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Removal Mechanism of Organics in Biological Tower

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Removal mechanism of a pilot biological tower was investigated using segmented and total depth approaches. Graphical analysis done on BOD ad COD results of filtered samples collected from every three feet depth of the tower indicated that the mechanism is better represented by total depth removal than segmented removal. Removal Kinetics and scope for running BOD and COD tests in parallel is discussed.

Introduction

In Biological tower, the removal of organic wastes is accomplished primarily by microorganisms which are attached to medium contained in the filter process, the early version of biological tower, have been chiefly concerned with physical aspects and empirical equations and there has been a definite lack of research regarding the biological and biokinetic nature of the treatment process. Lack in understanding of the treatment mechanism has led to design problems, loading problems, maintainance and operation problems, and ultimately to reduced performance level. Biological tower process has been found to be a compatible modern process of wastewater treatment (Bentley & Kincannon 1976) which needs less space and energy than most of the processes (Kincannon & Gaudy 1978). Different empirical equations and kinetic models are used for modeling the design and are found elsewhere (Gallor & Gotaos 1964, Veiz 1948, Schulze 1966, Eckenfelder 1963, Atkinson et al. 1963). This study compares the first order reaction rate concept of Eckenfelder (1963) and total loading concept of Kincannon and Stover (1983) in context to the total depth and segmented depths approach of treatment mechanism of a pilot plant tower using sewage as the wastewater.

Biochemical Oxygen Demand (BOD) is the most universally known evaluating parameter for wastewater treatment process. Chemical Oxygen Demand (COD), another evaluating parameter, is hardly found in the guidelines or standards of pollution control agencies but is an useful determinant (Gaudy & Gaudy 1980). Both parameters, the BOD and the COD have been used for description of the treatment mechanism.

Materials and Methods

Description of Pilot Plant Biological Tower

A pilot plant biological tower of total 6m depth 33cm x 33cm cross-sectional area, containing growth modules of 0.11 m^3 and spacing of about 7.5-10cm depth for sample collection was used to treat sewage. The tower consisted of a series of three separate towers, each of 2m depth. The plastic media provided a specific surface area of 127m^2/m^3. The influent was pumped to the top of the first tower, where it was dispersed evently over the cross-sectional area by a splash plate and allowed to trickle down through two growth modules and collected in a wet well at the bottom. The fluid collected in the wet well was continuously pumped to the top of the second tower, identical in every respect to the tower. Then it was pumped to top of the third

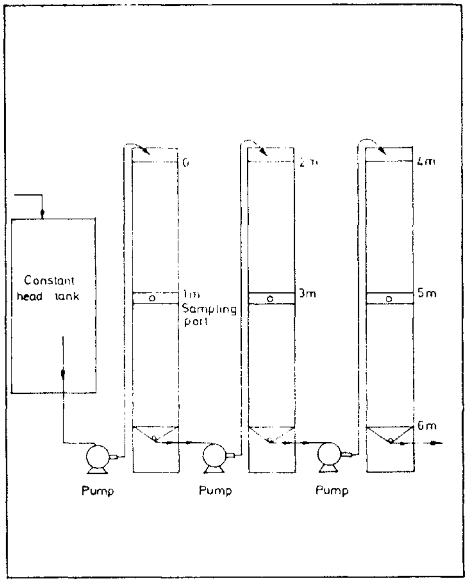


Figure 1. Schematic drawing of the experimental biological tower pilot plant

tower, which was also identical in every respect to the other two towers. The trickled down effluent was disposed into the sanitary sewer system at this point. Figure 1 is the schematic representation of the pilot plant Biological Tower.

Sampling and Tests

The pilot plant was operated at three hydraulic loadings, 54, 59, and 117 $m^3/day/m^2$. For each loading, samples were collected three times a week for about two months. Each set of samples contained seven representative grab samples collected at 0 (influent), 1, 2,3,4,5 and 6m (effluent) depths of the tower. A period of about at least three weeks was allowed in between the change of hydraulic flow rates to let the system approach a steady-state condition. The steady-state conditions were ascertained by obtaining comparable values of *p*H and BOD in samples of consecutive days.

The study of the removal mechanism of the sewage was based on the results obtained from BOD and COD tests performed on the collected filtrate of the sample. The five-day BOD analysis was done for every sample in accordance to modified method (Stover et al. 1983). The COD analysis was performed once every week on a set of samples following standard method (American Public Health Association 1980).

The study had the advantage of the situation that the pilot plant was treating sewage collected mainly from students dormatories of a school and was of only domestic type. The changes of hydraulic loads and collections of samples were planned with the sessions of schools so that a hydraulic loading is not affected by session and off-session. It helped to reduce the effect of the fluctuations of influent concentration on the study for a specific loading.

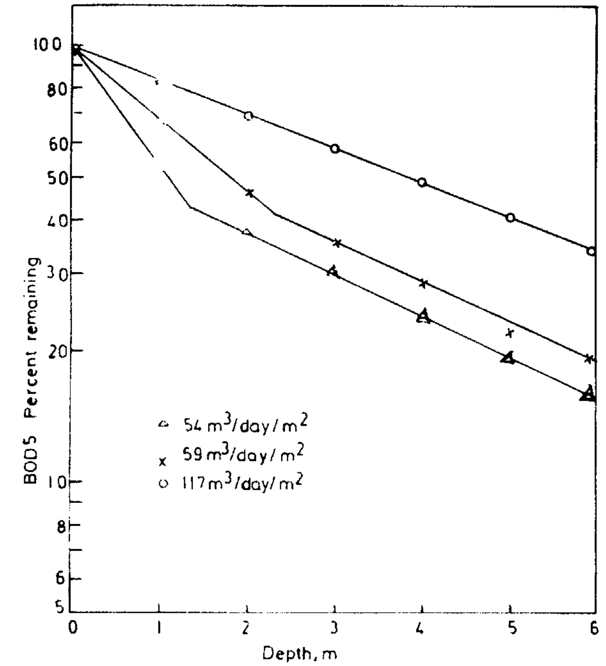
Analysis

The first order reaction rate concept and the total organic loading concept are applied, first to the total depth and then to the segments of the tower. Semilogarithmic graphical plots are used for the first order reaction rate kinetics (Eckenfelder 1963). The organic loading rate concepts are represented by graphical plots on the basis of the following model of Kincannon and Stover (1983):

$$Se = Si - \frac{Si.\ U_{max}}{K_B + (F)\ Si/A} \qquad \text{......(1)}$$

Rearranging Equation (1), the following equation may be written

$$\frac{1}{F(S_i - S_e)A} = \frac{KB}{U_{max}} \cdot \frac{1}{(F)(S_i/A} + \frac{1}{U_{max}} \qquad \text{......(2)}$$



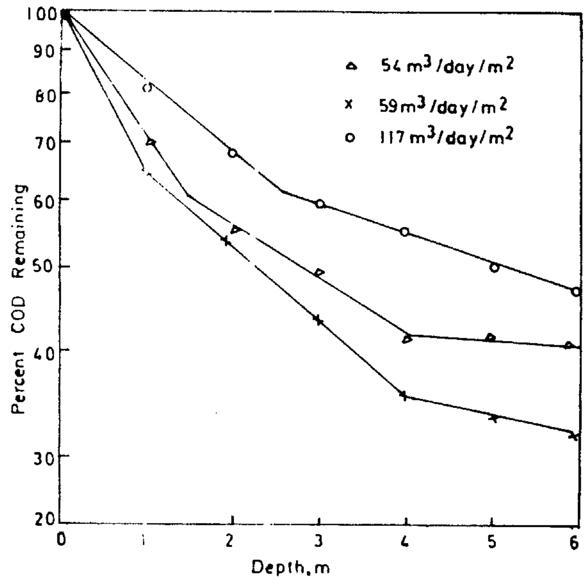


Figure 2 Semi-logarithmic relationship of pecent BOD remaining with depth during different hydraulic flow rates

Figure 3. Semi-logarithmic plots of percent COD remaining with depth

where F = hydraulic flowrate, kg/day/m^2; Si = influent substrate concentration, mg/1, Se = substrate concentration at point of measurement, mg/1; U_{max} = maximum substrate removal rate, kg/day/1000m^2; K_B = proportionality constant, kg/day/1000m^2; A = surface area of volume, 1000m^2; $F\ (Si)/A$ = Organic loading rate of BOD or COD kg/day/1000m^2. U_{max} and K_B can be determined from the intercept and slope of the straight line.

To compare the results obtained by using the above mentioned design kinetics, the graphs are plotted on the basis of average values at different depths for different sets at each hydraulic loading. Therefore, there are seven average data points at each loading. The detailed data can be found elsewhere (Bilqis 1984).

Results

The summary of the characteristics of the influent treated by the biological tower is shown in table 1. It clearly indicates that the system biomass was induced to three different conditions which varied in respect to loadings and influent concentration.

Figure 2 is semilogarithmically plotted to show BOD removal with depth. BOD curves in figure 2 indicate that the result of 117m^3/day/m^2 is following the first order reaction and is not showing any shift in the rate constant for the total depth of the tower. The results of 54 and 59m^3/day/m^3 hydraulic loadings show shift in kinetics at different depths of the tower. The result of 54m^3/days/m^2 shows change in removal rate constant earlier than other loadings; because during the loading it had the lowest food-to-microorganism ratio and so naturally it went to substrate limiting condition faster than the other loadings.

Figure 3 is plotted as semi-log of percent COD remaining with total depth of tower. All the COD curves of figure 3 show shift in kinetic. For 54 and

Table 1 *Characteristics of influent treated by the pilot plant biological tower*

Hydraulic Loadings (m^3/day/m^2)	BOD mg/1				COD mg/1			
	Min	Max	Average	Median	Min	Max	Average	Median
117	53	138	88	88	130	160	142	140
59	60	100	84	84	98	182	118	105
54	42	69	58	60	125	160	144	146

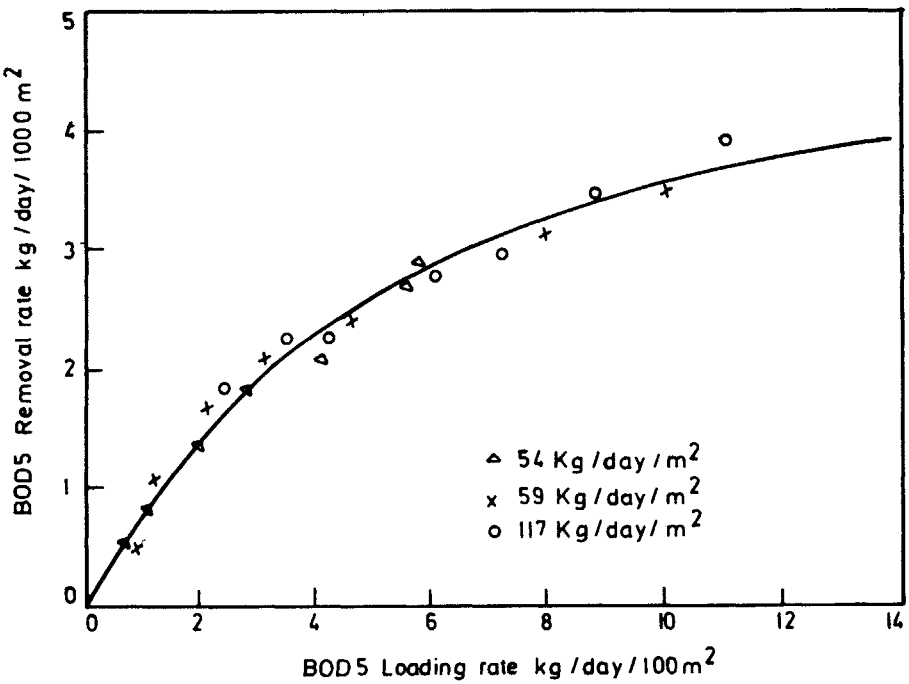


Figure 4. Relationship of BOD removed as a function of BOD loading rate

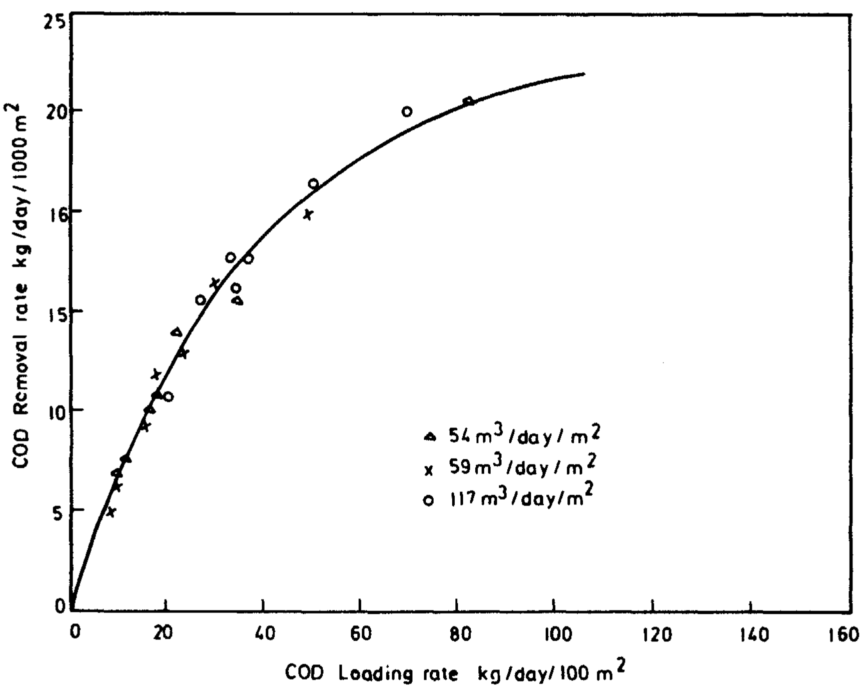


Figure 5. Relationship of COD removal rate as a function of COD loading rate

$59m^3/day/m^2$ loadings, BOD (figure 2) shows removal of substrate throughout the depth. The COD results for the same loadings (figure 3) show slower or no removal, that means oxygen demand based on biological degradation is not accounting for all carbon content of sewage, there is carbon which is represented through chemical demand of oxygen. This conforms that during all three hydraulic loading the system experienced complex biophysical and biochemical interactions and resulted into change in organic carbon concentration affecting the kinetics of the svstem.

Figures 4 and 5, the removal rate curves of BOD and COD respectively are plotted based on organic loading and organic removal rate (Kincannon 1982) show a tendency for saturation kinetics (as shown by the hyperbolic shape). Figures 6 and 7 are linear form of the total organic removal rate curves for the average values of BOD and COD respectively following the equation of Kincannon and Stover (1983). Since the computation of U_{max} and K_B values are dependent on linear relation, the values of correlation coefficients were determined. Figures 6 and 7 shows a high positive linear correlation of about 0.96 for BOD and 0.94 for COD, respectively.

Now the same first order removal rate concept and the organic loading rate concept are applied for every 1 m depth segment of the tower from the entrance of the influent to the exit of the effluent. Figures 8 and 9 are the semilogarithmic plots of percent BOD and COD remaining with segment of the tower, calculated as the proportion of BOD and COD concentration at exit of a specific segment to its concentration at the entrance of the segment. The sharp fluctuations are observed with segment. Every segment has different kinetic constant. A general expression for the whole system by using first order approach is not possible due to these kinetic changes.

The organic loading theory of kincanon and Stover (1983) have been applied to the BOD and the COD results of every segment and the details of use of organic loading equation to every segment is found elsewhere (Bilqis 1984). As an example of the complexity of the study table 2 is presented to shows the values of U_{max} based on the BOD results. To compare the linear correlation of the equation at every segment the values of R at different stages are also presented in table

Table 2 *Biokinetic constants of total organic loading concept against 1m segments (depth) of the pilot plant biological tower*

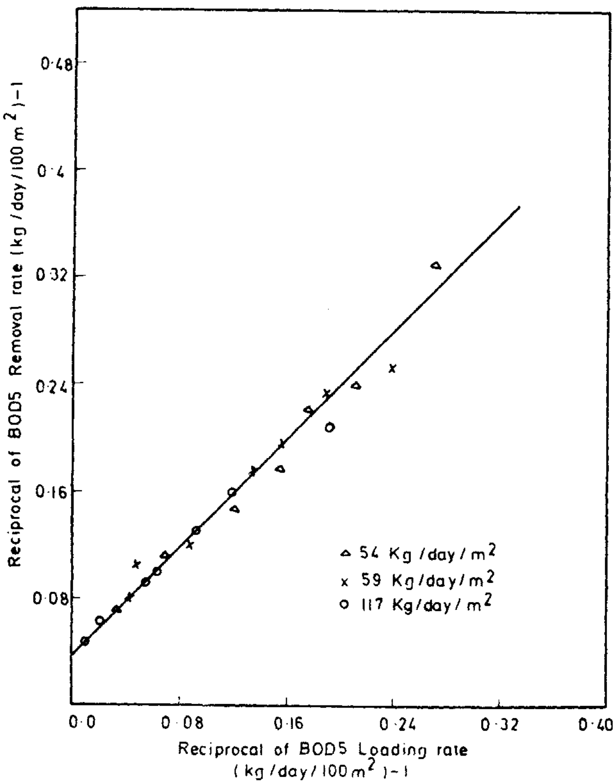
Segment	Depth (m)	U_{max} (kg/BOD/ day/1000 m^2)	Correlation coefficient, R
1	0—1	24.4	0.6
2	1—2	20.0	0.6
3	2—3	9.76	0.5
4	3—4	8.76	0.5
5	4—5	3.9	0.5
6	5—6	3.9	0.4

2. The values of U_{max} are seen to have a decreasing tendency with segments. Table 2 also indicates (from R values) that the scattering of computed data based on Kinacannon and Stover (1983) was increasing wth the progress in segments of depths. Similar trends were also shown for the COD results (Bilqis 1984). Therefore, from this complex nature of the kinetics it may be said that the application of the organic loading concept against segmented removal mechanism, as shown by Kincannon and Stover model (1983), is not feasible.

Discussion

The result clearly indicate that the removal mechanism of a biological tower can be described better by using the total depth of the tower rather than a segmented approach to the depth of the tower. The very continuous nature of the system (Bently & Kinacannon 1976) and the wide diverse group of attached, partly active biomass, leads it into a complex dynamic process of biophysical and biochemical complex reactions. This complex interrelating and interacting process, mainly relating the characteristics of substrate (sewage) and environmental factors, dictates the growth of microorganisms with depth of tower. Therefore, when the progessing reaction is segmented and each segment considered separately, the continuity of the big system ceases. A generalization of such approach for the whole system becomes difficult.

The first order reaction theory for the total depth of the tower shows shift in kinetics for both BOD and COD. Kincannon (1982) has found similar type of shift in the first order BOD kinetics for different type of wastewater,



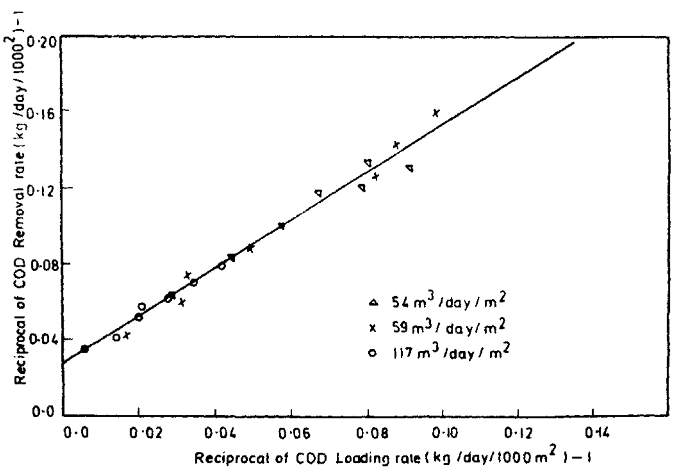


Figure 6. Reciprocal plot of BOD removal rate vs. BOD loading rate for total range of loadings
Figure 7. Reciprocal Plot of COD removal vs. BOD loading

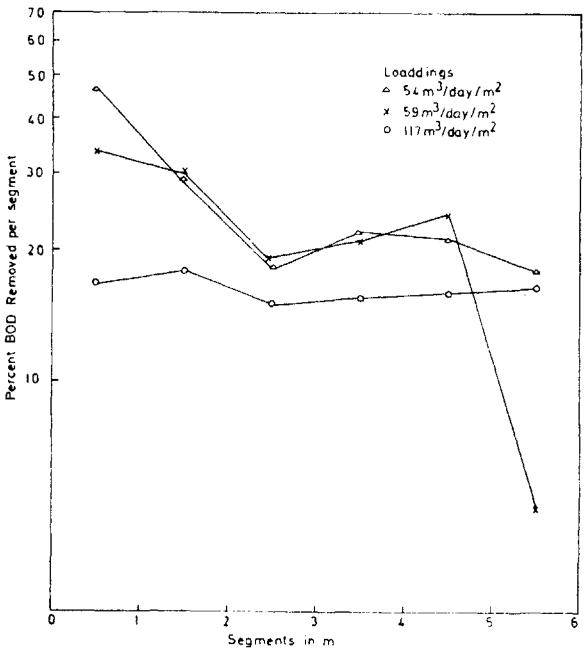


Figure 8. Percent BOD rrmoved per meter segment of the depth

which was being treated in a Biological tower. Kincannon (1982) suggested that shift in kinetic constant handicaps the use of Eckenfelder model (1963). The results of Kincannon and Stover's model (1983) show more acceptable curves, for BOD and COD, when applied for the total depth of the tower. The linear correlation-coefficient values of the plots for U_{max} and K_B also showed high correlation. The segmented approach for the analysis of treatment kinetics showed complex type of results which were beyond the applicability scope of the used first order or organic loading theories. The results indicated frequent fluctuations of kinetics with segments and within segements. Removal kinetics based on stages when applied for rotating biological contractor were also found unsatisfactory (Kincannon & Stover 1983).

Sewage contains a significant amount of less or non-biogestible compound like starch, cellulose, protein, greese etc. depending on the type of food consumed (Clarke et al. 1977, Hunter et al. 1965). The availability of easily biodegradable content of sewage decrease as it progress through the tower and consequently the concentration of less-biodegradable or nonbiogradable content of the sewage increases. The metabolic process analysis of the biomass also secrates end products which are usually organic compounds of less biodegradable nature (Doelle 1975). This contributes to the organic concentration. The BOD_5 test, which accounts the demand of oxygen mainly due to aerobic metabolism of seed, usually do not show the effect of less or non-degradable carbon content of the substrate which has the potentiality to show oxygen demand

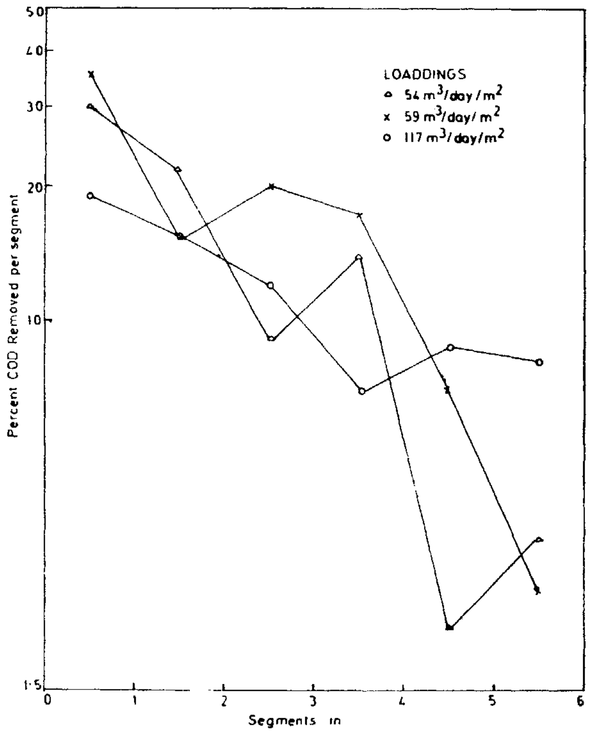


Figure 9. Percent COD removed per meter segment of the Depth

after 5 days or in the stream. Merits of BOD test is not conflicted but an user of the test should consider the limitations of the test and be aware about the possibilities of the demand of oxygen in natural water bodies. Because in water bodies a wide variety of microbial population exist. Depending on the type and the concentration of microbial population, the environmental condition, carbon concentration and its type, a wide variety of carbon can be degraded.

The results of chemical oxygen demand provides an option to know about the organic loads, and when conducted in parallel to the BOD tests, the approach is more helpful in evaluating or studying the removal mechanism. The change in COD removal mechanism during the 117 $m^3/day/m^2$ loading, when BOD was showing one rate, indicates the presence of less or non-biodegradable organic constant, in addition to the high quantity of biodegradable carbon content. When BOD and COD results for 54 and 59 $m^3/day/m^2$ loadings are compared, it is understood that the amount of easy or more biodegradable organic compound was being used up by microorganism, and the concentration of non-or less-biodegradable compounds was becoming more prominent. Therefore, analysis of BOD removal alone in the cases of less biodegradable wastewater like chemical industrial effluent containing complex carbon compund, may lead to serious design/operational flaws.

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