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Simulation and analysis of open raceway pond system at Manit, Bhopal

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Abstract. Microalgae can become completely faster than terrestrial plants and are a successful feedstock for viable appreciation including items that envelop pharmaceuticals, neutraceuticals, proteins and most significantly biofuels. Since the biomass productivity of microalgae absolutely depends emphatically on the temperature of development, point-by-point data on the temperature of the reactor as a component of time and topographic area is essential to assess the sincere capability of microalgae as a traditional feedstock. Microalgae is indeed a promising source of renewable biofuels, and techno-financial upgrades can be made by improving and controlling the stage of biomass development. This research explores the improved performance of a first-standard green growth development display that encompasses the effect of regular (and such) notions of climate in an open system related to creation. Thus, the simulation of the procedure is stochastic just as basic; it helps restore the dissemination of outcomes from normal changeability that speak to the daily acknowledgement. It also communicates variety day-to-night in the vitality based on cycling sunlight. The simulation is then used to optimize the design of the pond and the manages (growth time, depth of the raceway, pH control, etc.) to enhance protability. Because the simulation is stochastic, nonlinear, and with different optima, an optimization method for multiplayer direct inquiry is used with relentless state assembly criteria. Conclusions are that (1) representing common variety in optimization prompts detectable protability improvement, (2) model impact investigation uncovers where key science exploration is expected to support basic techno-monetary wonders, and (3) the stochastic optimization approach is broadly relevant.

1. Introduction

1.1 Factors affecting algae cultivation system in open raceway pond

More urbanization and developing industrialization have expanded the ecological contamination and a dangerous atmospheric devation [1-3]. In this manner, more consideration is being drawn on sustainability and the conditions that have prompted a typical practice to diminish outflows and along these lines an earth-wide temperature boost, coming about because of human exercises [1]. One approach to decrease the discharge of carbon dioxide is the reusing of carbon dioxide for microalgae cultivation by photosynthesis. Microalgae has tremendous mechanical and financial possibilities as successful hotspots for pharmaceuticals, health and natural foods, carotenoids, colorants, fine chemicals, biofuels, etc. Microalgae are unicellular life forms, which can be found in provinces or individual cells. Their most fascinating trademark is the capacity of understanding a photosynthetic response in a solitary cell. They are amazingly safe and may develop in various situations, from sea water to marine and hyper-saline water. Microalgae can be viewed as a fascinating option in contrast to increasingly ordinary biomass as a hotspot for biofuels production [4-7].

1.2 Simulation of open raceway pond
Modeling a yield simulation involves an extensive amount of data such as solar irradiation, local weather conditions and other planned cultivation systems technical parameters [8-11]. The precision dimension required for the forecast of vitality yields is based on the task improvement phase [1]. The software simulation subtleties are given. Using solar resource information and assessments of algae breakdown depending on apparent characteristics seen in existing tasks can be a fundamental sign of the vitality yield [12-14].

2. Methodology

2.1 Site information and system description
Present investigation centers around the algae cultivation system in open raceway ponds with paddle wheels for air circulation, as these frameworks are considered financially economical for substantial – scale creation and higher biomass productivity. Spirulina platensis was developed for small scale generation from research facility scale production. Impact of introductory fixation and data sources puts exceptionally less effect on the geometry of model. The open pond cultivated microalgae from the day 1 of the development by pulling back the volume and quickly supplanting it with new water. Normal water was added daily for substituting the volume to make up for day by day evaporation or water losses.

The temperature data that is used to validate the model was based on a small-scale open pond system built at the Maulana Azad National Technology Institute, Bhopal, M.P, India. The pond had the capacity of 600 litres. Paddle wheel was used for proper aeration which was connected to 1hp motor.

2.2 Simulation using open raceway simulator
Input Data
Location/Climate
Hydraulic Retention Time
Pond Depth
Influent Temperature
Figure 1 illustrates the inputs for simulation using algae raceway simulator.

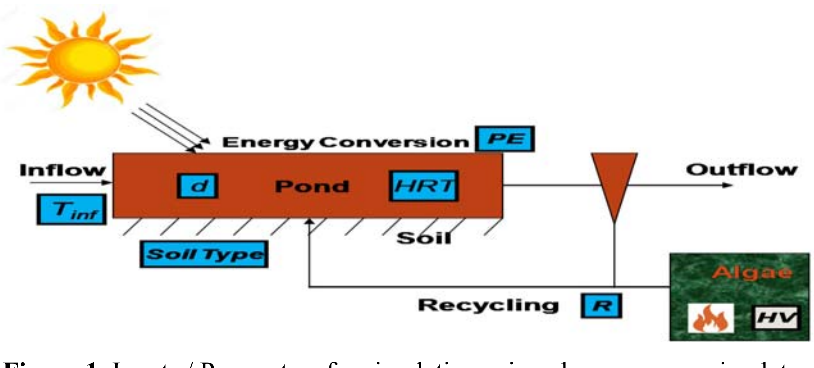

Figure 1. Inputs / Parameters for simulation using algae raceway simulator.

Climatic Conditions at MANIT Bhopal

- Average Temperature- 25 °C
- Average Highest Temperature- 35.7 °C
- Average Lowest Temperature- 10-12 °C
- Average Precipitation- 1137 mm
- Average Relative Humidity- 38 %

Output Parameters

- Algae production
    - Algal Daily Productivity
    - Algae Concentration
    - Nitrogen Consumed
    - Phosphorus Consumed
    - Hydraulic Retention Time
    - Pond Depth
- Water Consumption
    - Daily Evaporation
    - Water Use
    - Rainfall
- Temperature Variations

3. Results

3.1 Simulation of open pond system in Bhopal climatic conditions

- MANIT Bhopal ranges from 23.21° N longitudes and 77.40 °E latitude and receives massive solar radiation throughout the year.
- The biomass productivity is significantly affected by the local climatic conditions, light intensity and contamination etc.

3.2 Solar resource assessment

Solar irradiance is the light energy output from the entire Sun's disk, measured on Earth. It looks at the Sun as we would be a star rather than an image. A measure of the brightness of the entire Sun at a wavelength of light is the natural spectral irradiance. The daily average irradiance ranges from 3.67 kW h / m2/day to 6.45 kW h / m2/day with 5.5 hours of annual average sun shine. The monthly solar fraction variation illustrated in figure 2 at MANIT Bhopal. Spirulina algae cultivation is significantly affected by local climatic conditions (environmental temperature, humidity, light intensity, etc.), solar radiation availability, and micro-climate parameters such as wind speed, concentrations of dust, etc. Microalgae growth is greatly influenced by the minimum and maximum ambient temperature. Similarly, special consideration should be given to humidity as spirulina grows best in humid weather. High atmospheric humidity can adversely affect spirulina growth as it condenses and forms a nighttime deposit on the pond. The irradiance and ambient temperature variation is shown in figure 3. The monthly average of MANIT Bhopal's direct and diffused daily irradiance is shown in figure. 4. The whole year sun path diagram and day length variation is illustrated in figure 2. Figure 4 displays the annual average variation in solar daily irradiance, diffuse and direct beam radiation at the annual ambient temperature. The average annual ambient temperature ranges from 17 °C to 37 °C, which is very suitable for spirulina cultivation, but pond surface temperature may sometimes exceed ambient temperature. Relative humidity at Bhopal is about 40 to 66 % during early mornings and 45 to 78 % during afternoon in monsoon season. Bhopal is located in the middle of India, where humidity does not reach too high and varies from 10 % to 40 %, which is why beam radiation is always much higher than diffuse radiation. Diffuse radiation may increase during the rainy season (July, August and September) due to cloud scattering of radiation and humid environment. In April (6.59 kW h / m^2 day)

[7] and in August (3.70 kW h / m^2 day), the site receives maximum solar radiation. Solar fraction is determined as the fraction of solar energy used or solar energy used to convert energy into any form of energy [15-17].

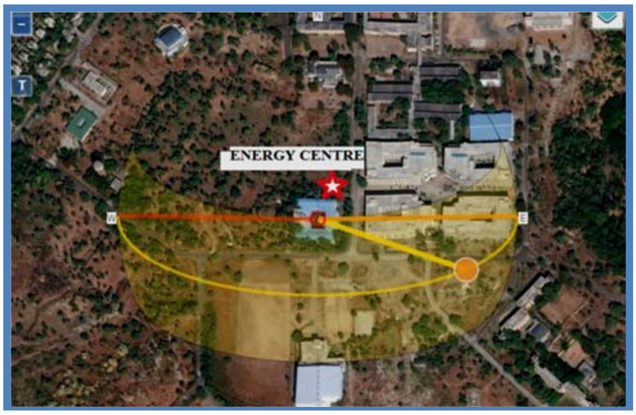

Figure 2. Solar irradiance profile at MANIT, Bhopal.

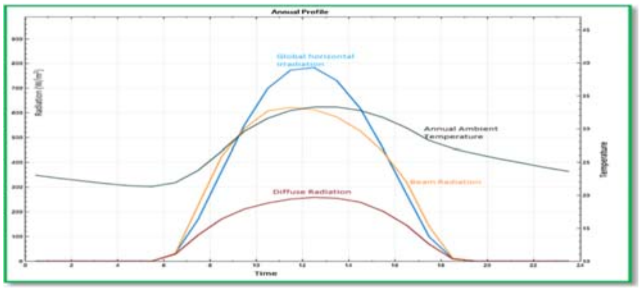

Figure 3. Variation of ambient temperature at MANIT Bhopal.

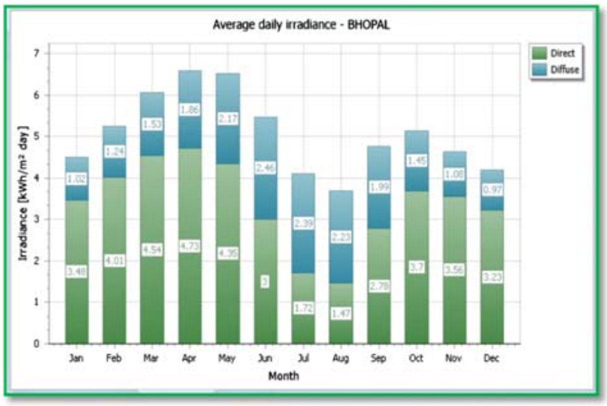

Figure 4. Variation of solar daily irradiance at MANIT Bhopal.

3.3 Biomass productivity prediction

While modeling algal productivity outdoors is key to monitoring full-scale development's monetary and natural execution, the greater part of the models heretofore created for this reason have not been approved under completely applicable conditions, particularly concerning temperature varieties. The goal of this investigation was to ponder the recreations representing both light and temperature and built utilizing parameters tentatively determined utilizing momentary indoor trials. Reenactments at Bhopal climatic conditions demonstrates that temperature control in external growth systems would require massive vitality measures without impressive algal biomass increases. Earlier appraisals ignoring the effect of temperature minor departure from algal productivity in cultivation frameworks may be in this way be incorrect.

The model has been used to predict the outdoor open pond productivity operated under Bhopal climatic conditions (these predictions have not been compared with experimental data).Variations in algae biomass productivity and algae concentration is given in figure 5 and figure 6. Algal biomass production and concentration depends on the climate change and different environmental factors. Algae can be easily cultivated and harvested, all depends on its doubling time. Spirulina has a higher growth rate. Biomass productivity as per the simulation data can be highest during summers when the temperature is most favourable for the growth of spirulina microalgae. Algal cell concentration can also be affected by the light intensity. If concentration is higher, light intensity should also be higher. Algae productivity and concentration is maximum in month of March and April when temperature and humidity conditions are favourable for spirulina maximum productivity and concentration For the MANIT, Bhopal location, daily solar irradiance, air temperature, wind speed, and rainfall, together with monthly daytime and nighttime relative humidity averages for the year 2018, were obtained from the NASA.

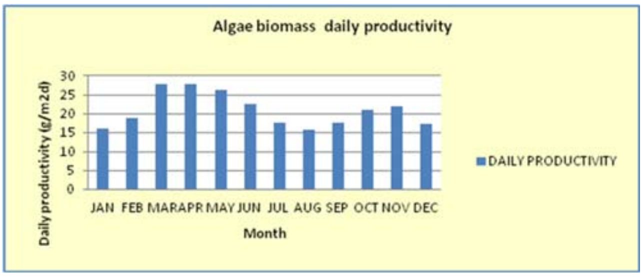

Figure 5. Variation in daily productivity of algal biomass.

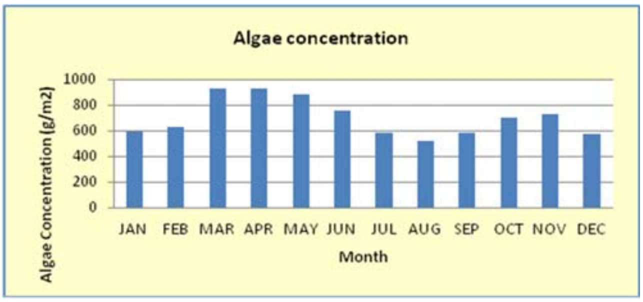

Figure 6. Variation in algae concentration with climate change.

3.4 Impact of depth and HRT on productivity and water demand.
Studies show how depth of pond (or water column) and pond °HRT impact productivity and demand for water in raceway ponds.

3.4.1 Impact of pond depth on productivity and water demand. The thermal inertia is legally connected to the mass of water in the pond and thus the depth of the water segment for a given cultivation surface area. Thus, the shallower the lake, the more remarkable are the algae's diurnal temperature vacillations. Diminishing the depth for a given hrt marginally improves by and large productivity by allowing daytime temperatures to climb near the ideal temperature for photosynthesis and prompting a faster reduction in temperature at nighttime, thus reducing evening respir.ation In a Mediterranean climate, profitability can be expanded by 8 % if the depth of the lake decreases from 0.5 to 0.1 m [18-20]. Reducing the depth of the lake, despite additional heating hazards. The continuous event of high temperatures may prompt breakdown of culture, which would affect the cost of annual productivity and inoculation.

The reduction in the water request prove is driven to a large extent by a decrease in the rate of water withdrawal from the pond (equation 1) despite an expansion in the losses of daytime evaporation as the temperature increases.

3.4.2 Impact of HRT on productivity and water demand. By and by, the cell concentration for which all available light is captured is moderately low (e.g., 0.1 kg m-3), so usually high HRT° estimates have an adverse effect on net productivity by accelerating respiration losses as algae stay longer in the pond. The Hydraulic retention time was calculated using the equation (1) [4].

$$HRT_i = \frac{V_i}{V_{s,i}} = \frac{Sd_i}{V_{s,i}} \tag{1}$$

Where,
Vi, is the culture volumes (m3)
S is the Surface area (m2)
di is the depth(m)
Vs, is the extracted volume of water
i is the day

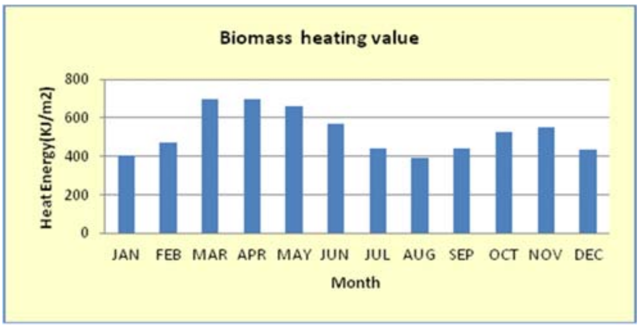

Figure 7. Variation in dry biomass heat energy with climate change.

Evaluating the economic viability and sustainability of processes involving shallow algal ponds requires the ability to forecast the productivity and environmental impact of these frameworks. It is therefore important to predict the water temperature of the pond accurately. Precisely predicting the temperature of the pond is important in the primary occurrence since temperature affects the rate of different photosynthesis reactions.variation in dry biomass heat energy with time and climate has been illustrated in figure 7. During the month of March when the temperature is high during summers the biomass heating value is at its highest range. Figure 8 illustrates the variation in water use/evaporation and rainfall with climate.

This temperature reliance creates (i) optimal growth within a certain narrow temperature range, (ii) algae to die beyond a certain temperature threshold, and (iii) algal light saturation to arise at comparatively low light intensity at low temperature, for example in the morning. Second, it is also possible to use an accurate temperature model to optimize temperature control strategies to maximize algal productivity by estimating the amount of heat to be added to or removed from the pond. Examples of the studies ' temperature control techniques involve (i) maintaining optimum temperature throughout (ii) reducing temperature to avoid high temperature growth inhibition and (iii) raising morning temperature to optimize the productivity of light utilization. Finally, accurate assessment of temperature is crucial as evaporation from shallow algal ponds is positively correlated with the temperature of the water. This ensures that the temperature directly impacts these processes ' green and blue water footprint, typically regarded as the volume of evaporative water loss per unit of produced biomass. Different water temperature prediction models have been studied in lakes, wastewater treatment ponds, aquaculture ponds, and other similar systems. The aim of this paper is to present the widespread model in shallow algal ponds for temperature prediction.

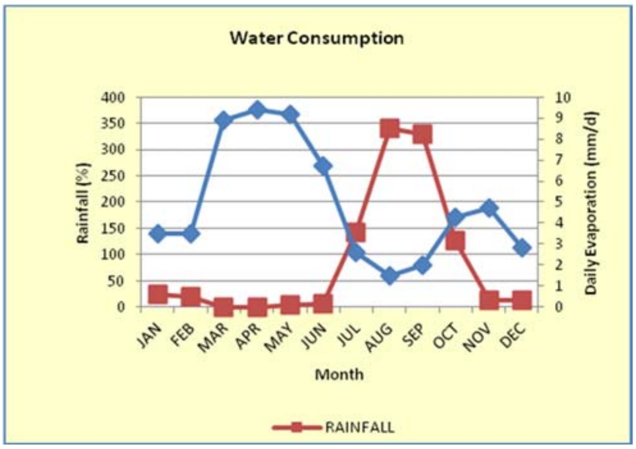

Figure 8. Variation in water use/evaporation and rainfall with climate.

4. Conclusion

Most reported biofuel production assessments are predicated on cultivation in raceway ponds since these technologies are generally regarded more cost-effective than closed photobioreactors. Be'chet et al. showed, however, that temperature fluctuations in shallow ponds can also be significant, with seasonal variations reaching 30 °C in a temperate climate. Therefore, the results presented here suggest that temperature should also have a significant impact on algal productivity in raceway ponds and that failure to account for its effect may result in overestimating cost-effectiveness and environmental performance in these systems. Suitable auditing for evaporation seems to be the best approach to the new universal model and confirms that the most relevant to predicting the rate of evaporation is a theoretical approach. The inaccuracy of the temperature prediction introduced by the use of alternative heat flux expressions described in the literature could lead to an overestimation or underestimation of algal productivity and water evaporation rate of approximately 40% and 300%, respectively. Finally, our study shows that deserts in closed photobioreactors are very challenging areas for algae cultivation. Although deserts generally offer high irradiation levels and large tracts of accessible non-arable soil and therefore are often recommended as suitable for algae cultivation, reactor temperatures in these regions may rise to 50 °C and above.

Given that water for cooling reactors is usually rare in these areas, it would be necessary to make further technical changes to reduce the temperature of cultivation. One option is to use nets stretched over panel rows that provide shade during the year's hottest times. However, the impact of such an approach on reactor temperatures is not clear and future research needs to address. In addition, technical cooling measures are generally associated with costs. Few algae are capable of resisting growing temperatures of 50 °C, mostly cyanobacteria. Algae cultivation in uncooled photobioreactors is theoretically possible even in hot environments such as deserts by using such thermophile organisms. Currently, however, there is little practical experience for large-scale thermophilic algae cultivation. Further research should be focused on extending the simulation tool to cover promising reactor types other than flat panel reactors in the context of the demonstrated importance of temperature simulation. However, the most important thing is to implement a temperature-sensitive microalgae growth model to calculate realistic productivity values for plants cultivating outdoor algae and site-specific growth conditions. An implementation of this kind is subject to our ongoing work. Whereas the simulations portrayed here depend on the criteria set, the findings suggest that intending to evaluate effectiveness without taking into consideration process optimization or local constraints can result in substantially different results. This raises the risk that full-scale, practically achievable field outcomes may have been quantified inaccurately by prior assessments.

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References
[1] Béchet, Q., Shilton, A., Park, J. B., Craggs, R. J., & Guieysse, B. (2011). Universal temperature model for shallow algal ponds provides improved accuracy. Environmental science & technology, 45(8), 3702-3709.
[2] Jayaraman, S. K., & Rhinehart, R. R. (2015). Modeling and optimization of algae growth. Industrial & Engineering Chemistry Research, 54(33), 8063-8071..
[3] Endres, C. H., Roth, A., & Brück, T. B. (2016). Thermal reactor model for large-scale algae cultivation in vertical flat panel photobioreactors. Environmental science & technology, 50(7), 3920-3927.
[4] Béchet, Q., Shilton, A., & Guieysse, B. (2016). Maximizing productivity and reducing environmental impacts of full-scale algal production through optimization of open pond depth and hydraulic retention time. Environmental science & technology, 50(7), 4102-4110.
[4] Béchet, Q., Shilton, A., & Guieysse, B. (2014). Full-scale validation of a model of algal productivity. Environmental science & technology, 48(23), 13826-13833.
[5] Soni, R. A., Sudhakar, K., & Rana, R. S. (2017). Spirulina–From growth to nutritional product: A review. Trends in food science & technology, 69, 157-171.
[6] Shukla, A. K., Sudhakar, K., & Baredar, P. (2016). Design, simulation and economic analysis of standalone roof top solar PV system in India. Solar Energy, 136, 437-449.
[7] Zeng, F., Huang, J., Meng, C., Zhu, F., Chen, J., & Li, Y. (2016). Investigation on novel raceway pond with inclined paddle wheels through simulation and microalgae culture experiments. Bioprocess and biosystems engineering, 39(1), 169-180.
[8] Soni, R. A., Sudhakar, K., & Rana, R. S. (2016). Biophotovoltaics and Biohydrogen through artificial photosynthesis: an overview. International Journal of Environment and Sustainable Development, 15(3), 313-325
[9] Vargas, J., Dias, F., Mariano, A., Balmant, W., Rosa, M., Savi, D., ... & Ordonez, J. (2017). Modeling and simulation of microalgae derived hydrogen production in compact large scale photobioreactors. In APS March Meeting Abstracts..
[10] Papáček, Š., Matonoha, C., & Petera, K. (2017, May). Modeling and Simulation of Microalgae Growth in a Couette-Taylor Bioreactor. In International Conference on High Performance Computing in Science and Engineering (pp. 174-187). Springer, Cham.
[11] Blanken, W., Postma, P. R., de Winter, L., Wijffels, R. H., & Janssen, M. (2016). Predicting microalgae growth. Algal research, 14, 28-38..
[12] Soni, R. A., Sudhakar, K., & Rana, R. S. (2019). Comparative study on the growth performance of Spirulina platensis on modifying culture media. Energy Reports, 5, 327-336.
[13] Apel, A. C., & Weuster-Botz, D. (2015). Engineering solutions for open microalgae mass cultivation and realistic indoor simulation of outdoor environments. Bioprocess and biosystems engineering, 38(6), 995-1008.

[14] Cappai, L., de Ville d'Avray, M. A., Mdere, O., Linnekoski, J., Verdú, E. R., & Fernández, E. C. (2017). Simulation-based study of the energy requirements linked to the temperature control of micro-algae culture in outdoor photobioreactors.
[15] Sudhakar, K., & Soni, R. A. (2017). Carbon Sequestration Through Solar Bioreactors: Industrial Strategies. In Carbon Utilization (pp. 143-155). Springer, Singapore..
[16] Gao, X., Kong, B., & Vigil, R. D. (2018). Simulation of algal photobioreactors: recent developments and challenges. Biotechnology letters, 40(9-10), 1311-1327.
[17] Shahriar, M., Deb, U. K., & Rahman, K. A. (2017, June). Simulation of temperature effect on microalgae culture in a tubular photo bioreactor for local solar irradiance. In AIP Conference Proceedings (Vol. 1851, No. 1, p. 020021). AIP Publishing.
[18] Huesemann, M., Crowe, B., Waller, P., Chavis, A., Hobbs, S., Edmundson, S., & Wigmosta, M. (2016). A validated model to predict microalgae growth in outdoor pond cultures subjected to fluctuating light intensities and water temperatures. Algal Research, 13, 195-206.
[19] Bernard, O., Mairet, F., & Chachuat, B. (2015). Modelling of microalgae culture systems with applications to control and optimization. In Microalgae Biotechnology (pp. 59-87). Springer, Cham.