## 2.1 Biological Wastewater Treatment Processes

AS, TF, and RBC are the most common three wastewater treatment processes. They provide different biological conditions of living due to their design and operation. In AS, the variation of organisms found, in terms of species, is less than those encountered in TF and RBC. The organisms occur in biological wastewater treatment are bacteria, fungi, algae, protozoa and metazoa. The main role of bacteria is the primary transformation and degradation of dissolved organic matter. Relatively more fungi are present in biofilters, such as, TF and RBC, where the pH is lower. However, bacteria are still a dominant microbial group in these biofilters. Algae are present on the surface of biofilters where the light and food are abundant. Another microbial group commonly found in biofilters is protozoa. The roles of protozoa are the grazing on bacteria, fungi, algae and suspended organic matter resulting in better quality effluent. The last group is metazoa, which are mainly rotifers, crustaceans and insects. Their distribution pattern is similar to that of protozoa and they can be found in biofilters and in underloaded AS.

The difference in microbial growth in biological wastewater treatment units is largely based on a mechanism called selection. Selection mechanism of each type of biological wastewater treatment is rather different. In biofilters, the selection of organisms is based on adhesion and growth while the selection mechanisms in AS unit operation are electron acceptors, substrate, settling or flocculation characteristics, temperature, growth rate and freely suspended microorganisms. In term of growth rate, an organism must be able to reproduce at a faster rate in order to survive in the system.

2.1.1 Design, Control and Operation of AS

AS process is the most routinely used suspended growth process for municipal and industrial wastewater treatment because of its high organic matter removal efficiency. The system consists of two main components, which are an aeration tank and a settling tank, as shown in Figure 2.1.
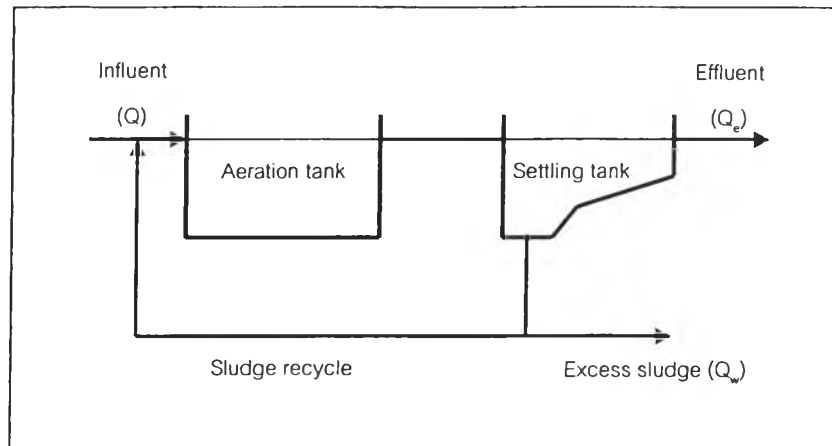
Source: Adapted from Henze, Harremoës, Jansen and Arvin (2002)

Figure 2.1 Activated sludge process diagram

In the aeration tank, mixing and oxygen (usually in the form of air) are provided in order to keep the mixture of sludge and wastewater in suspension and under aerobic conditions. The activated sludge-wastewater mixture is termed the mixed liquor or the mixed liquor suspended solids (MLSS). The unit contains living suspended biomass and inert suspended solids. The amount of suspended solids in AS unit operation is regulated through the suspended solids recycling and excess sludge removal.

In the settling tank, the solids and liquid are separated, and the solids at the bottom of the tank are returned to the aeration tank at a desired recirculation ratio. The ratio is dependent upon the desired MLSS concentration and the concentration of the settled solids in the recirculation flow. Organic matter that enters an AS process results in three outputs: carbon dioxide, excess sludge and organic matter remaining in the effluent.

The design of AS system can be based on volumetric loading and sludge loading. The design by means of volumetric loading, which corresponds historically to be the first method used, is based on the BOD-volumetric loading:

$$B_{V,BOD} = Q \times C/V \qquad (2.1)$$

Where $B_{V,BOD}$ = BOD volumetric loading; kg BOD/(m^3/d)

   Q = volume rate of influent flow; m^3/d

   C = concentration of organic matter; kg of BOD/m^3

   V = volume of aeration tank; m^3

Reasonable results can be obtained from this simple procedure only if the systems receive a uniform composition wastewater, in the way that the sludge concentration in the aeration tank is the same from system to system. Such condition is seldom found. Nevertheless, the volumetric loading cannot be used for the more complicated process design.

Using the volumetric loading as a design basis, in many cases, will be difficult or quite impossible because of the reasons mentioned above, consequently, if the sludge is used as the design basis, aerobic sludge age or SRT, in most cases, will be used instead as the design basis. The SRT is a very useful term because it basically relates to bacterial growth rate and it is relatively easy to use in design calculations and in the control of activated sludge (Lawrence and McCarty, 1970).

$$SRT = V\ X/(Q_w\ X_r + Q_e\ X_e) \qquad (2.2)$$

Where   SRT = solid retention time; d

V = volume of aeration tank; m^3

X = suspended solids concentration of aeration tank; kg/m^3

Q_w = volume rate of sludge wasted flow; m^3/d

X_r = suspended solids concentration of sludge returned; kg/m^3

Q_e = volume rate of effluent flow; m^3/d

X_e = suspended solids concentration of effluent; kg/m^3

It is assumed that X_e is very low, comparing with X or X_r, and X equals to X_r when the AS process works at high removal efficiency and the excess sludge is removed directly from aeration tank, the previous equation will be expressed as:

$$SRT = V/Q_w. \qquad (2.3)$$

Since volume of aeration tank, V, is constant, controlling of SRT is dependent on Q_w only.

When designing on the basis of sludge loading, the food to microorganism ratio (F/M) is another parameter that can be used. The parameter is analogous to SRT. Knowing the design value of F/M, the volume of the aeration tank can be found from the following equation:

$$F/M = Q \times C/(X \times V) \qquad (2.4)$$

Where   F/M = BOD sludge load; kg BOD/(kg VSS·d)

Typical values of the parameters used for the design and operation of complete-mix activated-sludge process are presented in Table 2.1.

Table 2.1 Typical values of the design parameters for CMAS process.

| Parameters	Values
SRT (d)	3-15
F/M (kg BOD/kg MLVSS.d)	0.2-0.6
Volumetric loading (kg BOD/m³.d)	0.3-1.6
MLSS (mg/L)	1500-4000
Total HRT (h)	3-5

Source: Metcalf & Eddy, Inc. (2003)

2.1.2 Design, Control and Operation of TF

TF is a conventional biofilm reactor and has been used for small- to medium-communities, primarily because of its simplicity and dependability. In the past two decades, TF processes have largely displaced by AS because of the higher standard effluent. To be able to treat wastewater satisfactorily, TF must have the following four components: the bacteria necessary for the required process attached with the filter medium, the efficient contact between wastewater and the biofilm, the controllable growth of bacteria in order to prevent clogging, and the supply of oxygen for organic matter degradation.

A TF system consists of a distributor, a filter bed, an underdrain system, and a sedimentation tank as shown in Figure 2.2. The wastewater is distributed over the filter, then trickles down over the medium and is collected after going through the filter bed by the under drain system. The filter medium of TF is stationary which typically are large gravel or crushed stone or synthetic plastics media. As the wastewater flows over the medium, microorganisms in the water gradually attach themselves to the medium and form a film. The organic material is then degraded by the aerobic microorganisms in the outer part of the slime layer (film). After the layer thickens through microbial growth, anaerobic organisms develop because oxygen cannot penetrate the medium surface, and sloughing process also occurs because substrates are not available to the anaerobes, which eventually digest themselves (endogenous respiration), causing the microorganisms near the surface lose their ability to attach to the medium. The sloughed solids are picked up by the underdrain system and transported to a sedimentation tank for removal from the wastewater.

The underdrain system of TF, which collects the filtrate and solids, is also served as a source of air for the microorganisms on the filter. The treated wastewater and solids are piped to a sedimentation tank where the solids are separated. Usually, part of the liquid from the settling tank or the filtrate is recirculated to improve wetting and flushing of the medium, and to optimize the process and increase the removal rate through the dilution of incoming wastewater (United States Environmental Protection Agency [U.S. EPA], 2000). Recirculation ratio used was up to 0.2.
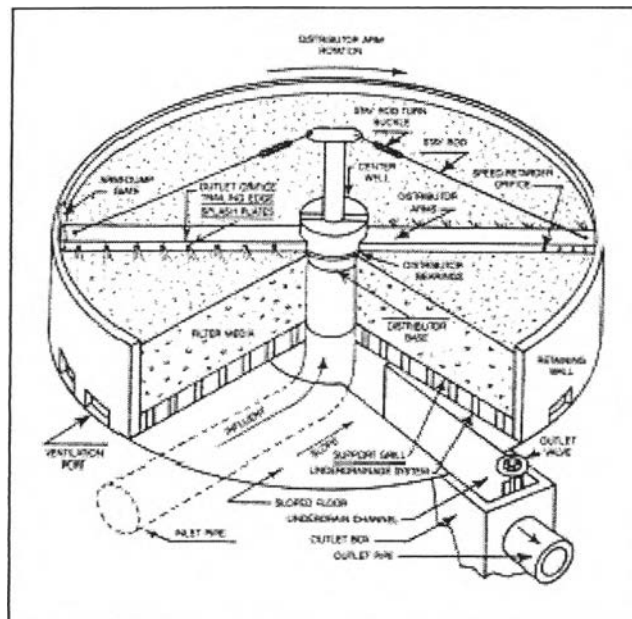
Source: U.S. EPA (2000)

Figure 2.2 Schematic of a trickling filter

The efficiency of TF is dependent on the adhesion of bacteria, contact of wastewater and biofilm, and reaeration of the water. However, the most essential demand on design and operation of TF is the control of the growth of the biofilm because an uninhibited development of biofilm can lead to clogging which will prevent the oxygen supply to the biomass (Wheaton, 1977). Higher organisms, such as worms, larvae, also contribute to the degradation of biomass and the biofilm sloughing. As a consequence, the filter can become a hatching plant for insects. For example, filter flies can be such a nuisance. According to the organic loading, hydraulic loading and the recirculation ratio employed, filters have been classified into low-rate or standard-rate, intermediate-rate and high-rate filters. The typical design information for TFs is shown in Table 2.2.

Table 2.2 Typical design information for TFs.

Design characteristics	Low-rate or standard-rate	Intermediate-rate	High-rate
Type of packing	Rock	Rock	Rock
Hydraulic loading (m^3/m^2-d)	1-4	4-10	10-40
Organic loading (kg BOD/m^3.d)	0.07-0.22	0.24-0.48	0.4-2.4
Recirculation ratio	0	0-1	1-2
Filter flies	Many	Varies	Few
Sloughing	Intermittent	Intermittent	Continuous
Depth (m)	1.8-2.4	1.8-2.4	1.8-2.4
BOD removal efficiency (%)	80-90	50-80	50-90
Effluent quality	Well nitrified	Some nitrification	No nitrification

Source: Adapted from Metcalf & Eddy, Inc. (2003)

Quantifying the biomass in TF system is impossible, unlike AS, since the attached growth in the TF is not uniformly distributed and the wastewater does not uniformly flow over the entire packing surface area. Broader parameters such as volumetric organic loading, unit area loadings, and hydraulic loading rates have been used as design parameters and to relate to treatment efficiency.

The design for TF is dependent on the BOD loading and removal efficiency, and recirculation ratio. After choosing these values, the volume of filter can be calculated according to the NRC equation (equation 2.5).

$$E = 100/[1 + 0.0561(W/VF)^{0.5}] \qquad (2.5)$$

Where E = BOD removal efficiency at 20°C, including recirculation and sedimentation, percent

W = BOD loading, lb/day

V = volume of filter bed, 10^3 ft^3

F = recirculation factor

The recirculation factor is calculated using equation 2.6

$$F = 1+R/[1 + (R/10)^2] \qquad (2.6)$$

Where R = recirculation ratio = recirculation flow/wastewater flow.

An alternative design method is to select a designed depth of filter bed and to calculate the cross sectional area of filter bed from equation 2.7, knowing the desired flow rate and hydraulic loading rate.

$$HLR = Q/A \hspace{3cm} (2.7)$$

Where HLR = hydraulic loading rate; m^3/m^2-d

Q = volume rate of influent flow; m^3/d

A = cross sectional area of filter bed; m^2

2.1.3 Design, Control and Operation of RBC

The RBC, another attached growth process, is a horizontal shaft of rotating plastic discs set in an open tank filled with wastewater, as shown in Figure 2.3. The unit operation consists of series of discs rotating alternately through wastewater and air. The diameter of each disc will depend upon the amount of disc surface area required to treat the wastewater. For a typical aerobic RBC, approximately 40 percent of the disc is immersed in the wastewater. The rotation creates efficient aeration of the wastewater and an efficient contact between wastewater and biofilm with considerably low energy consumption. Organics are removed as the discs pass through the wastewater, which flows through the disc by simple displacement and gravity.

The buildup of biological growth on the discs increases in thickness, forming a slime layer. The thickness of the biofilm is controlled by the turbulence at the disc-water interface, which is controlled by the slow rotational speed at 1 to 2 rpm by mechanical drive (U.S. EPA, 2004). As a requirement, the rotational peripheral speed on the disc should not be less than 0.3 m/s and the distance between the discs should be between 1.5 and 2.5 cm. When the slime layer on the discs are thick enough, biomass continuously sloughs from the discs and some suspended biomass develops within the RBC channels through which the discs rotate, making the additional of the sedimentation tank necessary. The recycling of sludge is not required because once the effluent is treated by the RBC; it flows to sedimentation tank for suspended solids removal.
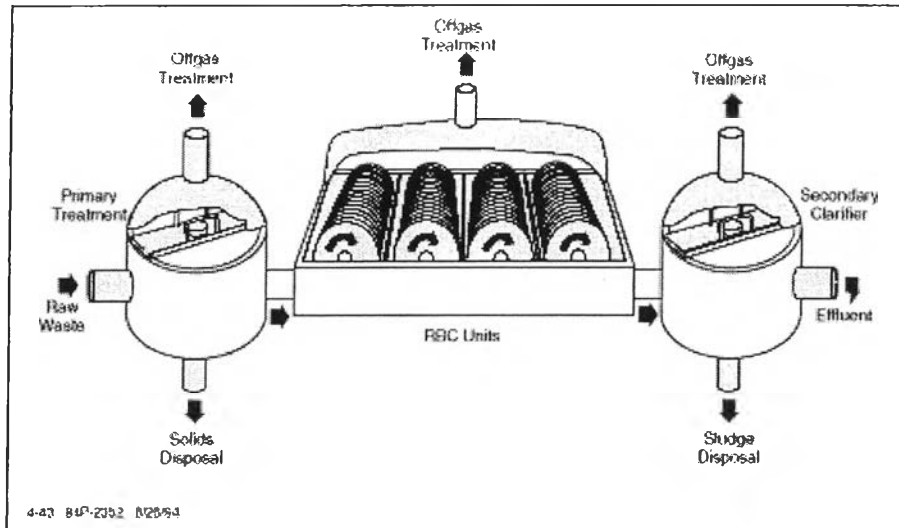
Source: http://www.frtr.gov/matrix2/section4/4_47.html

Figure 2.3 Schematic of rotating biological contactor

For a proper system design, the basic wastewater characteristics and effluent requirements must be determined. The process should be designed to remove at least 85% of the BOD from the domestic sewage. Typical design information for RBCs is presented in Table 2.3. However, in all RBC systems, the treatment performance can be controlled by these major factors: organic and hydraulic loading rates; influent wastewater characteristics; wastewater temperature; biofilm control; dissolved oxygen (DO) levels; and flexibility in operation. The principal design parameter for the RBC process is hydraulic loading rate, which is suitable to water with low organic concentrations, such as, municipal wastewater. Another design parameter of RBC process is organic loading rate, which is suitable to water with high level of organic concentration, such as, industrial wastewater.

In practice, the volume requirement of RBC tank of 0.005 m^3/m^2 of disc area is used for the design, and the volume of RBC tank can be calculated from equation 2.8.

$$V = 0.005 \times A \hspace{3cm} (2.8)$$

Where   V = volume of RBC tank; m^3

A = disc area; m^2

The disc area can be calculated based on the designed hydraulic loading rate and the desired flow rate using the following equation.

$$Q = HLR \times A \qquad\qquad (2.9)$$

Where HLR = hydraulic loading rate; m^3/m^2-d

Hydraulic retention time can be calculated using the equation 2.10 to let the wastewater circulate in the RBC tank for a sufficient time as suggested in Table 2.3.

$$HRT = (V \times 24) / Q \qquad\qquad (2.10)$$

Where HRT = hydraulic retention time; hour

Table 2.3 Typical design information for rotating biological contactors.

Parameter	Unit	BOD removal treatment level
Hydraulic loading	$m^3/m^2{\cdot}d$	0.08-0.16
Organic loading	g sBOD/$m^2{\cdot}d$	4-10
	g BOD/$m^2{\cdot}d$	8-20
Hydraulic retention time	hour	0.7-1.5
Effluent BOD	mg/L	15-30

**Source**: Adapted from Metcalf & Eddy, Inc. (2003)

2.2 Wastewater Quality Parameters Used in this Study

Numerous organic compounds can be found in wastewater and it is not possible to measure every single compound present. Several collective organic parameters are available for measuring total and biodegradable organics in water. Four of them, BOD_5, COD, BDOC, and UV_{254}, were used in this study and are reviewed here.

2.2.1 BOD_5

The concept of BOD analysis was the measurement of oxygen required by the microorganisms for the oxidation of organic matter and ammonium. Normally, the oxidation reaction (incubation) is performed in the dark at 20°C for 5 days. In the oxidation, energy for cell maintenance and the new cell tissue synthesis are obtained from an oxidized-portion of the waste to end products as shown in following the equation. (Metcalf & Eddy, Inc., 2003).

Oxidation:

$$CHONS + O_2 + bacteria \rightarrow CO_2 + H_2O + NH_3 + \text{other end products} + energy \quad (2.11)$$
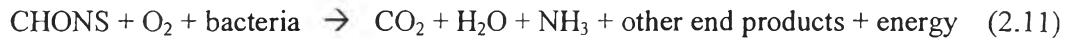
Concurrently, part of the energy released during oxidation is used for converting some of the waste into new cell tissue as shown in the following equation:

Synthesis:

$$CHONS + O_2 + bacteria + energy \rightarrow C_5H_7NO_2 \quad (2.12)$$
$$\text{(New cell tissue)}$$
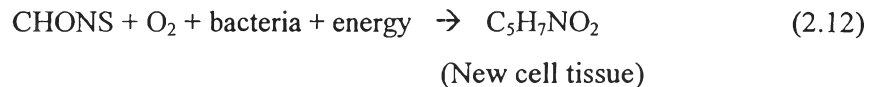
At last, the endogenous respiration process takes place after the organic matter is depleted; the new cells start to consume their own cell tissue to attain energy for cell maintenance.

Endogenous respiration:

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O \quad (2.13)$$
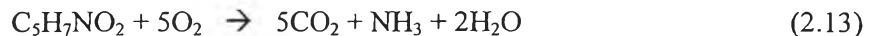
The oxygen required to complete the three processes mentioned above is so called the ultimate BOD or UBOD (Metcalf & Eddy, Inc., 2003).

The oxygen demands vary for different organics. This means that the BOD analysis only gives an approximate amount of the oxidized organic matter. Thus, the BOD value, which is calculated based on the oxygen demand in 5 days and the volume of wastewater in the BOD bottle, represents only a part of the biodegradable matter, usually from 60 to 70 percent. As a consequence, it is difficult to use BOD for the calculations of organic mass balances (Henze, Harremoës, Jansen and Arvin, 2002).

If the nitrification occurs, the measured BOD value will be higher than the true value due to the carbonaceous material oxidation. The oxygen demand associated with the oxidation of ammonia to nitrate is called nitrogenous BOD (NBOD). However, the nitrification effect can be suppressed by using various chemicals and the BOD result is known as carbonaceous BOD (CBOD).

The limitations of the BOD test are 1) the test is time consuming 2) the test is not sensitive at low organic concentrations and therefore is not applicable to drinking water samples, 3) the results are not very accurate and represent only a portion of biodegradable organics, 4) wastewater with toxic constituents must be pretreated and 5) the effects of nitrifying organisms must be suppressed. These limitations make the BOD test insufficient to be used for effective process control (Reynolds and Ahmad, 1997).

However, there are no suitable measurements to substitute for it. BOD results are still used to estimate the quantity of oxygen demand for biologically stabilizing organic matter, to design the biological wastewater treatment system, to determine the efficiency of treatment systems, to measure the wastewater effluent for complying with the wastewater discharge permits and to indicate characteristics of wastewater.

2.2.2 COD

The COD test is a chemical oxidation process used for measuring the amount of oxygen equivalent to the organic contents of the wastewater. In the process, organics in a water sample react with dichromate or digestion solution ($K_2Cr_2O_7$ solution) under acidic condition. This chemical test is a more rapid test than the BOD test, it can be completed within 2.5 hours at 150°C, and a rapid COD test, which takes only about 15 minutes has been developed (Metcalf & Eddy, Inc., 2003).

The main limitation of COD test is that it does not distinguish between biodegradable and non-biodegradable organic matter (Ellis, 1989; Reynolds and Ahmad, 1997). However, the COD fractionating has become more important in measuring the organic removal efficiency of wastewater treatment systems. The two major fractions of the COD, particulate and soluble COD (PCOD and SCOD), can be separated through sample filtration. COD of the filtrate represents soluble COD (Metcalf & Eddy, Inc., 2003).

2.2.3 BDOC

BDOC is a bioassay test, which is similar to the BOD test in principles. The BDOC methods rely on the reduction of DOC, as opposed to DO in the BOD method, after the sample is exposed to heterotrophic microorganisms. There are two main categories of BDOC methods: batch reactors or static methods (Servais *et al.*, 1987 and 1989; Joret *et al.*, 1988; Khan *et al.*, 1998a and 1999) and biofilm reactors or dynamic methods (Lucena *et al.*, 1990; Ribas *et al.*, 1991; Kaplan and Newbold, 1995). The batch procedures generally consist of sterilization and reinoculation with bacteria assemblage. The contents are well mixed and incubated for a sufficient time. For the biofilm procedures, the sample is passed through a column, which consists of biomass of bacteria assemblage attached on solid supports (Wanaratna, 2001). The biofilm procedures are suitable to the needs of the water treatment industry because the procedures are able to determine the BDOC of the water, which continuously pumped through the bioreactors (Ribas *et al.*, 1997). However, the batch and biofilm methods, share the same concept that is BDOC is determined from the difference in

DOC values before and after a period of controlled biochemical reaction, and also obtain no significant different results (Ribas *et al.*, 1997). The batch BDOC methods, especially for wastewater, are reviewed in details in Section 2.2.3.1 since a batch method was used in this study while the dynamic methods are reviewed briefly in the following paragraph.

Kaplan and Newbold (1995), Lucena *et al.* (1990), and Ribas *et al.* (1991) introduced a shorter period measurement for BDOC by using dynamic reactors. Inlet samples were passed through the glass column, which was filled with filter sand or glass balls. These inert support media were responsible for the attachment of microorganisms. After DOC consumption of microorganism, the BDOC value was calculated from the difference between the DOC concentrations of the inlet and outlet water samples. The measurement of Ribas *et al.* (1991) took approximately only 3 hours, but it has difficulty in standardizing the method and long startup period.

2.2.3.1 BDOC Static Method

Servais *et al.* (1987) introduced a batch BDOC protocol for measuring the biodegradable organics in waters. The method relies on the use of an inoculum of natural assemblage of bacteria, developed in a natural environment from which the sample was collected. BDOC measurement was based either on the reduction of DOC during incubation (10 to 30 days) or on an estimate of the flux of organic matter utilized by bacteria, deduced from biomass and mortality measurements. Servais *et al.* (1989) modified the DOC reduction based approach of their own method (Servais *et al.*, 1987) by fixing the 20°C incubation period at 28 days. Both of the methods by Servais *et al.* (1987 and 1989) were limited to samples with low concentrations of DOC (< 4 mg/L) as found in drinking water because the adequacy of dissolved oxygen during the incubation is not assured.

Khan *et al.* (1998a) combined the original batch BDOC protocol (Servais *et al.*, 1989) with the BOD test techniques to make it applicable to reclaimed and secondary treated wastewater samples. The modified method could be applied to moderately low DOC concentration wastewater (DOC = 4 to 15 mg/L). The main modification of this method included of the uses of seed control and sample dilution. The strength of this modified protocol was that simultaneous determinations of DOC, BDOC and ultimate SBOD (SBOD$_u$) of water samples could be accomplished.

BDOC is calculated by multiplying the difference between DOC reductions of the sample and of the seed control, after 28 days of incubation, with the dilution factor (F) while $SBOD_u$ is determined in a similar manner.

$$BDOC \ (mg/L) = [(DOC_i - DOC_f) - (DOC_{bi} - DOC_{bf})] \ F \qquad (2.14)$$

$$SBOD_u \ (mg/L) = [(DO_i - DO_f) - (DO_{bi} - DO_{bf})] \ F \qquad (2.15)$$

Where F = (mL of dilution water + mL of sample) / mL of sample

DOC_i = DOC of sample before incubation

DOC_f = DOC of sample after incubation

DOC_{bi} = DOC of seed control before incubation

DOC_{bf} = DOC of seed control after incubation

The applications of the modified method showed that BDOC concentrations of reclaimed wastewater at 28 days of incubation at 20°C and 37°C temperatures were not different. For secondary wastewater, the incubation temperature affected on the BDOC concentrations. The BDOC exertion at 28 days at 20°C was only 75 % of the BDOC exertion at 37°C.

Although this method is sensitive, it was found to be too time consuming for routine wastewater quality parameter. Consequently, in order to reduce the incubation time from 28 days to 5 days, Khan *et al.* (1999) applied larger inoculum sizes and/or more concentrate inoculum to the samples to shorten the incubation time so that it could be used as a routine parameter. Standard solutions, secondary effluent, and ozonated secondary effluent were the three types of samples studied. The modified batch BDOC procedure was adapted by filtering samples with glass fiber filter (GF/F) after the incubation to remove suspended inoculum. The results showed that employing 2 mL MLSS inoculum into ozonated secondary effluent and incubate at 37°C indicated the fastest BDOC exertion rate; as a consequence, the incubation time may be reduced to 5 days. Moreover, the determination of $BDOC_5$ of ozonated secondary effluents from high SRT plants can be accomplished using either 2 or 10 mL of MLSS inocula tested at both temperatures, but it was recommended that MLSS inoculum should not be larger than 10 mL because of possible excessive release of DOC from the seed.

2.2.3.2 BDOC Applications

BDOC has been used for 1) indicating raw water quality, 2) indicating finished water quality, 3) designing, monitoring, and optimizing operational conditions of biologically activated carbon (BAC) system, 4) measuring the effect of water treatment processes other than BAC, 5) indicating wastewater quality and treatment performance. Since this study focuses on $BDOC_5$ in wastewater, only the applications related to wastewater and kinetics of BDOC exertion are reviewed here.

Servais *et al.* (1998) studied the impact of wastewater effluent from the city of Paris and its suburbs on the river Seine. Pools of BOD, DOC, particulate organic carbon (POC), BDOC and biodegradable fraction of POC (BPOC) were analyzed. Organic matters in the wastewater were characterized using BDOC and BPOC, instead of BOD and COD, because of their higher accuracies. BDOC and BPOC were calculated based on the differences between the DOC and POC concentrations at the beginning of the batch test and at the end of incubation after the steady state was reached. Different processes of wastewater treatments, which are decantation, nitrification biofiltration and activated sludge process, were used. The study showed that decantation process mainly removed POC, and activated sludge process could improve the removal efficiency of BDOC with increasing SRT.

Khan *et al.* (1998b) used BDOC to indicate wastewater reclamation plant performance and treated wastewater quality. Increasing in biodegradability during ozonation of reclaimed wastewater could be detected. Higher BDOC concentrations were observed in the effluent of treatment plants with low SRT. It was suggested that BDOC could be used as a water quality parameter for secondary effluents. Comparing with DOC, $SBOD_u$, or SCOD, BDOC could indicate the quality of secondary effluent with higher precision and accuracy.

Babcock *et al.* (2001) investigated the characteristics of effluents of bench-and full-scale activated sludge systems related to SRT by using a simple $BDOC_{28}$ method. The relationships between BDOC and other parameters, such as, COD, $SBOD_5$, and DOC of effluents were also studied. The results showed that the longer the SRT, the lower SCOD and the larger VSS values of the effluent. By treating synthetic wastewater, the relationship between BDOC concentration of effluent after steady state and SRT can be predicted. There was no clear relationship between SRT and effluent $BDOC_{28}$ from the full-scale wastewater treatment plants. However, good correlations between effluent $BDOC_{28}$ and effluent DOC, $SBOD_5$ and SCOD values were found.

Wanaratana (2002) investigated the effect of control parameters of biological wastewater treatment systems on effluent BDOC using two bench-scale biological reactors, which are AS and TF, and a full-scale RBC system to ensure the utility of BDOC in characterizing the secondary treated wastewater. The results showed that BDOC is more appropriate wastewater quality parameter than $SBOD_5$ or DOC. BDOC could be used as a reliable parameter for evaluating the efficiency of biological wastewater treatment process, especially when highly quality secondary effluent is produced. For AS unit, higher BDOC removal was observed at higher SRTs. BDOC removal of the TF unit decreased when HLR was increased. For RBC, no trend between $BDOC_{28}$ and HLR was observed.

2.2.4 Ultraviolet Absorbance at 254 nanometers and Specific Ultraviolet Absorbance

Ultraviolet light at 254 nm which is the most commonly used UV wavelength for measuring unsaturated double bonds and aromatic organics, which are the main groups of compounds that make up natural organic matter (NOM) in water. UV_{254} is often used as a simple surrogate measurement for DOC. The measurement does not require a change in the sample characteristics and therefore required much less time and effort per analysis than do the techniques described above (Benjamin *et al.*, 1999). For some waters, linear relationships were observed between DOC concentration and UV_{254}.

Another parameter that can indicate the relative amount of aquatic humics in water is SUVA. The definition of SUVA is UV_{254} expressed as per meter of absorbance divided by DOC concentration in mg/L, giving the unit of SUVA as m^{-1}/mg/L. SUVA can be used to indicate the nature of DOC in water samples as described in Table 2.4 (Edzwald *et al.*, 1990).

Table 2.4 Guidelines of SUVA for indicating DOC characteristics in water.

SUVA values	Guidelines
4 to 5	The DOC of a water sample is composed of aquatic humic materials in a large portion. It means that the DOC is relatively hydrophobic, aromatic, and of high molecular weight compared to waters with lower SUVA values.
Less than 3	The DOC of a water sample is composed of non-aquatic humic materials in a large portion. It means that the organic matter is relatively hydrophilic, less aromatic, and has lower molecular weight compared to waters with higher SUVA values.

Source: Adapted from Edzwald *et al.* (1990)

2.2.4.1 UV$_{254}$ and SUVA Methods

UV absorbance (A) is the logarithm of the intensities ratio of the incident light (I_0) and the transmitted light (I). According to the Beer-Lambert Law, it is related to the molar absorptivity or molar extinction coefficient (ε), the thickness of the substance, such as the path length of the cell (b) and the molar concentration of the substance (c).

$$A = \log (I_0/I) = \varepsilon bc \qquad (2.16)$$

UV$_{254}$ can be used as an indirect measurement of BOD. The relationship between UV$_{254}$ and BOD of wastewater is also well-known (Reynolds and Ahmad, 1997). However, UV$_{254}$ is more related to organic carbon (Ellis, 1989). Previous research showed strong relationships between UV$_{254}$ and the DOC in natural water (Reynolds and Ahmad, 1997). As mentioned above, the ratio between UV$_{254}$ and DOC in the water sample is SUVA. DOC can be measured from the total organic carbon analysis of the sample filtrate through a 0.45 μm pore size filter.

2.2.4.2 UV$_{254}$ and SUVA Applications

Gong and Edzwald (1981) studied seasonal removal of the organic matter and trihalomethane (THM) precursors of a conventional wastewater treatment plant. Samples were filtered through a glass fiber filter and measured for UV$_{254}$. UV$_{254}$ varied with seasonal changes. UV$_{254}$ absorbance was a good indicator of non-volatile TOC (NVTOC) and had a relationship with total THMs (TTHMs).

Mrkva $et\ al.$ (1983) evaluated the correlation between UV$_{254}$ and COD of river waters with various degrees of organic pollution. The study was conducted on medium- and high-polluted rivers. Selected reaches of the rivers were mainly polluted with lignin and humic substances and phenolic wastes, and UV$_{254}$ of these river waters was high. The strong relations of UV$_{254}$ absorbance and COD, evaluated mathematico-statistically by a computer and supplemented by graphs, demonstrated that the spectrum absorbance in the UV range is an important indicator of organic pollution in rivers. The absorbance module at 254-nm was also suitable for both laboratory analysis and automatic monitoring of dissolved organic matter concentration.

Edzwald $et\ al.$ (1985) showed that UV$_{254}$ was an excellent surrogate parameter for estimating the organic carbon concentration of raw water. Also, UV$_{254}$ can be used for monitoring pilot plant and full-scale water treatment plant performances for removal of

nonpurgeable total organic carbon (NPTOC) and total trihalomethane formation potentials (TTHMFP). UV_{254} was considered as a surrogate parameter because it can be measured more easily, rapidly, and inexpensively than the traditional parameters.

Duguet *et al.* (1986) chose UV_{254} for monitoring the performance of ozonation, which was used for organic matter removal from drinking water. During ozonation of various waters in a semi-batch reactor, the kinetics of UV_{254} reduction was examined. The result showed that the monitoring of ozonation process based on the reduction in levels of organic matter could be easily accomplished from the treated water UV absorption measurement.

Reynolds *et al.* (1997) examined industrial and domestic sewage in the UK by studying from the properties of fluorescence. An absorption band at around 280 nm and a fluorescence maximum at 340 nm were used. UV_{254} of the sewage samples were also investigated. It was found that fluorescence rationally correlated with corresponding BOD values. UV_{254} and BOD values of three sewage treatment works exhibited a linear relationship and when the data were analyzed with a linear regression and high correlation coefficients were observed.

Khan *et al.* (1998b) applied SUVA for characterizing the DOC of reclaimed wastewater samples. After the wastewater went through five ozone columns, no significant change in DOC, gradual reduction of UV_{254}, and reduction of SUVA was observed. The results also showed that the increasing of BDOC was associated with the decreasing of UV_{254}.

Wanaratna (2002) analyzed the UV_{254} of effluent samples from new and old sections of a full-scale RBC plant. The effluent of the new section, which was operated at higher HLRs, had slightly higher UV_{254} than the effluent of the old section. The results suggested that the new section effluent contained more UV absorbing compounds. Since the new section produced worse quality effluent, compared with the old section, which has lower BOD_5, it may be possible to use UV_{254} as a wastewater quality parameter.