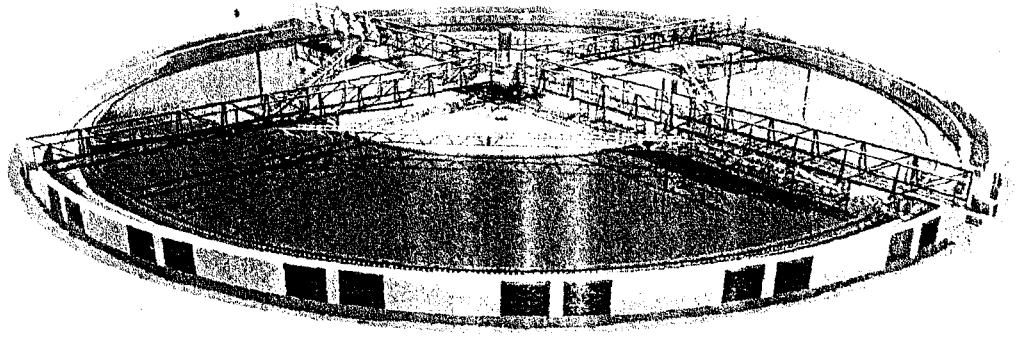
What You Should Know Before Buying A Biochemical Oxygen Demand (BOD) Analyzer

A reference guide to the history and methodology of oxygen consumption measurement in wastewater treatment. Includes a do-it-yourself feature and benefit worksheet.



Anatel®

orporation • 2200 Central Avenue • Boulder, CO 80301
elephone (303) 442-5533 • Fax (303) 447-8365

Table of Contents

Introduction	3
A Brief History of the Biochemical Oxygen Demand (BOD) Test	4
BOD-5: The 5-Day Test	6
BOD-5 Estimation: Accelerated Tests	7
A New Technology for Monitoring the Oxygen Demand of Wastewater	13
Ten Questions to Ask Before Purchasing a Wastewater Biomonitoring System	17
Worksheet for Comparing BOD Monitoring Instruments	21
References	22

1st printing January, 1995

Introduction

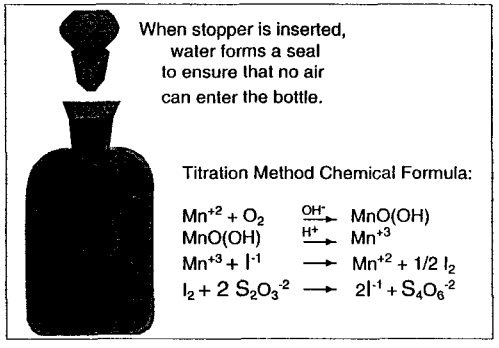
Throughout history, culture and civilization have been linked to man's ability to effectively dispose of waste and protect water supplies. Only during the past century, however, have real, scientific measurements been available to help determine the impact of the waste that we discharge into our waterways. Today, the world's growing pressures of population and industrialization make measuring, monitoring, and treating waste essential if we are to protect the environment and conserve resources for ourselves and future generations.

... measuring the amount of oxygen consumed helps us to understand the characteristics of the waste and to design effective treatment before discharge to the environment.

Since the late 19th century, oxygen has been recognized as necessary for all living species, including the micro-organisms found in our environment, sewage, and wastewater. By 1950 it became apparent that microbes feeding on the extra nutrients in untreated sewage consumed so much oxygen from the water that they could biologically kill our lakes and rivers. Because these micro-organisms require specific amounts of oxygen to metabolize the organic materials present in wastewater, measuring the amount of oxygen consumed (commonly known as biochemical oxygen demand or BOD) helps us to understand the characteristics of the waste and to design effective treatment before discharge to the environment. Understanding the current methods available for making these measurements is the first step toward maintaining an economical and efficient waste treatment process.

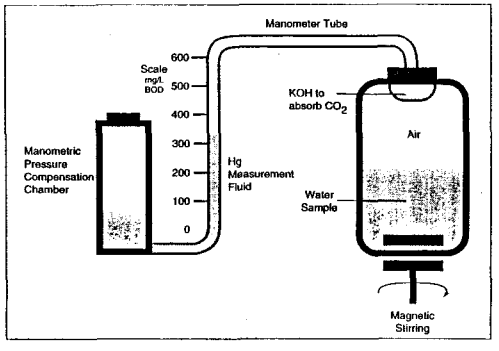
A Brief History of the Biochemical Oxygen Demand (BOD) Test

In 1888 Winkler published his titration method for the determination of oxygen in water (1). Saturated oxygen levels in clean water were determined to be approximately 9.1 mg/L and levels above 3 mg/L appeared to sustain a healthy aquatic environment. Substrates demanding oxygen levels above 9.1 mg/L required dilutions which could cause significant measurement error and were a source of considerable inconvenience, especially for BOD levels above 300 - 500 mg/L. To prevent interference and erroneous BOD measurements, lengthy aeration procedures were necessary to ensure that all of the background BOD in the dilution water was degraded by naturally occurring microbes. As with any wet chemistry method, skillful experimental technique was required to complete the test quickly and prevent oxygen from dissolving into the sample after it was exposed to the atmosphere. Despite its many difficulties, the titration method for the determination of oxygen in water was popular until the mid 1970s.



Winkler titration method prevents oxygen from dissolving into the sample.

By the early 1900s the Warburg Apparatus had become the standard method for measuring the amount of a gas produced or consumed during a chemical reaction and it became quite popular for determining BOD. As the microbes metabolize the nutrients present, they consume oxygen, creating a pressure differential which is measured manometrically.

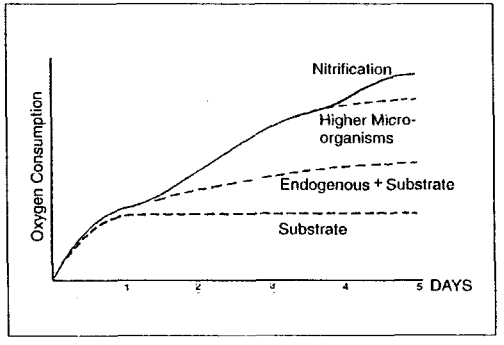


Warburg-type apparatus.

The carbon dioxide produced during the metabolism process is easily absorbed in a solution of potassium hydroxide to prevent interference with the measurement.

In 1927 Sierp published the first reference to a BOD method specifically designed to measure the amount of oxygen required to biodegrade substances in water for waste treatment. His studies indicate that, under most circumstances, biodegradation at 20 °C requires 5 days to reach stabilization (2).

By 1936 this test, called *BOD-5* to denote its required 5-day incubation period, had been accepted as the standard for measuring the biological pollution burden and for designing waste and sewage treatment plants for industry and municipalities throughout the world.



Oxygen consumption takes at least 5 days to approach stabilization with the BOD-5 test.

In 1956 Professor Clarke invented the polarographic oxygen sensor which remains the standard for measuring dissolved oxygen in liquids (3). The Clarke electrode simplifies the method for measuring the oxygen in water but does not solve the inconvenience of dilutions or the 5-day wait for results. The oxygen sensor method has largely replaced previous techniques for determining the oxygen demand of waste substrates in the 5-day BOD-5 test.

BOD-5: The 5-Day Test

Methods to measure dissolved oxygen have progressed remarkably in this century and BOD-5 has long provided useful information about the biodegradability of wastewater. However, the 5-day test period is considered inconvenient, tedious, and too time-consuming to provide the required information soon enough to make changes to the wastewater treatment process. Knowledgeable decisions to aerate, divert incoming streams, pretreat, or increase the activated sludge concentration can only be made with timely and accurate information. With continuously fluctuating volumes and unpredictable concentrations of waste, no operator can afford to wait 5 days before making decisions that affect the performance and the cost-effectiveness of the treatment process. As a consequence, much inaccurate guesswork still results in expensive over-treatment, or environmentally damaging under-treatment of wastes.

... much inaccurate guesswork still results in expensive over-treatment, or environmentally damaging under-treatment of wastes.

Typically, governmental regulatory agencies endorse standard methods organizations which designate BOD-5 as the test method required for measuring BOD. The method is used to regulate the levels of waste that an industry can discard to a municipal plant for treatment. BOD-5 is also used to measure the effectiveness of municipal and industrial wastewater treatment plants (WWTP), which can only discharge treated water below a specified BOD level into the environment.

BOD-5 Estimation: Accelerated Tests

Although the 5-day BOD-5 test is government-mandated to ensure adherence to environmental laws, supplemental accelerated tests can provide information sooner to estimate BOD-5 results and improve the WWTP's performance, often at significant cost savings.

I. Chemical Methods

Correctly designed, accelerated BOD methods that are biologically based can reflect the true biological activity and performance of the WWTP and provide information that allows the operator to make immediate, knowledgeable decisions to maintain maximum efficiency of his facility.

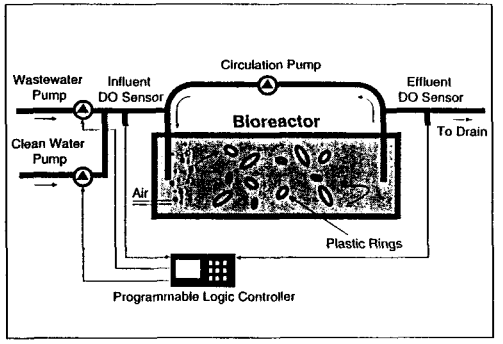
Several faster, alternative methods for estimating BOD-5 have been developed. Two that have become popular are total oxidizable carbon (TOC) and chemical oxygen demand (COD). Both of these are chemical tests that reduce the need for sample dilutions and can provide results within 30 minutes under optimal conditions. However, these tests are non-biological and do not provide any information about the biodegradability of the waste or its treatability in a WWTP. The COD test has an added disadvantage of using toxic reagents (dichromate and mercury) during the analysis.

As the demands of industrial and municipal wastewater treatment and governmental regulations increase, it is clear that rapid biological methods are needed to compliment the standard 5-day BOD-5 test. Correctly designed, accelerated BOD methods that are biologically based can reflect the true biological activity and performance of the WWTP and provide information that allows operators to make immediate, knowledgeable decisions to maintain maximum efficiency of their facilities.

II. Biological Methods

Numerous methods and techniques have been developed to measure oxygen uptake or consumption during the microbial metabolism of waste compounds in water. Understanding the older technologies allows us to appreciate better the new and optimal methods for measuring accelerated BOD and utilizing the results to obtain the most accurate prediction of BOD-5.

IIa. Measuring Oxygen Uptake With An Immobilized Constant Biomass



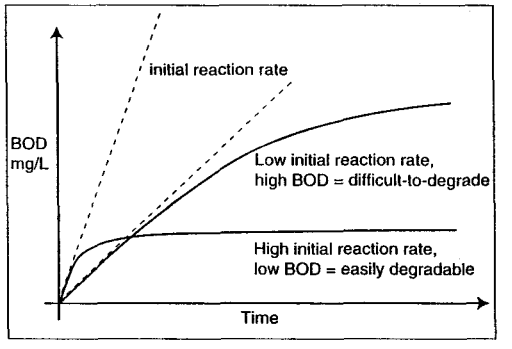
The immobilized constant biomass is not representative of the WWTP sludge.

One method requires the preparation of a constant biomass by pumping wastewater through a continuously aerated, 3-5 liter reaction vessel containing numerous rings or disks. Microbes adhere to these rings and after a few days form a constant biomass. A wastewater stream, diluted with clean water, is pumped continuously through the reaction vessel which is equipped with a dissolved oxygen sensor at its influent and effluent ports. A constant dissolved oxygen ratio between the two sensors is maintained by diluting the concentration of wastewater with the clean water. The difference between the dissolved oxygen levels is used to calculate the accelerated BOD.

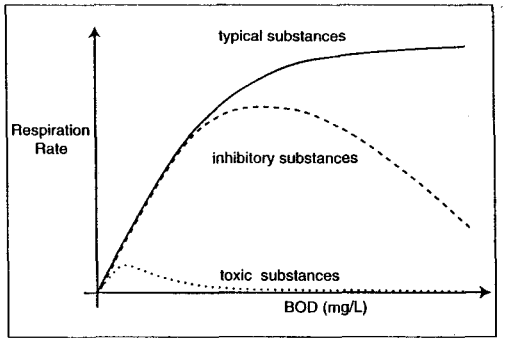
The method has many disadvantages including:

• **The biomass is not representative of the current WWTP sludge.** The dilution of the wastewater by clean water favors the growth of microbes more commonly found in low nutrient environments (4). These microbes can metabolize the nutrient BOD quite differently than the predominant micro-organisms in activated sludge and cause a significant error in the BOD calculation.

• **Diluting the waste stream to maintain a constant oxygen uptake level favors the growth of nitrifying microbes** in the reaction vessel. These microbes act quite differently than those used in the reaction to measure BOD-5 and can cause significant measurement error since they require more oxygen to oxidize NH_4^+ to NO_3^- than carbon to CO_2 (4).



Instruments which mistakenly interpret a high initial reaction rate as high BOD can lead operators to erroneous control decisions.



Failure to distinguish between decreasing BOD and increasing toxicity can lead to killing the instrument's biomass and causing extensive downtime.

• **This system fails to distinguish between changes in BOD concentration (loading), and changes in degradability of the substrate.** The instrument reacts in the same manner to constant BOD and changing degradability as it does to changing BOD and constant degradability, so the operator can never determine whether it is the BOD level or the degradability of the waste that is changing.

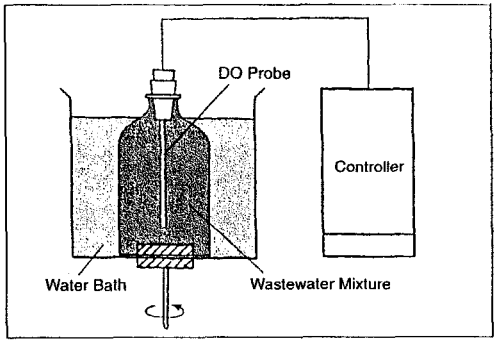
• **This system cannot distinguish between decreasing BOD concentration and increasing toxicity.** Some constant biomass instruments misinterpret a respiration rate decrease due to toxic or inhibitory substances as a reduction in BOD load. As a result, they decrease rather than increase the dilution, which exacerbates the problem further and poisons the biomass.

• **A new biomass must be prepared when there are significant changes in the sample,** or when a toxic event occurs. Preparation of the biomass can require several days.

• **Most importantly, a true steady endogenous respiration state is never achieved in any application where the substrate composition changes** because the growth and continual regeneration of the biomass are completely substrate dependent.

IIb. Respirometers Using Dissolved Oxygen (DO) Probes

Dissolved oxygen respirometers used to measure the oxygen uptake in wastewater are designed for the laboratory or on-line operation. Their operating principle consists of completely filling a reaction vessel with the wastewater mixture, saturating it with oxygen, and monitoring the oxygen uptake until the oxygen concentration of the mixture is reduced to 2 mg/L. The oxygen consumption rate is then measured and extrapolated to obtain BOD.

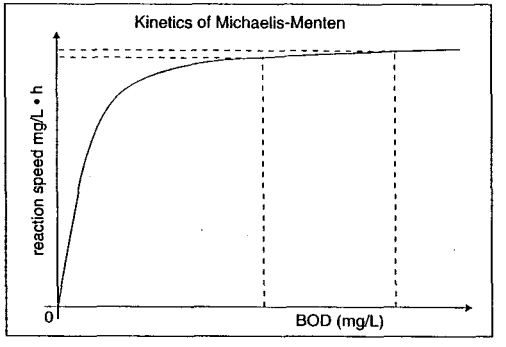


Schematic of a dissolved oxygen respirometer.

These systems have many disadvantages which prevent the user from understanding the actual characteristics of the wastewater. For example:

• **This technique is neither continuous nor real-time.** The sample vessel must be emptied, flushed, refilled, and aerated for each measurement. This cumbersome, non-continuous technique can easily miss changes in BOD loads being discharged into the WWTP.

• Since the amount of oxygen available is limited to the difference between saturation (approximately 9.1 mg/L) and 2 mg/L, **only a very small amount of the waste substance (BOD) is consumed** and the results reflect only the most easily degradable compounds. Recent studies show that the oxygen consumption rate of a sample varies as a function of the biodegradability of the substrate (5). These methods cannot measure difficult-to-degrade substances that might be the most significant compounds in the waste stream.



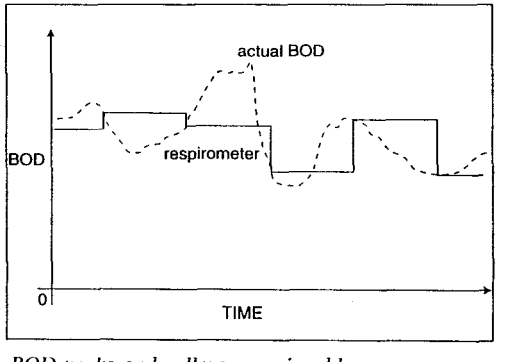
Similar reaction rates can be obtained from very different BOD values (6).

• **These systems lack the sensitivity to distinguish between samples with different oxygen demands** at high BOD levels because the oxygen consumption rates approach maximums that are nearly identical.

• **It is impossible to determine if the BOD load has increased or decreased or if there has been a change in the microbial concentration.** Oxygen consumption rates, as measured by respirometric methods, are dependent on both BOD and microbe concentrations. A constant BOD load can show different oxygen consumption rates as the microbe concentration changes.

• **Respirometers often miss the difficult-to-degrade substances and result in an inaccurate estimation of the true BOD,** since their short analysis times allow only a partial degradation (usually the easily degradable substances).

• **Dissolved oxygen probes can clog or plug** quite easily in the presence of waste particles. Constant cleaning and frequent replacement are required.



BOD peaks and valleys are missed by many respirometers.

IIc. Manometric Respirometers

Manometric respirometers have many of the same disadvantages as the dissolved oxygen versions described previously, including **batch sampling instead of continuous on-line measurement.**

• As the reaction time is extended to obtain more accurate oxygen demand values, it is more likely that **the measurements fail to detect changes in the BOD levels** that can occur in the wastewater. These variations are especially important in industrial and smaller municipal WWTPs where discharges can have a major impact on changing BOD loads.

• Manometric measurements **fail to account for the introduction of error by atmospheric barometric pressure** fluctuations.

IId. Dissolved Oxygen Probes

Oxygen probes are used throughout the wastewater industry to detect dissolved oxygen (DO) at various stages of the treatment process.

If the BOD increases and the microbes present are insufficient to effectively degrade the substrate, the DO values can remain constant and the waste substances are not treated.

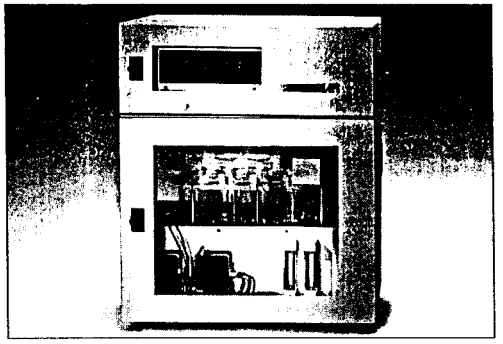
Some of their disadvantages include:

• **DO probes clog easily**, are inconvenient to clean, difficult to maintain, and expensive to replace.

• **They only measure the oxygen dissolved in the water, not the amount consumed by the microbes**. An increase in DO could mean either a reduction in the number of microbes due to toxicity or a reduction in BOD loading. If the BOD increases and the microbes present are insufficient to effectively degrade the substrate, the DO values can remain constant and the waste substances are not treated.

• **Measuring only DO provides information far too late** in the treatment process to be useful, reducing the process efficiency and increasing operating costs and the risk of BOD discharge violations. For example, DO probes cannot detect increasing BOD loads and therefore do not allow the operator sufficient time to add additional sludge or to increase aeration to the primary treatment tanks.

A New Technology For Monitoring The Oxygen Demand Of Wastewaters

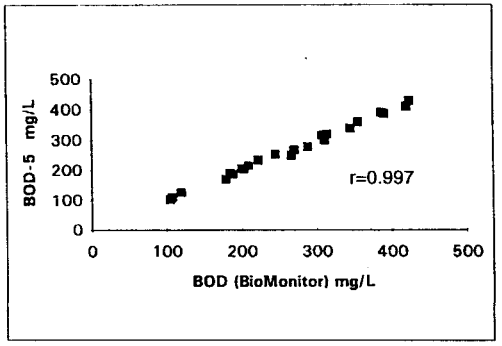


BioMonitor showing the cascade reaction vessels.

In 1986 LAR GmbH was founded to design and produce instrumentation specifically to help WWTP operators maintain maximum performance of their treatment processes with automated, on-line methods that provide the most useful data as quickly as possible. The BioMonitor addresses these needs accurately, efficiently, and economically.

The Features and Benefits of the BioMonitor:

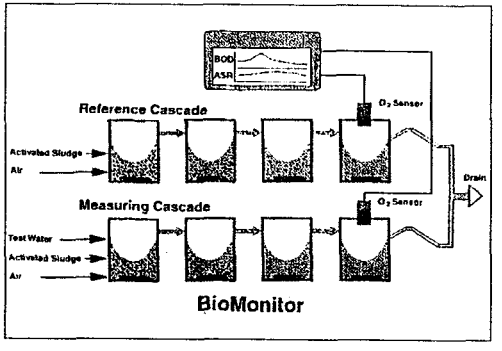
• **The BioMonitor's design most closely reproduces the process of the actual WWTP** to ensure that the results are directly applicable to the actual treatment operation. The wastewater and sludge are pumped directly from the plant source, continually aerated, and react in the BioMonitor's patented, dual, 4-vessel cascade-reactors. Because the BioMonitor results reflect the actual treatment design, they are better predictors of BOD-5, and therefore enable optimal process control of the WWTP and help operators meet regulatory requirements.



The BioMonitor provides outstanding correlation with BOD-5.

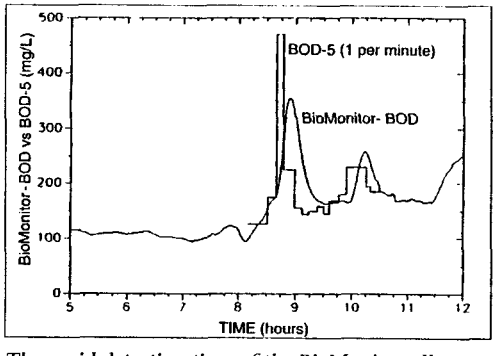
• **The correlation to BOD-5 values is consistent and excellent** (7). The BioMonitor detects even the fastest BOD changes and reports accurate values. The data graph at left compares BOD-5 and BioMonitor values from a discharge in a beverage factory. Note the BioMonitor's excellent correlation to BOD-5.

• **The dual, 4-vessel cascade-reactors degrade all of the organic substances available** so that the true oxygen demand is measured. Increasingly difficult-to-degrade substances are consumed sequentially in the reactors and total degradation and complete oxygen demand are approached by the end of the fourth vessel. Measuring the amount of oxygen required for complete degradation rather than a short-term oxygen uptake rate is the most accurate method for calculating the true biochemical oxygen demand.



The dual, 4-vessel cascade-reactors ensure complete degradation of both easy and difficult-to-degrade substances. The ratio of sludge-to-water is user-selectable.

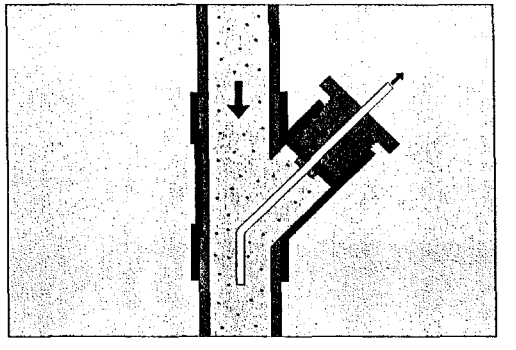
• **The unique design allows complete degradation of the substrate** in the fastest time possible so that the BioMonitor detects even brief BOD excursions or upsets in the wastewater stream. Analysis times are user-selectable and changes in the BOD levels can be detected in as little as 4 minutes while the cascade degradation requires only 20 minutes to approach completion. The rapid detection time is achieved by pumping air to the reactor vessels four times faster than the sludge and wastewater. Therefore, the oxygen demand is detected within 4 minutes while the actual user-selectable ratio of sludge-to-water mixture requires 20 minutes to reach the end of the fourth reactor vessel.



The rapid detection time of the BioMonitor allows close tracking of BOD-5.

• **The dual, 4-vessel cascade-reactors allow the endogenous respiration (respiration of the sludge only) to be measured** simultaneously with the oxygen consumption due to the BOD load. Measuring the endogenous respiration of the sludge in the second set of cascade vessels and subtracting it from the oxygen consumption due to the degradation of the substrate is the only known method for accurately measuring the true oxygen demand of the wastewater. Both values are reported. The endogenous respiration is the best indicator of sludge activity and can also detect long-term toxic effects like heavy metal poisoning. This unique feature of the BioMonitor makes it the standard of excellence for accurate, accelerated BOD measurements.

• **The instrument design eliminates clogging of the electrode** by positioning the oxygen sensor in the gas phase rather than in the water mixture. Maintenance and replacement costs are reduced and system reliability is increased.

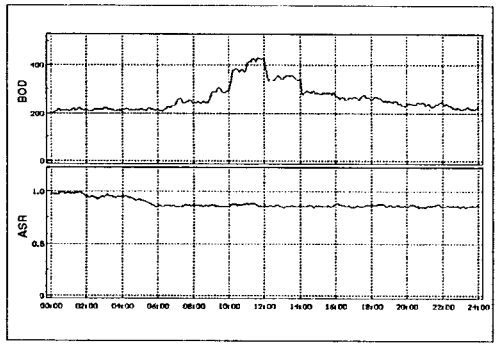


The patented FlowSampler utilizes the particles' momentum to prevent clogging.

• **The patented, filterless FlowSampler ensures the most representative sample possible and completely eliminates any chance of clogging.** Although filtration systems remove unwanted large particles, they also eliminate small representative ones that "contain" BOD and should be measured to prevent erroneous results. These designs can also clog easily, are inconvenient to use, and increase the maintenance costs of the instrument.

• **The BioMonitor's rugged, stainless steel design meets the European IP 65 standard (similar to NEMA 12).** All of the connectors to external devices, including controllers, pumps, printers, and computers, are sealed to prevent any chance of water damage. The housing can withstand even the harshest conditions inside the wastewater treatment plant and ensures reliable, on-line operation for many years.

• **The onboard computer is MS-DOS® based,** and includes easy-to-use menu-driven software and a complete HELP directory. The current oxygen demand and endogenous respiration can be displayed alone in a large, easy-to-see format or in time-based graphical and tabulated forms. Data from dry substances monitors can easily be ported to the BioMonitor so that specific oxygen uptake rates (SOUR) can be reported. Similarly, the true BOD load can be displayed and reported using flow-rate information. A floppy drive allows at least 45 days of data to be stored to a disk for post-run processing at a remote computer.



Sample BioMonitor printout showing endogenous sludge respiration and the BOD peak of approximately 2 hours.

Ten Questions To Ask Before Purchasing A Wastewater Biomonitoring System

The most meaningful and useful BOD calculations are derived from a biological process that closely resembles the actual operation of the WWTP.

1. Does the instrument really measure what is occurring in the treatment plant?

The most meaningful and useful BOD calculations are derived from a biological process that closely resembles the actual operation of the WWTP. For example, the biomass or sludge from the plant should break down the substrate exactly the same way in the instrument as in the aeration basins and clarifiers. Only the BioMonitor uses the exact same process as the WWTP to measure the oxygen demand of the waste substrate. The design also ensures that all of the substrate, including easy and difficult-to-degrade substances, is metabolized by the microbes so that the BOD result obtained is the most accurate possible.

2. Does the instrument measure true oxygen consumption or demand and not just a rate?

Instruments that measure oxygen consumption rates are dependent upon the substrate and microbe concentrations, both of which vary. Since the reaction in these types of instruments is not complete, it is impossible to be sure if a change in the oxygen consumption rate is due to a change in the microbe concentration, the BOD load, or the degradability of the substrate. Therefore, using the consumption rate to calculate oxygen demand is always suspect. To avoid possible error, the instrument must be capable of directly making oxygen consumption measurements based upon complete degradation of the substrate.

Measurements that are limited to short, fixed times often only measure easily degraded substances and erroneously report the oxygen uptake required for the more difficult-to-metabolize compounds that are present in the wastewater sample. The BioMonitor measures true oxygen demand and also ensures that all of the substrate has been consumed, including the difficult-to-degrade substances.

3. Does the instrument provide data fast enough to make the necessary decisions to maintain plant performance?

Decisions to increase aeration and sludge concentrations require information as quickly as possible before the wastewater enters the primary treatment. The analyzer should be installed on-line and be capable of providing fast results for process evaluation. On-line operation allows the detection of changing BOD loads which might require increased aeration, adjustment of the return sludge flow, or diversion of waste streams to holding tanks or lagoons. Fast detection and interface capabilities to computers or programmable logic controllers (PLC) increase the automation of the plant and can significantly reduce associated operating costs. The BioMonitor responds to BOD changes within 4 minutes so that the operator can make the immediate decisions required to maintain optimal and economical plant performance.

The BioMonitor, because it reflects exactly the operation of the WWTP, provides the highest and most consistent correlation to BOD-5 results.

4. Is the instrument really measuring a representative sample?

Obtaining the most representative waste sample possible is necessary to ensure accurate results. Methods using filtration remove small particles, which can account for as much as 50% of the BOD in the waste stream, and should be avoided. Improved methods which ensure homogenous and typical samples should be used. The patented, filterless FlowSampler ensures the most representative, homogenous sample possible for the BioMonitor's analysis. Any chance of clogging has been eliminated and small particles that can represent a major portion of the BOD are included in the sample that enters the reactor vessels.

5. Does the instrument provide the highest correlation to BOD-5 values?

Although the BioMonitor is designed to provide the information required to maintain optimal conditions within the WWTP, it is desirable that the data are compatible with the standard BOD-5 test required for regulatory compliance. The BioMonitor, because it reflects exactly the operation of the WWTP, provides the highest and most consistent correlation to BOD-5 results.

6. Does the instrument measure the endogenous respiration of the sludge?

The endogenous sludge respiration does change as a function of the microbe concentration and aeration and can be a real factor that affects the accuracy of the oxygen demand measurement (8). The instrument should be able to distinguish between endogenous sludge respiration and the oxygen consumed during the degradation of the sample. The BOD interference and error caused by endogenous respiration can be significant, especially for difficult-to-degrade compounds where the metabolic breakdown by the microbes is slow. Only the BioMonitor measures the endogenous respiration separately and simultaneously with the substrate degradation (9). Both values can be reported separately and the endogenous respiration subtracted from the substrate oxygen consumption for the most accurate measurements possible.

The BioMonitor includes signal output functions that allow direct interface to programmable logic controllers.

7. Does the instrument provide interface capabilities for programmable logic controllers (PLC), serial, and analog devices?

The BioMonitor includes signal output functions that allow direct interface to programmable logic controllers. It has one bi-directional RS-232 port for data acquisition and BioMonitor control, one analog output for BOD and one for activated sludge respiration (0-20 mA or 4-20 mA selectable) and includes a connection for a serial or parallel printer (all opto-electronically isolated). An optional printed circuit board provides five totally programmable relays for interface to remote devices and alarm indicators, as well as one 0-20 mA or 4-20 mA input for external analog signals. This input allows the BioMonitor to automatically calculate and display the BOD load or specific oxygen uptake rate (SOUR) with data from a flowmeter or turbidimeter. These flexible interface capabilities, combined with the rapid detection of changing BOD, provide the information needed to maintain optimal WWTP operation at all times.

8. Are the data and hardware compatible with standard software packages and personal computers?

The BioMonitor's on-board computer is MS-DOS based so that all of the data are directly compatible with PC software programs, such as Excel® or Lotus®, for post-run analysis. Files are available in the standard spreadsheet or ASCII format. In addition, a floppy drive is standard and each disk can store more than 45 days of uninterrupted data.

9. Is the instrument rugged enough to withstand the harsh conditions of a WWTP?

Continuous operation and accurate results require a system that is well-engineered and designed for rugged operation in the most difficult environments. It should be capable of operating day and night for years with minimal maintenance. The BioMonitor's stainless steel housing protects the instrument from even the worst conditions that can exist in a WWTP. The robust, self-cleaning design ensures reliable operation, low maintenance costs, and maximum return on investment.

... saves money by intelligently reducing blower operation, optimizing return sludge flow, and diverting toxic waste streams.

10. Can the instrument really save operating costs?

The BioMonitor's completely automated, continuous analyses let the operator understand and control the wastewater process at all times. Complete automation means no additional laboratory personnel are necessary and many process variables can be eliminated. Better control saves money by intelligently reducing blower operation, optimizing return sludge flow, and diverting toxic waste streams.

Worksheet for Comparing BOD Monitoring Instruments

FEATURES & BENEFITS	BIOMONITOR	BRAND X
Design parallels actual treatment plant	Uses the exact same principle as the actual treatment plant to ensure representative results	
Measures oxygen consumed, not oxygen available or rate of oxygen consumption	Measures total oxygen consumed, the same as the BOD-5 test, allowing immediate detection of changes in loading, sludge viability, or effluent characteristics	
Fast results	Analysis times are user-selectable and as fast as every 4 minutes, providing optimal plant performance	
Measures representative sample	Patented, filterless sampling system includes small particles to ensure a representative, homogenous sample	
Immediate sludge re-generation after toxic event	Continuous sampling means no sludge-regrowth necessary after toxic events	
True continuous on-line measurement	Actual sample and sludge which reflect exactly the current conditions of the WWTP are pumped to the BioMonitor and measured continuously	
Low maintenance	Completely automated operation, self cleaning and robust engineering mean minimal maintenance	
High correlation to BOD-5	Measures biological, not chemical oxygen uptake, ensuring the highest BOD-5 correlation available	
Measures endogenous rate of sludge respiration	Simultaneously measures respiration of sludge alone, and with wastewater, to protect against measurement interference between the two	
Complete degradation of substrate	Cascade-reactors mean easy and difficult-to-degrade substances are all completely metabolized by the microbes, just like BOD-5	
Process control capability	Includes bi-directional serial port for data acquisition and BioMonitor control, two 4-20 mA outputs, and optional relays for remote devices and alarms	
User friendly software	On-board computer is MS-DOS based and includes complete HELP menu and menu-driven parameter controls	
Sturdy design to withstand harsh conditions	Rugged, stainless-steel housing ensures reliable, on-line operation for many years	

References

1. L. W. Winkler, "Die Bestimmung des im Wasser gelosten Sauerstoffs"; *Berichte der Deutschen Chemischen Gesellschaft*, Vol. 21, p. 2843-2854, (1888).

2. F. Sierp, "Eine neue Methode zur Bestimmung des biochemischen Sauerstoffbedarfs"; *Technisches Gemeindeblatt*, p. 179, (1927).

3. L. C. Clark, Electrochemical Device for Chemical Analysis, US Patent 2.913.386 (from 17.11.59).

4. R. Courchaine, "The Significance of Nitrification in Stream Analysis"; Proceedings 18th Industrial Waste Conference, Purdue Univ. (1965).

5. P. Wilderer et al, "Kritik am BSB-5 als Verschmutzungsparameter"; *GWF-Wasser Abwasser*, Vol. 118, p. 357-364, (1977).

6. C. T. Calm, "The Culture of Micro-Organisms in Liquid Medium"; *Methods of Microbiology*, Volume 1, Chapter VIII, p. 255-326 (1969).

7. H. Heckershoff and U. Wiesmann, "Ein neues Messgerat fur die Betriebskontrolle und Regelung von Belebtschlammanlagen"; Part 1 Korrespondenz Abwasser, Vol. 33, p. 508-513, (1986), Part 2 Korrespondenz Abwasser, Vol. 33, p. 600-606, (1986).

8. U. Pilz, "Kontinuierliche, Simultane Messung des Biochemischen Sauerstoffverbrauchs und der Belebtschlammrespiration"; *Gewasserschutz, Wasser, Abwasser*, Vol. 127, p. 121-136, (1991).

9. S. Hover et al, "An Interpretation of the BOD Test in Terms of Endogenous Respiration of Bacteria"; *Sewage Industrial Wastes*, Vol. 25, p. 1163-1173, (1953).