4	2	1.7	1.4
0.6	2.1	1.7	1.4
0.8	2.1	1.7	1.5
1.0	2.2	1.8	1.5

Table 12. Removal of turbidity with respect to alum dose in experimental salt gradient solar pond.

Alum dose: 45 mg/l **Initial turbidity: 3 NTU**

Depth of NCZ in m	Residual turbidity after 30 minute in NTU	Residual turbidity after 60 minute in NTU	Residual turbidity after 120 minute in NTU
0.2	1.2	1	0.9
0.4	1.3	1.1	0.9
0.6	1.3	1.1	1
0.8	1.4	1.1	1
1.0	1.5	1.2	1

Conclusion

Turbidity in real solar pond is unavoidable. It has a very drastic effect on the thermal performance of pond. Still coagulation as described above has been found to be successful in removing the turbidity. The experimental methodology described above had been successful in bringing down the turbidity to 1 NTU, which is an acceptable value. Of course, the required alum dose is significantly high. While extrapolating these results for a real pond, some additional care is required. The present study is done for a confined tank of water, which is small in dimensions. A real pond is having very large dimensions and it is very difficult to maintain uniformity throughout. Further a real pond is exposed to atmosphere and continuously receives air born turbidity. Hence a real pond may either require an even higher alum dose or may not yield turbidity as low as 1 NTU.

Nomenclature

l_1	Thickness of UCZ (m)
l_2	Depth from surface to the interface of NCZ-STZ (m)
l_3	Thickness of STZ (m)
L	Depth of pond (m)
NCZ	Non-convective zone
STZ	Storage zone
UCZ	Upper convective zone
SGSP	Salt gradient solar pond

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