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Application of a Multichannel Respirometer to Assess the Biokinetic Parameters of Industrial Wastewater

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Abstract

In this study, some important biokinetic parameters of industrial wastewater were assessed by a locally fabricated multichannel respirometric device. A revised theoretical approach has also been incorporated in the determination of biokinetic coefficients (yield coefficient, reaction rate and biodegradability) using the concept of headspace gas respirometry. Wastewater samples from different industrial sources were studied by the device in presence of freshly cultured seed inoculums as biomass agent. It is found that the results obtained from the respirometric bioassay can easily evaluate the overall operation and treatment efficiency achieved by an industrial effluent treatment plants (ETPs).

Keywords: Multichannel respirometer, wastewater, yield coefficients, OUR, biodegradation, ETPs.

Introduction

Wastewater disposal is a burning issue of the day in Bangladesh. Different programs are being undertaken to reduce the severity of the problems. Environmental laws and legislations are being customized for proper application. Various guidelines are enforced to follow. Industrialists are very much concern to handle this problem soundly. However, selecting an efficient and low-cost treatment option is a very crucial matter[1-3].

Industrial wastewater could be treated by physical, chemical and or biological processes. The biological system in form of activated sludge can be a cheapest and feasible choice in the context of our country since it solely depends on the natural biodegradation process and requires less operation and maintenance efforts. However, the space requirements are much higher for this particular type of treatment in compare to other conventional options. The amount of space depends on the biodegradability of organic matters of the wastewater which actually associated with the biokinetic parameters of the microbes and gravitational settling characteristics of activated sludge. A typical biological unit of wastewater treatment consists of two parts i. aeration reactor ii. sludge separation unit. The size of the reactor solely depends on the microbial growth kinetics. So in order to optimize the reactor volume, this kinetics should be studied thoroughly[3,4].

In the present study, a low cost respirometric device fabricated in the Laboratory of Center for Environmental Process Engineering (SUST, Bangladesh) has been used for the determination of wastewater biokinetic coefficients. The respirometric device measures the oxygen concentration in the gas phase by manometric method. Its performance has been tested with a standard Glucose-Glutamic acid (GGA) solution, and the oxygen uptake data acquired from the biodegradation of the solution have been compared with those reported in the literature[5-7]. Efforts have been made to correlate various biokinetic parameters with the oxygen uptake data revealed form the experimental respirograms[8,9]. These parameters can assist users in *decision making* with regard to treatment *efficiency* improvements and optimization of the ETPs.

Biokinetic parameters: Biodegradability and rate of biodegradation: The concept, 'biodegradability' expresses the capability of an object to undergo biodegradation (manifested by the decrease in the chemical oxygen demand, *COD*)[8,10]. The *COD* has both biodegradable and non-biodegradable components as follows:

$$\mathrm{COD} = \mathrm{COD_{In}} + \mathrm{COD_{sI}} + \mathrm{COD_{sB}}; \quad \text{with} \quad \mathrm{COD_{sB}} = \mathrm{S} \qquad (1)$$

The subscripts *In*, *sI* and *sB* denote respectively the insoluble, soluble inert and soluble biodegradable constituents of the *COD*. The subscript *S* symbolizes substrate concentration in the sample. In a biodegradation process, the insoluble and inert constituents of the *COD* remain unaffected and the oxygen uptake is only related to the biodegradable constituents, COD_{sB}. Thus,

$$\Delta\mathrm{COD} = \Delta\mathrm{COD_{sB}} = \Delta\mathrm{S}; \quad \text{with} \quad \Delta\mathrm{COD} = \mathrm{COD_0} - \mathrm{COD}$$
$$\text{and } \Delta\mathrm{S} = \mathrm{S_0} - \mathrm{S} \qquad (2)$$

Where the subscript *0* stands for the parameter at the time t=0.

The biodegradability, α_0, of an effluent could be defined as follows:

$$\alpha_0 = \mathrm{COD_{sB,0}}/\mathrm{COD_0} = (\mathrm{COD_0} - \mathrm{COD_\infty})/\mathrm{COD_0} \qquad (3)$$

Where the subscript ∞ stands for the parameter at the time $t\rightarrow\infty$. In a biodegradation process, COD_{sB} is assumed zero at the time $t\rightarrow\infty$. Conventionally a BOD-COD ratio is taken as a measure

for the biodegradability of an effluent. The BOD of an effluent is defined as the oxygen uptake (*OU)* in a biodegradation process in a given time *t*. The *BOD* value increases with the biodegradation time, and conventionally, the criterion for the effluent quality is accepted to be BOD_5 (with biodegradation time $t = 5$ days) and the biodegradability is defined as

$$\alpha_s = \mathrm{BOD_u}/\mathrm{COD_0} = \mathrm{OU_\infty}/\mathrm{COD_0} \quad (4)$$

Where BOD_u known as ,ultimate *BOD*' is the oxygen uptake for $t \to \infty$.

From the way of definition of the biodegradability, it becomes evident that α_0 is a seed-independent and α_s is a seed-dependent parameter. But if the oxygen uptake is measured for the biodegradation with naturally grown or adapted microorganism, the biodegradability, α_s, defined by the equation (4) is quite sound for practical purposes. The biodegradability, α_0, defined by the equation (3) is of theoretical interest and could also be used for practical purposes.

Relationship among COD, activated biomass concentration, X, yield coefficient, Y and oxygen uptake, OU: In a biodegradation process, the biodegradable portion of the substrate *COD* is partly oxidized (measured as *OU*) and partly included as microbial cell-*COD* growth, (measured as *COD* equivalent of *ΔX*). Thus

$$\Delta\mathrm{COD} = \Delta\mathrm{COD_{sB}} = \Delta\mathrm{OU} + \Delta\mathrm{COD_{cell}} \quad (5)$$

For the simplicity of the analysis, the effect of decay rate k_d of the microorganism is ignored and the following linear relations are assumed[9]:

$$\Delta\mathrm{COD_{cell}} = \mathrm{O_x}\Delta\mathrm{X} \quad (6)$$

$$\Delta\mathrm{X} = \mathrm{Y}\Delta\mathrm{COD} \quad (7)$$

Where *Y* is the yield coefficient; mass of cells produced per unit mass of substrate utilized (mg *X*/mg *COD*), and O_x is the oxidative potential of the biomass. Combining equation (5-7) we obtain

$$\Delta COD = \gamma \Delta OU; \quad with \quad \gamma = 1/(1 - YO_x) \quad (8)$$

And

$$\Delta X = \beta \Delta OU; \quad with \quad \beta = Y/(1 - YO_x) \quad (9)$$

The *ΔCOD* vs. *ΔX* (equation 7) and *ΔCOD* vs. *ΔOU* (equation 8) (or *ΔX* vs. *ΔOU* (equation 9)) data could be fitted to straight lines to give the parameters, *Y* and O_x. Thus, *Y* can be determined from individual batch kinetic tests for *ΔX* vs. *ΔCOD* data using a laboratory fermentator. A rough estimation of *Y*, assuming an average value of O_x in the range of 1.42-1.48, however, seems satisfactory for respirometric analysis of biodegradation using two measured values of *COD* at a given time-interval and the corresponding oxygen uptake[11]. Then for the calculation of the parameter *Y*, the equation (8) is rewritten as follows:

$$\mathrm{Y} = (1 - \Delta\mathrm{OU}/\Delta\mathrm{COD})/\mathrm{O_x}; \quad \text{with} \quad \mathrm{O_x} = 1.42 - 1.48 \quad (10)$$

It is difficult to collect samples for *COD* from a respirometric device without affecting the preciseness of the measurement of oxygen uptake. Thus, it is recommended that the *COD* be measured initially and after the respirometric experiment is completed. For the present analysis, the *COD* was measured initially and after an experimental period of 120 h and *Y* was calculated by the following relation:

$$\mathrm{Y} = \left(1 - \frac{\mathrm{OU_{120}}}{\mathrm{COD_0} - \mathrm{COD_{t=120}}}\right)/\mathrm{O_x}; \quad \text{with} \quad \mathrm{O_x} = 1.45 \quad (11)$$

Where OU_{120} is the cumulative oxygen uptake for the time *t*= 120 h. Having the value of *Y*, the value of β can be estimated (see equation 9).

Calculation of biodegradability and the rate of biodegradation: For effective operation of an activated sludge plant, the biodegradability (defined by the Eq. (3) or (4)), and the biodegradation rate must be high. Combining the equation (3) and (8), and the equations (4) and (8), we have

$$\alpha_0 = \gamma \mathrm{OU_\infty}/\mathrm{COD_0} \quad (12)$$

$$\alpha_s = \mathrm{OU_\infty}/\mathrm{COD_0} \Rightarrow \alpha_0 = \gamma\alpha_s \quad (13)$$

And combining the equation (3) and (8), for the rate of biodegradation, we have

$$|\mathrm{dCOD_{sB}}/\mathrm{dt}| = |\mathrm{dCOD}/\mathrm{dt}| = \gamma(\mathrm{dOU}/\mathrm{dt}) \quad (14)$$

Thus practically α_0 and α_s are equivalent (simply multiple by a factor, γ). As the Eq. (14) shows the biodegradation rate is equivalent to oxygen uptake rate. Thus, the biodegradation process (resulting in the gradual decrease in the *COD*) is manifested by the *OU* uptake from the system and its control could be done following the *OU* profile only.

The *OU* vs. *t* data are usually found to be described by a first order rate equation of the type[3]:

$$\mathrm{OU} = \mathrm{OU_\infty}\left(1 - \mathrm{e^{-kt}}\right) \quad (15)$$

Correspondingly, the *COD*-decreasing rate (biodegradation rate) is given by the following relation:

$$|\mathrm{dCOD}/\mathrm{dt} = \gamma(\mathrm{dOU}/\mathrm{dt})| = \gamma \mathrm{k} \mathrm{OU_\infty} \mathrm{e^{-kt}} \quad (16)$$

Thus, the whole task of evaluating the biodegradability of a wastewater is reduced to the determination of γ (or *Y*) and to collect *OU* vs. *t* data.

Material and Methods

BIOSUST multichannel manometric respirometric system (MRMR)--principle of operation and data treatment: The present unit is a specially designed device based on the principle of headspace gas respirometry. It consists of six respirometric units (RU), each of which can operate independently. The oxygen consumption of the reference and the sample solutions with different dilutions can be studied simultaneously with the MRMR. Each RU of the device is identical to that in figure 1 and comprises a constantly stirred batch reactor (CSBR) and an open tube manometer unit.

The CSBR of all the six RUs are placed in a common water bath, the temperature of which is maintained by a temperature control system. The body structure of the respirometer is organized in two sections: i. Reaction section (situated on the rear side of the apparatus) containing the six reactors with all accessories (figure 2) and ii. Measuring section (situated on the front side of the apparatus) containing the six manometers (figure 3). A detailed calibration study using standard GGA solution was performed to authenticate the results obtained from the respirometer[12,13].

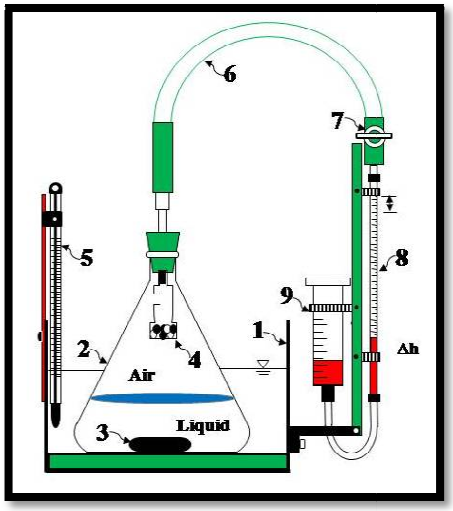

Figure-1
Schematic diagram of a single respirometric unit (RU)
1- Water bath, 2- Constantly stirred batch reactor (CSBR), 3- Magnetic stirrer with stir-bar, 4- CO_2 absorber, 5- Thermometer, 6-Connecting tubing, 7- Control valve, 8- Measuring arm of the manometer and 9- Manometric liquid reservoir

Initially the reactor is open to the atmosphere and as it is closed, the time counts. In the biodegradation process, oxygen is consumed from the liquid phase and carbon dioxide is evolved. Therefore, the equilibrium between the concentration of oxygen in liquid and gas phases is violated. Thus, oxygen is continuously transferred from the gas to the liquid phase. The carbon dioxide evolved in the process remains partially dissolved and the remaining amount is trapped by the CO_2-absorber and thus it does not have appreciable effect on the volume and pressure loss in the gas phase. Thus, the volume and pressure loss detected by the manometer depends solely on the oxygen depletion in the gas phase[12]. The measured negative pressure is converted into oxygen uptake (OU) value using the following equation.

$$OU = \frac{P^0 M_{O_2}}{RT}\left(1 + \frac{\rho g V^0_{(g)}}{S_m P^0}\right)\Delta v \qquad (17)$$

Where, P^0 Standard atmospheric pressure (Pa), M_{O2} Molecular mass of the oxygen (kg/mol), R Universal gas constant, (J/mol.K), T Working temperature, (K), $V^0_{(g)}$ Gas volume in the reactor (m^3), S_m Cross sectional are of the manometer tube (m^2), ρ Density of the manometer-liquid, (kg/m^3), g Gravitational acceleration (m/sec^2), Δv Change in volume in the gas phase as measured by the manometer tube, (m^3)

Figure-2
Rear view of the BIOSUST respirometer (Model no: MRMR BS-102) with six reactor units

Figure-3
Front view of the BIOSUST respirometer (Model no: MRMR BS-102) with six manometers

Results and Discussion

Wastewater was sampled from four different industries namely food, leather, textile and pharmaceutical. The test samples were collected from such points at the industrial premises that they may be considered 'freshly produced wastewater'. Thus it is assumed that the samples do not contain significant amount of microorganisms to initiate biodegradation process. The composition of the wastewater generated in the factory/industry varies with the production status at a given moment and as such the samples cannot be considered as averaged ones. But still the samples bear the characteristics and nature of the source they belong to. Table 1 presents the characteristics of the industrial wastewater studied for biodegradability.

Table 1
Some important parameters of the industrial wastewater under investigation

Wastewater type	Physical appearance	pH	TS, ppm	DS, ppm	SS, ppm	COD, mg/L	NO_3, mg/L	PO_4, mg/L
Food processing industry	Milky white, very foul smell	8.2	780	370	410	630	30	29.5
Leather industry	Dark blue, light foul odor	7.2	1100	390	710	800	100	433
Textile industry	Slightly Opaque, foul odor	7.7	530	270	260	1040	20	610
Pharmaceutical industry	Light brown, very foul odor	5.3	611	340	271	780	50	24.4

For seed preparation, some wastewater was collected from the canal, where the wastewater from the food industry is disposed to. It was put in a 10-L vessel, fed with some nutrient materials and aerated continuously to nurture bacterial culture. This culture was used as 'seed' to the respirometric investigation of the industrial samples. With that end, the seed water was filtered through normal filter paper and 10 ml of it was added to 290 ml of the industrial sample taken in the reactor vessel of the RU for oxygen uptake study.

The oxygen uptake profile of the industrial wastewater has been presented in figure 4 while the rate profile for the same samples is shown in figure 5. The COD of all the wastewater samples are around 1000 mg/L, but the oxygen uptake differs much from one another. The initial oxygen uptake rate is the highest for wastewater from leather industry followed by food processing, pharmaceutical and textile industries respectively.

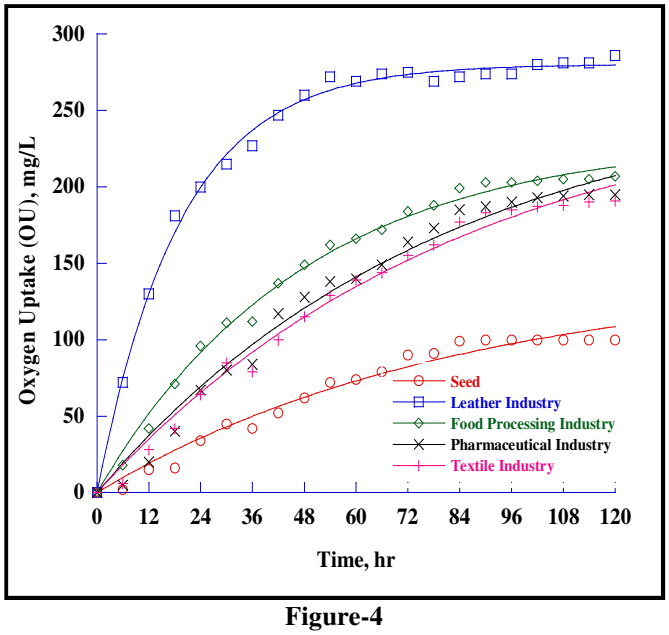

Figure-4
Oxygen uptake profile for four different industrial samples during 120 hrs of incubation

The biodegradation parameters of the four industrial wastewater samples are presented in table 2. The parameters have been estimated assuming that the value of the oxidative potential O_x is 1.45. Six parameters have been given in the Table. Some other parameters such as $C_{sB,0}$, α_s, β and γ can be calculated based on the given data. Also, the *COD*-profile as well as the growth of activated sludge, ΔX, in a biodegradation process can be generated with given parameters.

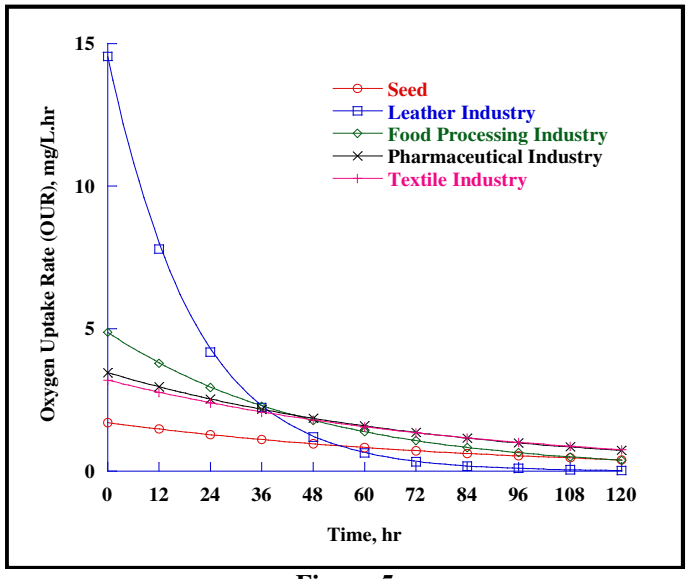

Figure-5
Oxygen uptake rate profile for four different industrial samples during 120 hrs of incubation

Sample from leather industry was found to have highest oxygen uptake value during 120 hr incubation period with a rate constant of 0.052 h^{-1}. This sample may contain appreciable amount of biomass (biological agent grown by putrefied animal body part) as well as biodegradable organic substrate (decomposed animal skin and flesh). However, both the values of α_s (seed dependent biodegradability) and Y, yield coefficient were observed minimum in case of textile industry. Sample from food processing industry shows maximum microbial yield coefficient as 0.46 with a biodegradation rate of 37%.

Table 2
The biokinetic parameters of four industrial wastewater samples (assuming O_x=1.45)

Wastewater sample	COD_0, mg/L	$*OU_{t=120}$, mg/L	$**OU_{t\to\infty}$, mg/L	k, h^{-1}	Y	α_s (Seed dependant)
Food processing industry	630	207	232	0.027	0.46	0.37
Leather industry	800	286	287	0.052	0.42	0.36
Textile industry	1040	191	267	0.012	0.39	0.26
Pharmaceutical industry	780	195	266	0.013	0.42	0.34

$*BOD_5$ - equivalent, $**BOD_u$- equivalent

Conclusion

A low-cost locally fabricated respirometric device called 'BIOSUST MRMR' has been incorporated for monitoring of biodegradation process in industrial wastewater and determination of biokinetic coefficients as well. Oxygen consumption results obtained from the respirometer solely depends on the sample composition within the test reactor. Therefore, sampling procedure plays an important role in finding the original value of the concerned pollution source. Both the quantity and type of biomass agent added or present in the test sample during the investigation have also a significant effect on the biodegradability of the sample. Finally it can be concluded that the respirometric technique could be a cheap and efficient method for the bioassay of industrial wastewater in the developing country.

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