Experimental Investigation of Effect of Meteorology and Turbidity on Operation of Salt Gradient Solar Pond in the Tropics

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Abstract- Studies are carried out for assessment of turbidity accumulation rate, its effect on radiation transmission and its control. The experimental studies are carried out at the location having tropical climate (21.05N, 75.57E, at 250 m from mean sea level). An underground pond of size 1m x 1 m x 2.5 m is constructed. It is filled with low turbidity water and chlorinated. The turbidity at several definite depth levels in the pond is monitored regularly over a prolonged duration. Chlorination has suppressed the biological growth in the water and thus enabling the measurement of rate of accumulation of wind born turbidity exclusively. The data base thus created is of great significance to the pond researchers and operators. In the second part of the study, the radiation transmission in the turbid water is measured using solari-meter. The experimental data thus obtained is compared with the calculated values of Wang and Yagoobi. (1994).This has validated the Wang and Yagoobi model and extended it beyond the range prescribed in the model. In the third part of the study, effectiveness of chemical coagulant in removal of artificially created turbidity is assessed. Thus, optimum coagulant dose is determined for various turbidity levels.

Keywords- Salt Gradient Solar Pond, Turbidity accumulation, turbidity control, Radiation measurement.

1. Introduction

Utilization of solar energy has challenges in terms of concentration techniques, storing technology, availability during daylight hours only, operational cost, maintenance cost and skilled human resources [13]. Usage of solar ponds as a cost-effective, eco-friendly method of collecting and storing solar energy at large scale has been an attracting field, as a potential solution to meet the ever increasing energy requirement of the world [1]. Solar ponds are the special systems that convert as well store the solar energy and allow it to be used with a long phase difference. Solar ponds are the promising technology for large scale solar thermal conversion and long term storage [3-5]

Salt Gradient Solar Pond (SGSP) is a reliable large area eco-friendly solar energy collector used to stores heat energy at the bottom. The thermal energy stored can be used for water desalination, process heat, electricity generation, etc.[10] Salty water is at the bottom with fresh water at the surface. The salt concentration layers create a gradient. The incident solar radiation is absorbed within the bottom of the pond. The hot and salty water cannot rise, as a result of its heavier from the fresh water at the highest layer. Hence, the upper fresh water layer acts as insulating blanket and therefore the temperature at the lowest of the lake will reach up to boiling point of salt solution. The most significant aspect of the solar pond system is that the big thermal mass of the pond acts as a heat store, and electricity generation can be done on day or night, as per need [15].

In the present work, experimental studies are carried out at the fields of Shrama Sadhana Bombay Trust‘s College of Engineering and Technology, Bambhori, Jalgaon, located in Jalgaon city of Maharashtra,India (21.05N, 75.57E, at 250 m from mean sea level). It is a tropical climate. The study is carried out during the months of April to August. April has clear sky and very high radiation with mild winds. May also has the same parameters associated with high winds. The high winds are responsible for large dust loads. In June the climate turns with the arrival of monsoon. The sky is cloudy with heavy winds. Sometimes sky is clear too with high radiation. In July and August the wind velocity again reduces. Sky is almost covered. Due to rains the landscape soil becomes moist and wind carries less dust load.

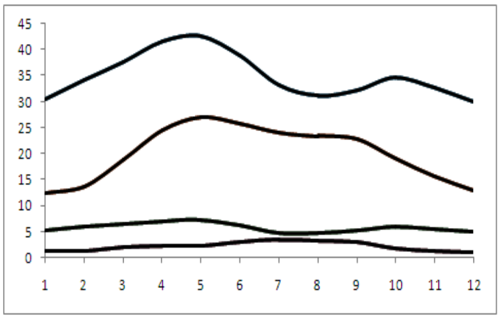
For experimental studies, an underground pond of size 1m x 1 m x 2.5 m is constructed in brick work and is plastered from inside and outside. The pond top is 25 cm above the ground level. Fig. 1 gives a view of the pond.

Fig. 1. A view of the experimental pond

2. Meteorological Factors Affecting the Pond Performance

The thermal performance parameters of Salt Gradient Solar Ponds are identified as ‘rate of warm-up’, ‘highest achievable temperature’, and ‘cumulative heat collection’. The overall efficiency and functional economics of pond is largely dependent upon these parameters. These parameters are strongly influenced by the meteorology. Consequently, specific to the meteorology of a geographic location, there is a best starting day for the pond as defined by Singh *et. al.*, [8]. Husain et al [5] have done rigorous analysis of influence of meteorology on pond‘s thermal performance. It is found that the starting day has strong influence in initial stage of pond warm-up; however the effect diminishes in long-term. Finally pond started on any day of the year acquires same highest temperature. It is also found that in order to retrieve maximum heat, waiting for the best starting day to commission a pond is not judicious, rather it is always more beneficial to commission the pond at the earliest possible day. The importance of best starting day must be interpreted in the right perspective. It must be noted that a pond started early, irrespective of starting day, shall always be ahead of a pond started later, in term of heat collection. This conclusion is of practical importance for taking decision regarding starting day to commission a pond.

The climate at the study location is tropical. Variation of various parameters is shown in fig. 2 [7].



Source: Mani A. *et. al.*, 1982

Fig. 2. Meteorological parameters for Jalgaon city (21.05N, 75.57E). Monthly average temperature values are in ^{0}C; solar radiation is in kWh/m^{2}.

It has high radiation coupled with high temperature during March to June. The period of July to October has cloudy sky and thus less radiation with moderate temperatures. Period of November to February is with lower temperatures and clear sky resulting into good radiation. However the average ambient temperature of the year, average solar radiation, the year and sky clearance factors are significantly conducive for the operation of salt gradient solar pond.

In the present analysis, the location is considered as city of Jalgaon in Maharashtra state, India at 21.05N, 75.57E. The location is in between the line of cancer and equator. The solar radiation is very strong and sky clearance is very high. It is coupled with the high ambient temperature and conducive location for salt gradient solar ponds. Over and above, the ground water is very low in this region is as an added advantage for SGSP establishment. Under these conditions the solar pond has a very rapid warm up rate. Consequently, the impact of starting day is also very significant. The analytical approach suggested in the present work is very useful. Fig. 3 and 4 represents storage zone temperature considering first day of the month as starting day for the months July to December and January to June.

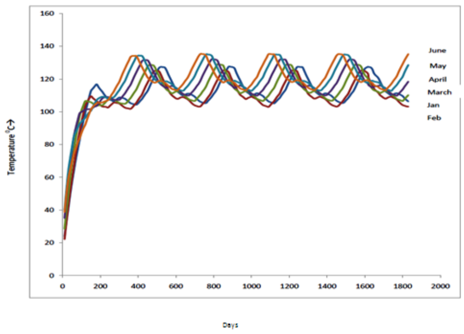


Fig. 3. STZ temperature considering first day of the month as starting day for the months January to June.

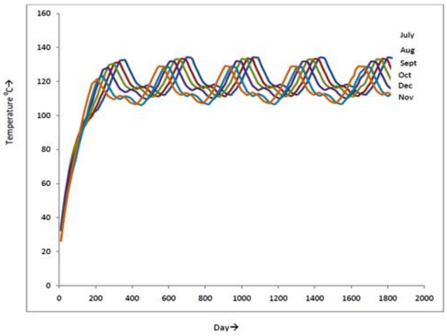


Fig. 4. STZ temperature considering first day of the month as starting day for the months July to December.

Fig. 5 and 6 shows storage zone temperature considering 15th day of the month as starting day for the month January to June and July to December.

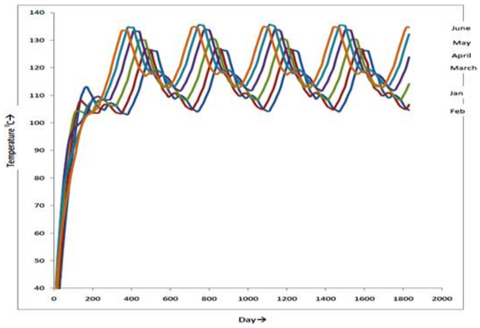


Fig. 5. STZ temperature considering 15th day of the month as starting day for the month January to June.

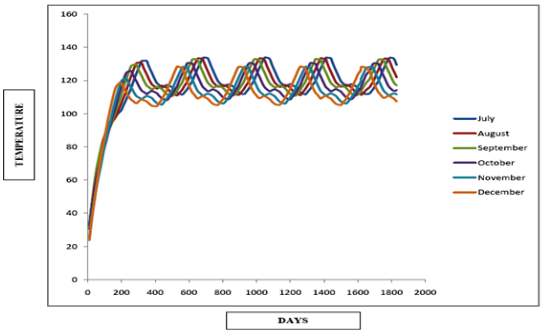


Fig. 6. STZ temperature considering 15th day of the month as starting day for the month July to December.

Also Fig. 7and 8 present Cumulative heat collection considering First day of the month as starting day for January to June and July to December.

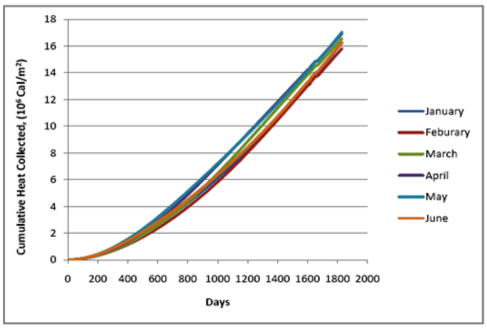


Fig. 7. Cumulative heat collection considering First day of the month as starting day for January to June.

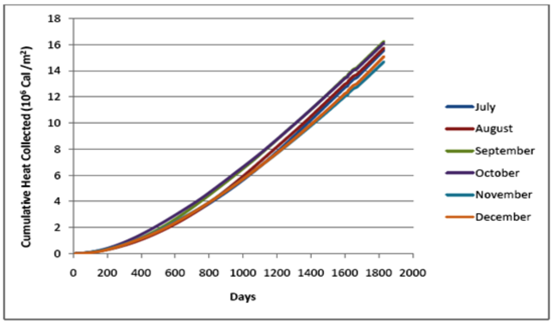


Fig. 8. Cumulative heat collection considering first day of the month as starting day for July to December.

The present work has conclusively established that summer is the best time to reach the highest temperature and maximum heat retrieval. These will economies the overall pond establishment and commissioning. The drastic difference between best and worst starting day for the location under study is of the order of over 183%. Hence judiouse selection of the starting day is extremely important. Such a selection can be possible only by simulation studies, as meteorological parameters are large in number and are complex in behavior. There is no mathematical or even empirical correlation exists to predict the impact of these parameters on the thermal performance of pond. Rather, such analysis can be done exclusively by simulation studies. Hence, the simulation model developed in the present work is incumbent for the economical design of the salt gradient solar pond.

3. Assessment of Turbidity and Its Control in SGSP

Salt gradient solar ponds are identical to large lakes. They are open to atmosphere and are recipient of impurities. The impurities decrease the clarity of its liquid content and consequently the thermal performance of the pond is degraded. Clarity of water is an important concern in salt gradient solar ponds for better performance. The importance of clarity is recognized by many researchers. The clarity is expressed in various ways by them. Researchers have identified the various sources of water clarity loss. Most of the previous studies on turbidity accumulation rates are lab scale studies. However the present work is an attempt to generate the turbidity accumulation data for the field conditions. Such information is of extreme importance to the pond researchers for carrying out realistic thermal performance analysis of the pond. It is also important to be noted that the rate of turbidity accumulation is specific to the geographic conditions including prevailing meteorology and the surrounding landscape. The present study is an attempt to assess the rate of turbidity accumulation in salt gradient solar ponds under natural environmental conditions. As a subsequent part of the study, experimentations are done to assess and enhance the clarity of water using coagulants. The field design parameters of the coagulation process are estimated in the present work. It is an attempt to gain experience in removing the turbidity by coagulation. The optimal coagulant dose and time of removal has been experimentally estimated.

4. Turbidity Accumulation

The experimental studies were conducted during April to August 2012. The turbidity is measured at every 10 cm depth. However, only top, 100 cm below and 150 cm below level data is being presented here. Fig. 9 shows the data of turbidity accumulation data for the said duration.

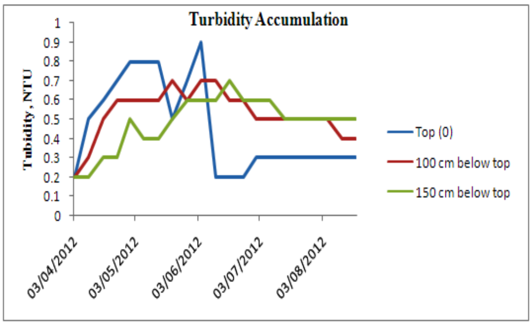


Fig. 9. Turbidity Accumulation from month of April to August, 2012

The following points were observed from the turbidity accumulation data:

1. The raw water used for the experimental work having turbidity 0.2 NTU which is below the Wang and Yagoobi [5, 6] range of turbidity that is $0.3 < \varphi < 5$ NTU. Water used for present work is conventionally treated. This shows that the conventional treatment methods do not effectively reduce the turbidity below 0.2 NTU. Hence for realistic analysis of pond, turbidity must be taken into account.

2. The rate of wind born turbidity accumulation is high during April and May compared to June-August period. This is obviously due to the dry-arid climatic conditions in the month of April-May. The rainfall wets the landscape their by reducing the lifting of dust in air.

3. During the dry climate, when wind brings heavy load of dust, the upper layers of the pond carry more turbidity. At later stage the turbidity sinks downward. This refers to the slow natural removal process.

4. The turbidity due to wind born dust alone is much less as compared to the turbidity due to biological life. It can be seen that that the turbidity grows quite rapidly [6]. This is due to the reason that the raw water used for pond is natural water and is rich in term of nutrients**.** Thus it provides an environment conducive for the biological growth. However in the present study the biological growth was effectively suppressed by the chlorine. Thus the rate of turbidity accumulation due to wind born dust alone was measured. It is found to be very less.

5. Turbidity Control

Many researchers have investigated the potential of coagulants in turbidity removal. Still the process has not been standardized. Coagulation is four stage processes as described in fig. 10 [14].

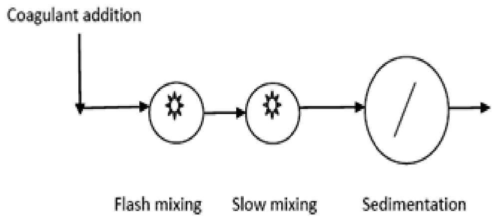


Fig. 10. Coagulation process

The stability of these gradients is vital for the functioning of pond. Mixing may lead to destabilization of layers and consequent failure of the pond. Thus in case of salt gradient solar ponds, the coagulation process is modified as shown in fig. 11.

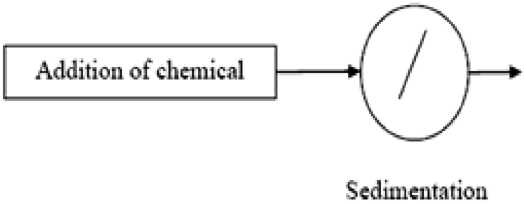


Fig. 11. Modified coagulation process

Turbidity removal is a complex process. Turbidity itself is a complex parameter. It includes a combination of concentration of suspended particles in a particular size, range, their shape, their hydro-philicity, their color and many other parameters. These parameters cannot be measured with desired accuracy. Hence turbidity removal cannot be mathematically modeled. It can be only described by the experimental data. Coagulation is one of the most effective turbidity control process. The procedure in which coagulation process works is undistributed the operation of SGSP and well suited. Alum dose cannot remove turbidity below 0.1 NTU. This is an important observation. In fact this means that pond designers must consider minimum 0.1NTU turbidity in water while estimating the thermal performance and efficiency for realistic estimations. The turbidity of top layer is reduced first and then it travels downward. Alum dose up to 50 mg/L can effectively reduce turbidity as high as 12 NTU. Alum dose does not increase in proportion to the turbidity. This is due to the complexities involved in the removal mechanism. In fact the alum removal process cannot be accurately modeled. The information generated from this experimental work will be useful guidelines for future pond researchers, pond designers and pond operators. The results for different level of turbidity control are shown in fig. 12 to 17.

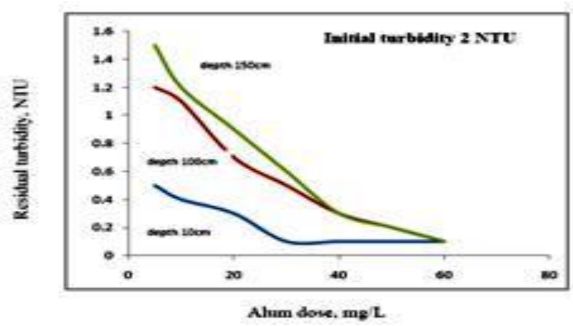


Fig. 12. Turbidity control by alum.

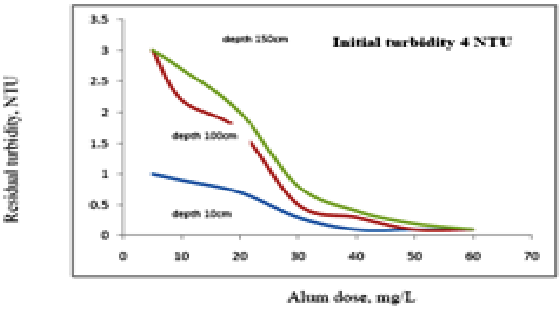


Fig. 13. Turbidity control by alum.

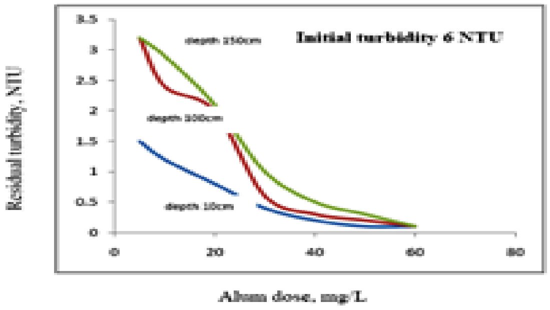


Fig. 14. Turbidity control by alum.

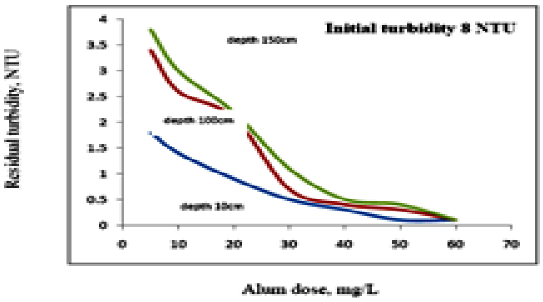


Fig. 15. Turbidity control by alum.

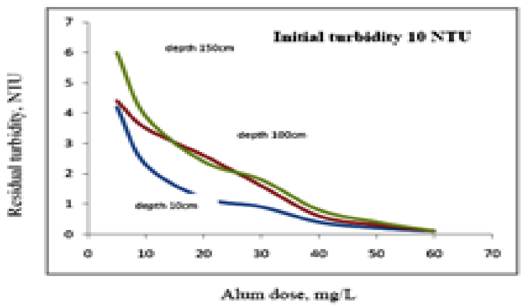


Fig. 16. Turbidity control by alum.

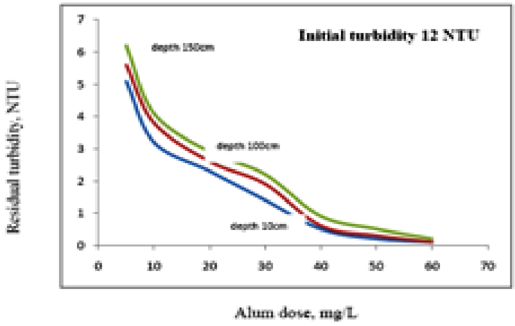


Fig. 17. Turbidity control by alum.

6. Effect of Turbidity on Radiation Transmission

Radiation transmission is a deeply explored aspect in SGSP. However all the earlier researchers have considered radiation transmission in clear or saline water. Yet the parameter of water clarity was first recognized by [2]. The term turbidity was first used by Wang and Yagoobi [11]. The turbidity has a very drastic effect on radiation transmission. Consequently it significantly reduces the thermal efficiency of the pond. In fact the effect of turbidity so much that it cannot be ignored in a realistic analysis of the ponds. However there are many researchers who have analyzed the pond considering turbidity free water. Such analyses are of mere academic significance yet have no practical application. A real pond always has turbidity and it must be taken into account for analysis. The present work has experimentally investigated the effect of turbidity on radiation penetration on solar pond. The experimentally measured values are compared with the theoretical model given by Wang and Yagoobi [11-12]. The radiation at the surface is always measured and is taken as the reference radiation value. The data is transformed for compatibility that all measured radiation values are divided with their reference radiation values at pond surface and are converted to the fraction of incident radiation. Now, these values are depicted from fig. 18 to 23. The values are also compared with the theoretical values calculated from Wang and Yagoobi model. However, the model is not applicable for the values below 0.3 NTU and above 10 NTU. Thus these values are not compared with the theoretical model.

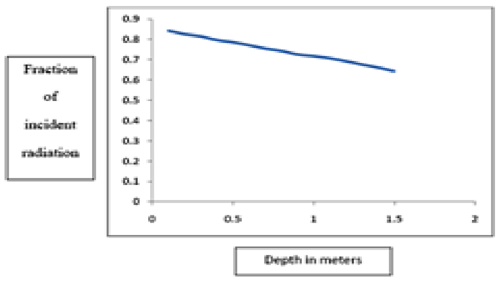


Fig. 18. Experimental values of radiation, turbidity = 0.1 NTU.

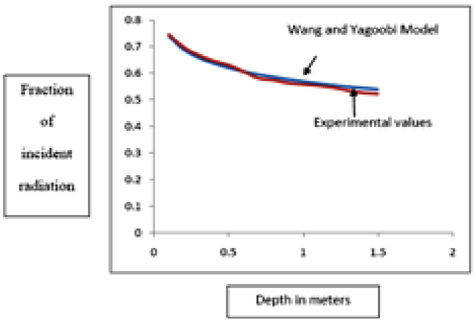


Fig. 19. Experimental values of radiation, turbidity = 0.4 NTU.

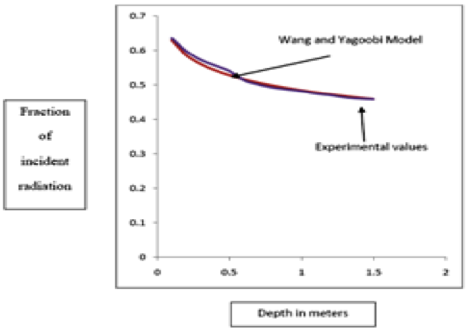


Fig. 20. Experimental values of radiation, turbidity = 1.2 NTU.

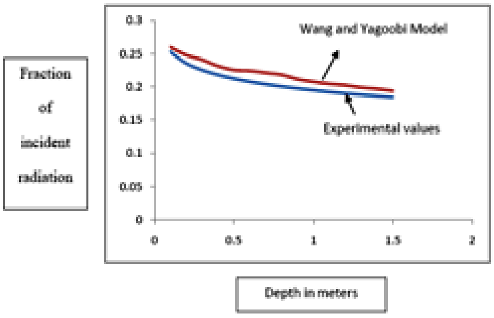


Fig.21. Experimental values of radiation, turbidity = 6.2 NTU.

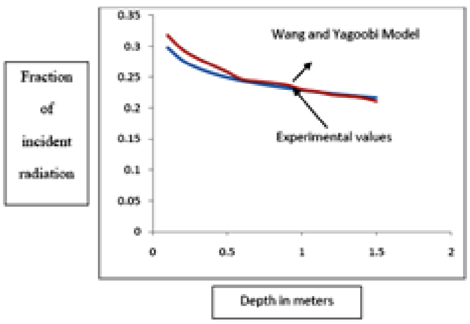


Fig. 22. Experimental values of radiation, turbidity = 9.4 NTU.

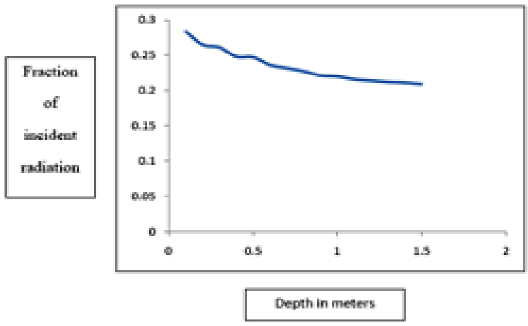


Fig. 23. Experimental values of radiation, turbidity = 12.9 NTU.

Figs. from 18 to 23 show that there is a good agreement between the theoretical values calculated by Wang and Yagoobi model and experimental values measured in the present experimental work. The deviation is very small. Fractional incident values are in the range 0.4 to 0.8 for turbidity range 0.1 NTU to 1.2 NTU. Also fractional incident values are in the range 0.2 to 0.3 for turbidity range 6.2 NTU to 12.9 NTU. It shows the significant adverse effect of the turbidity on radiation transmission. However the experimental values have taken into account the turbidity values below 0.3 NTU and above 10 NTU also for which the Wang and Yagoobi Model is not applicable.

7. Conclusion

Meteorology has strong influence on the thermal performance of pond. The starting day is an important consideration in thermal performance analysis. Starting day strongly affects the rate of warm-up. The time of maturation may vary by a factor of 1.83 depending upon the starting day. Starting day also affects cumulative heat collection significantly. Yet the importance of best starting day must be interpreted in the right perspective. It must be noted that a pond started early, irrespective of starting day, shall always be ahead of a pond started later, in term of heat collection. This conclusion is of practical importance for taking decision regarding starting day to commission a pond.

SGSP's are open to atmosphere. They essentially accumulate wind born turbidity. The present work has estimated the rate of turbidity accumulation and observed that the turbidity can be effectively removed by using alum for coagulation process. Alum dose in the range 50 mg/L can effectively reduce the turbidity of water. The turbidity cannot be reduced to zero level, yet it can be brought down to minimum permissible level.

The present work has done rigorous analysis of influence of meteorology on pond's thermal performance. This finding is of practical significance while planning to put a pond in operation.

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