

2.1.2 The BOD test

In the BOD test oxygen is used for the oxidation of organic material and this process requires the presence of micro-organisms. If the waste water does not contain enough of these micro-organisms, they must be added at the beginning of the test, together with mineral nutrients and a buffer to maintain a neutral pH.

While in the COD test the oxidation of organic material is essentially complete in less than two hours, in the BOD test the oxidation rate is very slow and will take several weeks. As it is impractical to wait such a long time for the result of the test, a standard period of 5 days has been introduced, even though it is well known that this period is not enough for complete oxidation. Because temperature has been found to affect the oxidation rate, a standard temperature of 20°C is used. Hence, unless differently stated, BOD means the BOD_{5,20} i.e. the BOD after 5 days of incubation at 20°C.

Some organic compounds (especially those with small molecules) can be metabolised immediately by micro-organisms. On the other hand, in most waste waters there are also suspended solids, colloids and macro molecules that need to be reduced by hydrolysis into smaller molecules, before they can be metabolised. Also some organic compounds have a very low rate of metabolism, thus resulting in a very low consumption of oxygen during the five day test period for BOD. The organic material metabolised during the test is determined by the oxygen consumption and is called the biodegradable material. Organic compounds that cause no measurable oxygen consumption are called non-biodegradable and are therefore not detected with this test.

In the case of biodegradable material, the oxidation will not be complete after 5 days of incubation, so that it is not possible to calculate a *priori* a theoretical value for a solution of a known composition, as was done above for the COD test. This is due to the fact that before the test it is not known which proportion of the organic material metabolised by the micro-organisms will be oxidised (hence contributing to the BOD) and which part will be incorporated in the cell mass. An often-used empirical equation for the consumption of oxygen and hence for the BOD in a solution of biodegradable material is:

$$\text{BOD}_{t,20} = \text{BOD}_{\infty,20} [1 - e^{(-k_{\text{BOD}}t)}] \quad (2.3)$$

Where:

- BOD_{∞,20} = ultimate BOD i.e. the BOD after a long incubation time (> 3 weeks) at 20°C,
when oxidation of the biodegradable material is assumed to be complete
BOD_{t,20} = BOD after an incubation time of "t" days at 20°C
k_{BOD} = organic material degradation constant (d⁻¹ at 20°C)
t = duration of test (days).

When a typical value of 0.23 d⁻¹ at 20°C is assumed, then with the aid of Eq. (2.3) the ratio of the BOD after an incubation time of 5 days and the BOD after a long (infinite) incubation period is given by:

$$\text{BOD}_{5,20}/\text{BOD}_{\infty,20} = 1 - e^{(-5k_{\text{BOD}})} = 0.68 \quad (2.4)$$

Equation (2.4) indicates that, for a k_{BOD} value of 0.23 d⁻¹, 68 percent of the biodegradable material is oxidised during the incubation period of 5 days. It is important to note that Eqs. (2.3 and 2.4) are empirical relationships, developed for sewage and that they do not apply necessarily to other waste waters.

The value of the organic material degradation constant k_{BOD} depends on the type of waste water used. In the Netherlands, for municipal waste water the variation of the k_{BOD} value is estimated between 0.15 to 0.8 d^{-1} (Roeleveld and van Loosdrecht, 2002). Although labour intensive, it is possible to calculate the k_{BOD} value from a series of BOD determinations, as is demonstrated in Figure 2.1

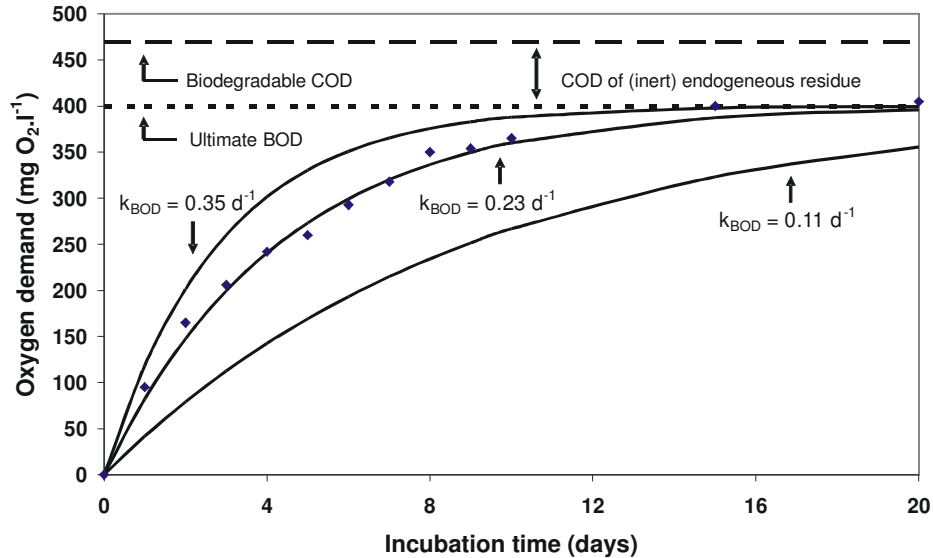


Figure 2.1 $\text{BOD}_{t,20}$ as a function of the incubation time for different k_{BOD} values

As a result of the decay of micro-organisms, part of the influent COD will in the end remain as an inert endogenous residue (refer also to Section 2.4.1) and will not exhibit an oxygen demand. Therefore the value of BOD_{∞} will always be lower than the biodegradable COD value (BCOD). Typically BOD_{∞} for biodegradable waste water is about 86% of BCOD. The BCOD line is shown in Fig. 2.1 as well.

To indicate the effect of different k_{BOD} values on the result of the BOD determination, the theoretical $\text{BOD}_{t,20}$ curves for $k_{\text{BOD}} = 0.11$ and 0.35 d^{-1} (with the same BOD_{∞} value of $400 \text{ mg O}_2\text{.l}^{-1}$) are plotted in Fig. 2.1. It now becomes evident that the use of a fixed ratio to link BOD_5 to BOD_{∞} could easily lead to large errors, when the waste waters are different in composition. To illustrate this point, for different k_{BOD} values the expected BOD_{∞} value is calculated based on the BOD_5 values in Fig. 2.1. For a true k_{BOD} value of 0.11 d^{-1} , the BOD_5 value is $168 \text{ mg O}_2\text{.l}^{-1}$ and using the assumed ratio of $\text{BOD}_5/\text{BOD}_{\infty}$ of 0.68, this yields an expected BOD_{∞} value of $249 \text{ mg O}_2\text{.l}^{-1}$. For a true k_{BOD} value of 0.35 d^{-1} this would yield a BOD_{∞} of $486 \text{ mg O}_2\text{.l}^{-1}$

It can be concluded that the reproducibility of the BOD test is much lower than that of the COD test. The data in Table 2.3 (Heukelian, 1958) are an example. The BOD determination of several solutions of single compounds with known concentrations was carried out. The observed standard deviations ranged from 13 to 62 percent of the average values: this is much larger than those determined for the COD test.

Table 2.3 also shows clearly that after 5 days the biological oxidation of organic material is still incomplete. In the last column, the ratio between the experimental BOD_5 value and the theoretical COD concentration is calculated. The experimental oxygen demand was only 36 (ethyl acetate) to 75 percent (glucose) of the demand for complete oxidation.

Table 2.3 Experimental values of the BOD₅ values for selected compounds, the standard deviation and the ratio between the experimental BOD₅ and the theoretical COD

| Component | n ⁰ of tests | BOD ₅ | Standard deviation | | BOD ₅ /COD _t |
|----------------|-------------------------|-------------------------------------|--------------------|----|--|
| | | g BOD ₅ ·g ⁻¹ | g·g ⁻¹ | % | g BOD ₅ ·g ⁻¹ COD _t |
| Acetic acid | 9 | 0.62 | 0.18 | 29 | 0.58 |
| Sodium acetate | 7 | 0.33 | 0.18 | 54 | 0.42 |
| Methyl alcohol | 11 | 0.86 | 0.11 | 13 | 0.57 |
| Ethyl alcohol | 12 | 1.25 | 0.23 | 18 | 0.60 |
| Glycerine | 6 | 0.75 | 0.14 | 19 | 0.62 |
| Formaldehyde | 5 | 0.57 | 0.30 | 53 | 0.44 |
| Acetone | 9 | 0.89 | 0.55 | 62 | 0.40 |
| Glucose | 10 | 0.80 | 0.45 | 56 | 0.75 |
| Ethyl acetate | 6 | 0.66 | 0.29 | 44 | 0.36 |
| Phenol | 5 | 0.76 | 0.25 | 14 | 0.74 |