

Mathematical Modeling of Bioremediation Potential of Microbes in Industrial Effluent

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Abstract: The analysis of potential of microbial population in bioremediation process against industrial effluent is developed using mathematical model. The logistic linear differential equation is derived from the basic principles and formulated for the growth model. This work is important in study of stability of bioremediation process in the certain period of time in the removal of pollutant. The developed model is applied to parameters total, suspended and dissolved solids, biological and chemical oxygen on demand and chloride. Further the untreated and treated effluents were analyzed for effluent tolerance index in the germination of *Cajanus cajan* (red gram).

Keywords: Marine streptomycetes, Sugar industry effluent, Biological treatment, Mixed consortium.

I. INTRODUCTION

As the result of industrialization our environment has obtained its considerable share in the form of pollutants and toxins [4] in the form of liquid and solid. The industrial pollutants or effluents are any wastewaters generated by industries which are typically treated and released into surface waters. If not treated properly, these can pose harmful effects to wildlife and aquatic ecosystems. The chemical compounds present in the effluent leads to the contamination of the water body and deteriorates water quality which in return cause significant effect to the aquatic ecosystem and possess serious health hazard [2, 5] for those who use the stream and river water for agriculture and domestic purposes directly such the rural and semi-urban population. They also alter the physico-chemical characteristics [7] of the receiving aquatic bodies and affect aquatic flora and fauna. Physico-chemical process employed in industrial effluent treatment involves high energy and cost for the removal of dissolved materials such as screening, coagulation, flocculation, activated carbon treatment, reverse osmosis, electro dialysis, ion exchange, chemical oxidation, trickling filtration and activated sludge digestion [10]. The bioremediation technique provide the cost effective-method of cleaning the contaminated environmental media with hazardous chemicals and metals etc., In the present paper efforts had been

made to develop the mathematical model for the prediction of pollution removal from the toxic effluent from sugar industry using actinomycetes strain, *Streptomyces species* (spp.) (*S. albus* and *S. clavuligerus*).

II. MATHEMATICAL MODEL

In the bioremediation technique certain assumptions are taken for the *Streptomyces* spp. containing toxic compounds. In this study the assumption is taken with increasing time and the concentration of pollutants decreases by the microorganism.

III. BIOREMEDIATION MODEL

Let P be the bioremediation potential of the *Streptomyces* spp. at the given time 't' from initial day of the experiment. Then the rate of change in P with respect to time t from the initial day of the experiment up to the time when the microbes attain equilibrium is directly proportional to P , at time t .

$$\frac{dp}{dt} \propto P = \mu P \quad (1)$$

Where, μ is a constant. On integrating equation (1)

$$\ln P = \mu t + C \quad (2)$$

Where, C is the constant of integration. To get the value of C , the initial condition is employed in equation (2) as the initial day of experiment i.e., $t = 0$; P will be maximum, let it be P_0 , then

$$\ln P_0 = \mu \cdot 0 + C$$

$$C = \ln P_0$$

Or

Putting the value of C in (2)

$$\ln P = \mu t + \ln P_0$$

Or

$$\ln P - \ln P_0 = \mu t$$

$$\ln P / \ln P_0 = \mu t$$

Or

$$P / P_0 = \exp(\mu t)$$

$$P = P_0 \exp(\mu t) \quad (3)$$

The model derived is valid only for $t > 0$. The value of μ depends upon the curve of difference according to the time lapse, i.e., μ will be positive if the curve is increasing, otherwise negative. From equation (3)

$$\mu = \{\ln(P / P_0)\} / t$$

Now take t as equal interval; $t_1, t_2, t_3, \dots, t_N$.

$$\mu_i = \{\ln(P / P_0)\} / t_i \quad \text{where } i = 1, 2, \dots, N$$

$$\mu = \frac{\sum_{i=1}^N \mu_i}{N}$$

Then by putting the value of μ in equation (3) we can predict the activity.

IV. MATERIALS AND METHODS

A. Sample Collection from Marine Sediment

The sediment samples from the marine environment was collected by using the core sampler at depth of 3 meters from two different area's of Tiruchendur, Bay of Bengal (Latitude: 8°29.80 N Longitude: 78°07.73 E), Tuticorin District, Tamilnadu, East Coast of India.

B. 16S rRNA Gene Partial Sequencing for Identification

The organisms were identified by 16S rRNA gene partial sequencing method. It is a typical approach of taxonomical classification based on similarity of known sequences in existing databases [12]. This tool provides reliability for rapid identification of genus-level and their differentiation from closely related organisms. The Genomic DNA was isolated from the pure culture, the rDNA fragment was amplified by high-fidelity PCR polymerase and the PCR (Polymerase Chain Reaction) product was sequenced using the forward internal primer. The gene 16S rRNA is present in all bacteria and related form occurs in all cells. It is the gene encoding of RNA component of small subunit of bacterial ribosome. 16S refers the rate of sedimentation in Svedberg units of RNA molecule

in centrifugal field. The advantage is results can be obtained within 1 day as compared to traditional microbiological testing which takes 7 days [11].

C. BLAST Technique

The BLAST technique (Basic Local Alignment Search Tool) provides a method for rapid searching of nucleotide and protein databases. As the BLAST algorithm detects local as well as global alignments, it's used to detect the regions of similarity embedded in unrelated nucleotides and proteins. These types of similarities provide important clues to the function of uncharacterized nucleotides and proteins. The sequenced data was aligned and analyzed to identify the microorganism and its close species.

D. Collection of Sugar Industry Effluent

The untreated sugar industry effluent was collected from a sugar industry located in Moganur, Namakkal district, Tamilnadu, India. The sample was transported to the laboratory immediately in a sterile container. For further analysis the effluent sample was preserved at 4°C.

E. Effluent Treatment by *Streptomyces spp.*

The filtered effluent was autoclaved at 121°C for 15 min to sterilize from other microorganisms. The parameters such as TS, TSS and TDS, BOD, COD and chloride were analyzed according to APHA [1], [9] using the raw effluent. The effluent sample each of 500ml was taken in the 3 sets of flask. To this sample 100ml of nutrient solution and 50ml of inoculum was added and each isolated strain was added as the single and mixed consortium (combination of both microbes) to the effluent samples which amends with the nutrients. To these samples microbial treatment was given for about 20 days with pH 9 and 40°C the flasks were kept in an incubator shaker with 180 rpm/min and experimented in triplicates. Here the data obtained from mixed consortium is taken for the analysis as it showed better activity than the single species. The physiochemical characteristics of the samples treated were analyzed at regular intervals of time period. The data collected after 20 days are omitted from calculating μ (Table II and III)

TABLE I: BIOLOGICAL TREATMENT OF SUGAR INDUSTRY EFFLUENT USING MIXED CONSORTIUM (VALUE±SE)

| Parameters (ppm) | Untreated effluent (mg/l) (t_0) | Treated effluent | | | | |
|------------------|-------------------------------------|---------------------|----------------------|----------------------|----------------------|--------------|
| | | 5 th day | 10 th day | 15 th day | 20 th day | % of removal |
| TS | 2100.67±0.12 | 1624±0.12 | 710.00±0.12 | 432.32±0.12 | 347.00±0.12 | 83.45 |
| TSS | 485.89±18.12 | 286.34±18.12 | 115.33±18.12 | 82.44±18.12 | 49.02±18.12 | 89.91 |
| TDS | 1614.78±30.12 | 1024.32±30.12 | 694.670±30.12 | 334.18±30.12 | 198.48±30.12 | 81.51 |
| BOD | 1020.00±4.99 | 804.32±4.99 | 432.33±4.99 | 244.13±4.99 | 102.00±4.99 | 90.00 |
| COD | 2015.00±15.47 | 1628.32±15.47 | 883.67±15.47 | 648.34±15.47 | 185.00±15.47 | 90.81 |
| Chloride | 384.420±0.24 | 211.13±0.24 | 118.00±0.24 | 89.12±0.24 | 46.00±0.24 | 88.03 |

Values are mean of three replicates, ppm - parts per million, SE-standard error

TABLE II: CALCULATION OF μ FOR TS, TSS, TDS

| TS | t_i^* | P_i | P_i/P_0 | $\ln(P_i/P_0)$ | $\mu_i = \{\ln(P / P_0)\} / t_i$ | Mean (μ) |
|-----|---------|---------|-----------|----------------|----------------------------------|----------------|
| | 0 | 2100.67 | 1 | | | -0.08877 |
| | 5 | 1624.12 | 0.77314 | -0.2573 | -0.05146 | |
| | 10 | 710.00 | 0.3379 | -1.08501 | -0.108501 | |
| | 15 | 434.32 | 0.20675 | -1.5762 | -0.10508 | |
| | 20 | 347.00 | 0.1652 | -1.8006 | -0.09003 | |
| TSS | | | | | | -0.07983 |
| | 0 | 485.89 | 1 | | | |
| | 5 | 286.34 | 0.5893 | -0.5288 | -0.10576 | |
| | 10 | 115.33 | 0.2373 | -1.4381 | -0.14381 | |
| | 15 | 334.18 | 0.68778 | -0.3743 | -0.02495 | |
| | 20 | 198.43 | 0.40838 | -0.8956 | -0.04478 | |
| TDS | | | | | | -0.09631 |
| | 0 | 1614.78 | 1 | | | |
| | 5 | 1024.32 | 0.63434 | -0.45517 | -0.09103 | |
| | 10 | 694.67 | 0.4302 | -0.84358 | -0.08436 | |
| | 15 | 334.18 | 0.20695 | -1.57528 | -0.10502 | |
| | 20 | 198.48 | 0.12291 | -2.09630 | -0.10482 | |

* t_i - No. of days

TABLE III: CALCULATION OF μ FOR BOD, COD, CHLORIDE

| BOD | t_i^* | P_i | P_i/P_0 | $\ln(P_i/P_0)$ | $\mu_i = \{\ln(P / P_0)\} / t_i$ | Mean (μ) |
|----------|---------|---------|-----------|----------------|----------------------------------|----------------|
| | 0 | 1020.00 | 1 | | | -0.07526 |
| | 5 | 804.32 | 0.78855 | -0.02375 | -0.00475 | |
| | 10 | 432.33 | 0.42385 | -0.85838 | -0.17167 | |
| | 15 | 244.13 | 0.23934 | -1.42987 | -0.28597 | |
| | 20 | 102.00 | 0.1 | -2.30259 | -0.46051 | |
| COD | | | | | | -0.08001 |
| | 0 | 2015.00 | 1 | | | |
| | 5 | 1628.32 | 0.80809 | -0.21308 | -0.04261 | |
| | 10 | 883.67 | 0.43854 | -0.82430 | -0.08243 | |
| | 15 | 648.34 | 0.3218 | -1.13383 | -0.07559 | |
| | 20 | 185.00 | 0.09181 | -2.38803 | -0.1194 | |
| Chloride | | | | | | -0.11039 |
| | 0 | 384.42 | 1 | | | |
| | 5 | 211.13 | 0.5492 | -0.59929 | -0.011985 | |
| | 10 | 118.00 | 0.30696 | -1.18103 | -0.1181 | |
| | 15 | 89.12 | 0.23183 | -1.46175 | -0.09745 | |
| | 20 | 46.00 | 0.11966 | -2.12310 | -0.10616 | |

* t_i - No. of days

TABLE IV: GERMINATION OF *C. CAJAN* USING SUGAR INDUSTRY EFFLUENT

| Parameter | Control | Untreated effluent (%) | Treated effluent (%) |
|---------------------------|---------|------------------------|----------------------|
| Concentration of Effluent | - | 100 | 100 |
| Germination (%) | 100 | 60 | 100 |
| Shoot length (cms) | 15.20 | 8.56 | 15.50 |
| Root length (cms) | 4.10 | 2.68 | 4.50 |
| Seedling length(cms) | 19.30 | 11.24 | 20.00 |
| Seedling vigour index | 1930 | 674.40 | 2000 |
| Phytotoxicity | - | 41.76 | - |
| Effluent tolerance index | - | 1.71 | - |

Values are mean of three replicates

V. RESULTS AND DISCUSSION

The parameters exhibited potential decrease in P of the *Streptomyces* spp. from the start to the end of the observation of the experiment. In the present study, germination of the plant *CajanusCajan (red gram)* were observed using untreated and treated effluents and the parameters such as germination percentage, shoot length, root length, seedling length and seedling vigor index were observed (Table IV). The observed germination was 100 per cent shoot length 15.50 cm, root length 4.50 cm, seedling length 20.00 cm and seedling vigor index 2000. The phytotoxicity was 41.76 per cent for the untreated effluent and the effluent tolerant index was observed as 1.71. The germination was decreased to 60% in untreated effluent as the high amount of toxicants present of in the effluent inhibits the germination and seedling growth of *C. Cajan*. This study showed the efficiency of the *Streptomyces* spp. in better management of wastes and useful ecological technique for the environmental and industrial applications.

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