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Biological Oxygen Demand

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Abstract: Bacterial oxygen consumption during reduced substance oxidation in water and wastewater is quantified by the biological oxygen demand (BOD). The most common types of biodegradable organic carbon (CBOD) and nitrogenous ammonia (NBOD) are the ones that contribute most to biological oxygen demand (BOD). These chemicals are found in abundance in the wastewaters produced by both plants and animals, as well as by humans (domestic and industrial wastewaters). Extreme dissolved oxygen depletion and fish deaths are two water quality issues that may result from the discharge of pollutants with high BOD levels. There are a lot of problems with the standard techniques for determining BOD in wastewaters, yet they have been mostly the same for decades. There have been suggestions for other approaches and ways of estimation. Different mathematical models have been developed to mimic surface water quality based on the kinetics of dissolved oxygen consumption due to BOD discharges. Due to its extensive use in several influential water quality models and its lengthy history, the BOD test will undoubtedly be assessed for many more years to come.

1. Introduction

The installation of sewer systems allowed for the disposal of both industrial and domestic wastewater—water from washing machines, toilets, and other appliances—and surface waters—from rivers and other bodies of water—with little or no treatment—as a result of the dramatic increase in urban populations in the late 19th century, brought about by industrialization. Primary wastewater treatment, which relied only on sedimentation basins, succeeded in removing big debris and easily settleable particles. However, most organic material, being either dissolved or having a low density, was not removed as it sank slowly. The consequent loading of organics into adjacent surface waterways rose in direct proportion to the number of humans. Microbial breakdown, which made use of surface water's dissolved oxygen (DO), was accelerated by the higher organic loading. Many instances of anaerobic conditions, which could not sustain desirable aquatic life like fish, and aesthetic water quality issues (see eutrophication and algal blooms) resulted from this consumption of DO and accompanying DO depletion. In order to address this issue, advanced wastewater treatment was used to biologically remove organic debris. Following the completion of more critical tasks, such as disinfection (the elimination of pathogens), the decrease in dissolved oxygen levels emerged as the principal issue related to water quality. From 1950 to 1970, several developed countries enacted laws to curb contamination of surface waters. Subsequently, wastewater treatment plants were granted licenses that set maximum permissible amounts of oxygen-demanding effluents (together with other pollutants such suspended particles) (Figure 1).

Figure 1 : Treated domestic wastewater being discharged into a stream

The phrase "biological oxygen demand" is often seen to be unsuitable by many engineers and scientists, however the acronym BOD stands for biological oxygen demand. The following simplified processes illustrate the use of these terminology to describe the oxygen intake or use by microbes during the aerobic oxidation of electron donors in water, including easily biodegradable organic carbon (e.g., sugars) and ammonia:

$C_6H_{12}O_6$ +6O_6 → 6CO_2 + 6 H_2O (1)

NH_3 +2 O_2 → NO_3 - + H_2O + H^+ (2)

Organic matter from decomposing plants and animal wastes are natural sources of biological oxygen demand (BOD) in surface waters. Poops, urine, detergents, lipids, grease, oils, etc., are all human sources of biological oxygen demand (BOD). Plants provide the building blocks for proteins, which animals then use. The two main chemical forms that contribute to biological oxygen demand (BOD) are hydrocarbon skeletons and ammonia, which are produced via the microbial processes of proteolysis, deamination, and ammonification. Numerous microbes, including bacteria and protozoa, mediate the metabolic oxidation of these reduced nitrogenous and carbonaceous chemicals in water.

A higher biological oxygen demand (BOD) indicates that the waste is more "concentrated" in the water, which is a common metric for assessing the efficacy of wastewater treatment plants. Instead of measuring the quantity of a particular chemical or group of chemicals, BOD measures the effect on the environment, which is the mass of dissolved oxygen consumed per volume of water sample, or mgO2 L-1. It is common practice to measure biological oxygen demand (BOD) in both the influent and effluent wastewaters of a treatment plant in order to assess its effectiveness. As mentioned in Water Quality: Chemistry of Wastewater, BOD is also a key indicator of surface water quality.

2. Theory

There are a variety of assays that can measure the biological oxygen demand (BOD) and determine the oxygen depletion rate in water or wastewater samples. When simulating surface water quality or wastewater treatment, this oxidation rate is often used. Theoretical considerations of a wastewater sample's biological oxygen demand over time are shown in Figure 2. Keep in mind that the oxygen demand, also called the BOD exerted, is increasing with time and is asymptotically getting close to its final value. What remains in the sample when BOD (degradable organics) approaches zero exponentially is represented by the inverse of the BOD exerted curve.

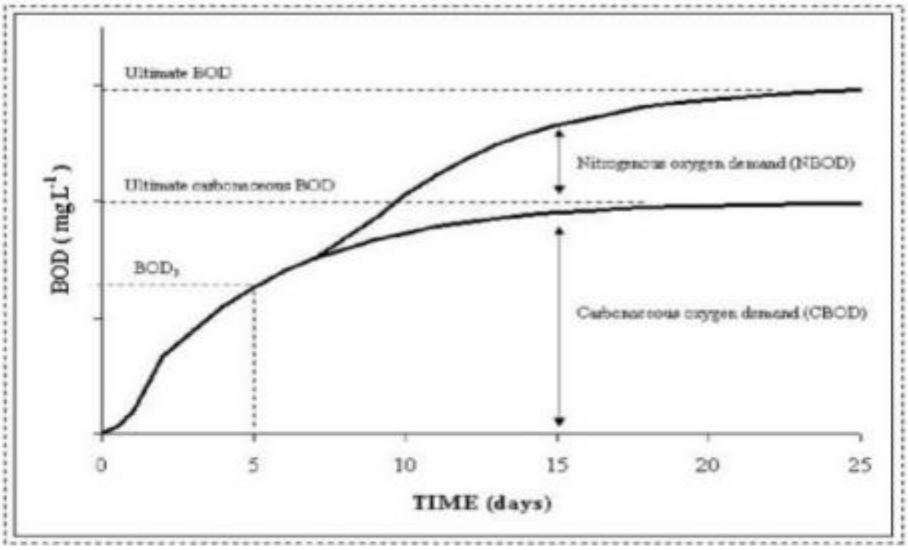

Figure 2: A theoretical representation of the biochemical oxygen demand of a wastewater as a function of time

2.1. Five-day BOD (BOD5)

The biological oxygen demand (BOD) test is a standardized method for determining the organic strength of wastewater. Under standardized and controlled settings, the quantity of oxygen used in a sample during a five-day period is assessed. In Section 3, the specifics of the examination are outlined. Although five days is usually not long enough to achieve full oxidation, it gives the microbes enough time to acclimate (as shown in Figure 2 on the first day) and to oxidize substantially (around 40 to 80 percent). Originating from early water quality investigations, which found that no English stream had a journey duration longer than five days to the ocean, the five-day timeframe has been commonly kept.

A measure of biological oxygen demand (BOD) is taken on the fifth day of incubation and is given as mgO 5 2 L-1 (or equivalently as parts per million, ppm). It is the difference between the first and final measurements of dissolved oxygen (DO).

5 final initial [BOD]=[DO] - [DO] (3)

The sample is either diluted or microbially seeded before extra nutrients are given, depending on its nature. A little adjustment to the equation is necessary in these instances (see to Section 3). There is a plethora of data for many different kinds of effluents accessible because to this test's regulatory usage throughout many decades (see Section 4). Sadly, this test does not provide much kinetic information and does not offer much insight for modeling.

2.2. Ultimate BOD (UBOD)

One way to measure how much oxygen aquatic microbes need to biodegrade organic materials is by looking at their ultimate biological oxygen demand, or [UBOD]. Mathematical models sometimes employ [UBOD] and the rate of oxygen consumption to forecast the effect of effluent on receiving bodies, such rivers and lakes. Therefore, the oxygen consumption rate is often calculated in the same analytical test as the [UBOD] value. During the measurement and in many water quality models, the carbonaceous oxygen demand ([CBOD]) and nitrogenous oxygen demand ([NBOD]) are distinguished. Although CBOD and NBOD both add to UBOD, their oxidation rates and levels are different (for more on this, see Water Quality).

2.3. Carbonaceous Oxygen Demand (CBOD)

COD and other oxidized end products are produced when carbonaceous molecules are oxidized, which consumes oxygen. This process is referred to as carbonaceous oxygen demand (CBOD). There are two main forms of reduced organic carbon: labile (quite biodegradable) and almost refractory (cellulose, for example). Actually, many different kinds of microbes feed on the substrate or each other throughout the oxidation process, which results in a cascade of biochemical processes that ultimately oxidize organic carbon. In contrast, the CBOD breakdown formulas are presented with simplified oxidation kinetics descriptions. One typical way to represent the oxidation reaction is as a first-order dependence on the concentration of carbonaceous biological oxygen demand (CBOD), where [CBOD] is the remaining demand in milligrams of oxygen per liter (mgO2 L-1), k is the first-order reaction rate constant (d-1), and [DO] is the concentration of dissolved oxygen (mgO2 L-1). One possible outcome of integrating this equation is:

$$\frac{d[\mathrm{DO}]}{dt} = \frac{d[\mathrm{CBOD}]}{dt} = k(\mathrm{CBOD}) \qquad (4)$$

where, [CBOD] is carbonaceous chemical oxygen demand remaining, usually in mgO_2L^{-1}, k is the first order reaction rate constant, usually d^{-1}, and [DO] is dissolved oxygen concentration in mgO_2L^{-1}. This equation can be integrated resulting in the following :

$[CBOD] = [CBOD]_0 \text{ x } e^{-kt}$ *(5)*

Where $[CBOD]_0$ is the initial CBOD concentration while t is the time in days.

It is possible to determine the final CBOD by continuing the experiment until the organic carbon has been completely oxidized. But this may take anywhere from twenty to fifty days, or even longer in extreme circumstances. We shall talk about the method's shortcomings later on. The Thomas Slope Method and a BOD5 approximation are two suggested test modifications that might provide speedier findings. Oxygen demand is first-order exponential, which is the basis for the [BOD5] value estimation. Oxygen consumption from carbonaceous sources must eventually surpassA decrease in CBOD is equal to the product of BOD5 and (1 - e-kt).

$$Ultimate\text{-}CBOD = BOD_5 \times (1 - e^{-kt})^{-1} \qquad (6)$$

$$\text{Ultimate-[CBOD]} = [BOD_5] \times (1 - e^{-kt})^{-1}$$

Where $[BOD_5]$ is the biochemical oxygen demand that is exerted over the five day period.

The reaction rate constant, denoted as k, may be found either experimentally or by consulting tables of values. Coefficients ranging from 0.1 to 0.2 d^{-1} are indicative of less rapidly biodegradable sources, such as river water, and higher ones ranging from 0.3 to 0.7 d^{-1} for more quickly biodegradable wastes, such as household wastewater. The inhibition of nitrogenous molecules and their subsequent non-contribution to total oxygen consumption is an assumption used while attempting to estimate the final CBOD value.

2.4. Nitrogenous Oxygen Demand (NBOD)

Nitrite is an unstable intermediate in the oxidation of nitrogenous molecules (mostly NH3) to nitrate, and the oxygen used during this process is known as NBOD. The oxidation of reduced nitrogen is thought to be carried out by just two types of bacteria, distinct from CBOD. Nitrifier bacteria often only exist in trace amounts in water because they are surface-based and attach themselves to floating particles. Figure 2 shows that the NBOD is not visible until about 7 days of incubation have passed. When the food supply for the heterotrophic microorganisms that consume biological oxygen demand (CBOD) decreases (i.e., as [BOD] exerted approaches the ultimate [CBOD] and the [CBOD remaining approaches zero), the nitrifiers, which normally grow at slower rates, thrive. Incorrect findings from the usual analytical test might be due to bottle effects, which occur when nitrifiers grow on the surface of the sample bottle and artificially boost nitrification. Consequently, it is recommended to estimate [NBOD] using a short-term measurement of 1 to 3 days. One reliable way to measure [NBOD] is to monitor the concentration of ammonia (or total Kjeldahl nitrogen, TKN, as a substitute) over a duration of one to three days. The stoichiometric value of 4.57 is used to estimate [NBOD] (and rate of oxygen consumption), while a lower value has also been considered due to the fact that some nitrogen is used up for cell upkeep.

So, the oxygen demand rate in samples may be determined:

$$\frac{d[DO]}{dt} = 4.57 + \frac{d[NH3]}{dt} = 4.57X\ kn[NH3]\ (7)$$

where k_n is the nitrification rate(typically d-1). Integrating and solving the above equation results in

$[NH_3] = [NH_3]_0 \text{ x } e^{-k_n t}$ (8)

Attempts to measure the [CBOD] and [NBOD] rates concurrently have been attempted, however as discussed in Section 3.2, bottle effects sometimes cause an inaccurate BOD value.

$$\frac{d[\mathrm{DO}]}{dt} = \frac{d[\mathrm{UBOD}]}{dt} = 4.57 \times k_n[\mathrm{NH_3}] + k[\mathrm{CBOD}]. \quad (9)$$

Dissolved oxygen components of wastewater, lake, and river models often make use of this equation in its numerous versions.

3. Measurement

Bioassays are used to quantify the biological oxygen demand (BOD) of water or wastewater samples. Biota are organisms that are employed in the test to find out how much of a certain component there is. Bacterial oxygen demand (BOD) tests employ microorganisms to oxidize and destroy a wide variety of chemicals found in the sample. Since [BOD] is equal to the total of [CBOD] and [NBOD], it is vital to differentiate between the two; yet, the word BOD is often used interchangeably with CBOD. The following is a synopsis of the BOD test methodology based on the detailed approach described in the American Public Health Association, the American Water Works Association, and the Water Environment Federation's publication and periodic revision of Standard Methods for the Examination of Water and Wastewater. The OECD Set of Guidelines for Testing of Chemicals include further biodegradability testing techniques. The basic oxygen demand (BOD) test typically finds the time-dependent change between the sample's initial and final dissolved oxygen readings.

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