Title:      **DIFFUSED AIR AERATION SYSTEMS FOR**
         **THE ACTIVATED SLUDGE PROCESS**

         **DESIGN PERFORMANCE TESTING**


**Author:**          **Professor T J Casey**

**DIFFUSED AIR AERATION SYSTEMS FOR THE ACTIVATED SLUDGE PROCESS**

**DESIGN   PERFORMANCE   TESTING**

## 1.  INTRODUCTION

Aeration systems normally perform two functions in activated sludge wastewater treatment processes, namely, oxygen transfer and mixing. While oxygen transfer may be regarded as the primary function, mixing is also important to ensure a full utilisation of the activated sludge reactor volume and a uniform dispersion of dissolved oxygen throughout the mixed liquor. However, in some applications of the activated sludge process, a mixing input is provided which is independent of the aeration system, thereby relieving the aeration system of its mixing function.

Where an independent mixing system is provided, the specific mixing power input required is dependent on the reactor configuration, being typically in the range 3 to 6 W/m$^3$. The specific power input required for oxygen transfer is generally not less than 8 to 10 W/m$^3$, even in high sludge age processes such as the oxidation ditch. Hence, aeration systems are generally likely to have a sufficient gross power input for their ancillary mixing function, provided that it is appropriately applied.

## 2. DIFFUSED AIR AERATION SYSTEMS

In diffused air systems, air is introduced to the mixed liquor through "diffusers", located at some distance below the liquor surface. Diffused air systems are broadly classified as coarse or fine bubble systems, depending on the size of bubble generated. Although the boundary between these two categories is not very sharply defined, fine bubble diffusers typically produce bubbles in the 2-5mm size range in clean water, while coarse bubble diffusers produce bubbles in the size range 6-10mm.

Coarse bubble diffusers typically consist of drilled holes or slots in a submerged air distribution system, the bubbles produced may be smaller than the orifice size, through being sheared off by the water pressure. The oxygen transfer efficiency (OTE) of coarse bubble systems is generally much lower than fine bubble systems (OTE is defined as the percent of oxygen transferred, at zero dissolved oxygen concentration).

Fine bubble diffusers (USEPA, 1989) are constructed from a range of materials including ceramics, porous plastics and perforated membranes. Ceramics and porous plastics have interconnected pore structures through which the air flows to be discharged at the diffuser surface as a bubble stream. Their pore structure is rigid and hence subject to fouling either due to impurities in the air or precipitation from the mixed liquor side. To prevent clogging of porous diffusers, it has been found necessary to reduce the dust content of air by appropriate filtration systems.

Perforated membrane diffusers are made from either thermoplastic or elastomeric sheet materials (plasticized PVC, EPDM rubber, neoprene rubber) of thickness 1-2mm. They are mechanically perforated with a pattern of small holes or slits, which expand as the air flow increases, hence they are commonly known as flexible membrane diffusers.

### 2.1 Oxygen transfer kinetics

It has been found from experimental observation that the rate at which the dissolved oxygen concentration (DO) in a body of water under aeration changes with time is proportional to the oxygen equilibrium deficit, as represented by the following equation:

$$\frac{dc}{dt} = k_L a\left(C_\infty^* - C\right) \qquad\qquad (1)$$

where C (mg/l) is the dissolved oxygen concentration, assumed to be uniform throughout the water bulk; dc/dt is the rate of change of oxygen concentration with time; $C_\infty^*$ (mg/l) is the equilibrium concentration (concentration reached at infinite aeration time), and $k_L a$ ($t^{-1}$) is the system oxygen transfer coefficient. Equation (1) has a general validity for a very wide range of aeration systems.

Equation (1) may be expressed in its integrated form as follows:

$$C = C_\infty^* - \left(C_\infty^* - C_i\right)\exp\left(-k_L a\, t\right) \qquad (2)$$

where $C_i$ is the initial (i.e. time zero) oxygen concentration, and C is the oxygen concentration after aeration time t.

The system oxygen transfer rate (OTR) is the product of dc/dt and the water volume (V) under aeration:

$$OTR = k_L a\left(C_\infty^* - C\right)V \qquad (3)$$

It should be noted that, in the case of diffused air aeration systems, the equilibrium concentration $C_\infty^*$ exceeds the standard handbook saturation concentration, due to the hydrostatic pressure on the rising air bubble stream.

## 2.2 System performance under standard and process conditions

Aeration system performance is usually specified with reference to standard test conditions, defined (ASCE, 1993) as follows: "tap water" as the aerated medium, water temperature 20°C, 1 atm atmospheric pressure, zero DO concentration. The system performance can then be expressed in terms of the following standard parameters:

Standard oxygen transfer rate (SOTR, kg $O_2$/h)
Standard oxygen transfer efficiency (SOTE, % oxygen absorbed)
Standard specific oxygen transfer efficiency (SSOTE, % oxygen absorbed per metre depth)
Standard aeration efficiency (SAE, SOTR/power input, kg $O_2$/kWh)

By insertion of the foregoing standard conditions to equation (3), the SOTR is expressed as follows:

$$SOTR = k_L a_{(20)} C_{\infty(20)}^* V \qquad (4)$$

where $C_{\infty(20)}^*$ is the equilibrium oxygen concentration at infinite aeration time at a water temperature of 20 °C.

The SOTE value is given by:

$$SOTE = \frac{SOTR}{0.228\, Q_{a(m)}} \qquad (5)$$

where $Q_{a(m)}$ is the influent air mass flow rate (kg/h); the mass fraction of oxygen in air is assumed to be 0.228 kg $O_2$/kg air.

In practice, clean water oxygen transfer tests are almost invariably carried out at prevailing water temperature and atmospheric pressure conditions, which differ from the standard conditions of 20 °C and 1 atm, respectively. Hence the measured values of $k_L a$ and $C_\infty^*$ need to be appropriately adjusted.

The transfer coefficient $k_La$ increases with temperature; its value at a temperature T ($^o$C) is correlated with its value at 20 $^o$C as follows:

$$k_La_{(20)} = k_La_{(T)}\,\theta^{(20-T)} \qquad (6)$$

where T is the water temperature ($^o$C); $\theta$ is a temperature correction factor, generally taken as 1.024 (ASCE, 1984).

The equilibrium concentration $C_\infty^*$ also varies with temperature and pressure; its value at the prevailing atmospheric pressure and water temperature conditions is correlated with its value at the standard conditions of 1 atm and 20 $^o$C as follows:

$$C_{\infty 20}^* = C_\infty^*\left(\frac{1}{\tau\Omega}\right) \qquad (7)$$

where $\tau$ is a temperature correction factor and $\Omega$ is a pressure correction factor:

$$\tau = \frac{C_{sT}^*}{C_{s20}^*} \qquad (8)$$

where $C_{sT}^*$ and $C_{s20}^*$ are the tabular values of dissolved oxygen surface saturation, at temperature of T $^o$C and 20 $^o$C, respectively, and at a standard pressure of 1 atm and 100% relative humidity.

$$\Omega = \frac{P_b}{P_s} \qquad (9)$$

where $P_b$ is the prevailing barometric pressure (atm) and $P_s$ is the standard barometric pressure of 1 atm.

Combining equations (4), (6) and (7), SOTR can be expressed in the form:

$$SOTR = k_La_T\theta^{(20-T)}C_\infty^*\left(\frac{1}{\tau\Omega}\right)V \qquad (10)$$

Two empirical factors, $\alpha$ and $\beta$, both dependent on water quality, are used to relate oxygen transfer under process conditions to measured performance under clean water conditions.

The clean water $k_La$ value is multiplied by a factor, $\alpha$, to correct for the influence of surfactant contaminants in the process water. Values of the $\alpha$-factor for diffused air aeration systems have been measured over the range 0.2 to 1.0. Values in excess of unity have been also been reported, for seawater and for aerators in very high energy input applications. The $\alpha$-factor is of particular significance for diffused air systems and is discussed in more detail later in this paper.

The clean water $C_\infty^*$ value is multiplied by a factor, $\beta$, to correct for the influence of high total dissolved solids in the process water. While the value of $\beta$ can vary from approximately 0.8 to 1.0, it is generally close to 1.0 for municipal wastewaters.

Taking all the foregoing factors into account, the rate of oxygen transfer to activated sludge mixed liquor (OTR$_f$), expressed in terms of standard clean water test values, is as follows:

$$OTR_f = \frac{\alpha(SOTR)\theta^{T-20}}{C_{\infty 20}^*}\left(\tau\Omega\beta C_{\infty 20}^* - C\right) \qquad (11)$$

where C is the mixed liquor DO concentration.

Likewise, the oxygen transfer efficiency under field conditions ($OTE_f$), can be estimated from the corresponding standard clean water parameter values as follows:

$$OTE_f = \alpha(SOTE)\theta^{T-20}\frac{\left(\tau\Omega\beta C^*_{\infty 20} - C\right)}{C^*_{\infty 20}}$$ (12)

## 3. PERFORMANCE TESTING OF DIFFUSED AIR SYSTEMS

Two types of standardised test procedures are available for diffused air systems (a) the clean water unsteady state test procedure (ASCE, 1993), and (b) the offgas test procedure, carried out under process conditions (ASCE, 1996). The clean water test provides the data required to compute the system $k_La_{(T)}$ and $C^*_\infty$ for insertion in equation (10) to calculate the system SOTR. Hence the system SOTE and SAE values can also be computed, if the airflow and power inputs are known. The offgas method provides a direct measurement of the system SOTE, under process conditions.

### 3.1 Clean water test procedure

The clean water test enables the determination of the characteristic process performance parameters, SOTR (kg $O_2$/h), SOTE (% $O_2$ uptake) and SAE (kg $O_2$/kWh). The test procedure involves de-oxygenation of the test water volume by gas-stripping or by the addition of a reducing agent such as sodium sulphite ($Na_2SO_3$). To accelerate the chemical reduction of oxygen, a catalyst such as $Co^{2+}$ is added at a concentration of about 1 mg/l. Because it is necessary to leave the aeration system in operation during the deoxygenation process, the amount of sulphite added is usually in excess of the stoichiometric amount by 10-20%.

The rate of re-oxygenation is then monitored, usually by a number of DO probes located at different depths. While one DO probe is sufficient in small well-mixed tanks, a minimum of two probes should be used; in large deep tanks a minimum of four probes is recommended. It is important that the DO probes are calibrated in advance and that they have a sufficiently fast response time (the probe time constant should not be less than $0.02/k_La$, ASCE, 1993).

For a reliable determination of $k_La$, it is desirable that the re-oxygenation measurement should extend over a wide value range, e.g. 10%-90% of equilibrium value. While it would be normal practice to record DO concentration using a data logger or similar, it is the author's practice to also record meter readings manually at 2 minute intervals over the re-aeration period.

The re-aeration data set for each DO probe is analysed, using regression analysis (Casey, 1996), to find the best-fitting values of $C_i$, $C^*_\infty$ and $k_La$ for insertion in equation (10) to compute an SOTR value for each probe. The system SOTR is taken as the average of the set of values thus generated.

An illustrative data set is presented on Fig 1, which shows a single set of test measurements for a diffused air system with a 4.7m diffuser submergence. It will be noted that the $C^*_\infty$ value of 117.2 % of the surface saturation value corresponds to an effective saturation depth of about 1.77m or 0.38 x diffuser depth (the effective saturation depth represents the depth of water under which the total pressure (hydrostatic plus atmospheric) would produce a saturation concentration equal to $C^*_\infty$ for water in contact with air at 100% relative humidity).
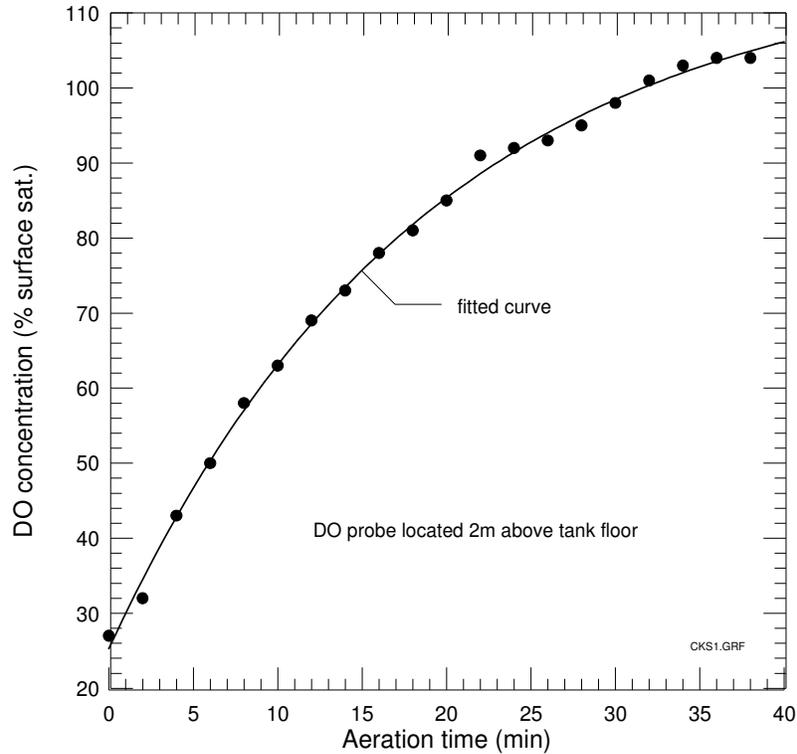
**Fig 1**          **Sample set of DO probe readings for diffused air system
clean water test measurement**
Diffuser submergence: 4.70m
Best-fit parameter values:     $C_i$ = 25.3 % surface sat.
                                     $C_\infty^*$ = 117.2 % surface sat.
                                     $k_L a$ = 0.053 min$^{-1}$

### 3.2 Offgas test procedure

The offgas test procedure provides a direct measurement of oxygen transfer efficiency under steady state or approximately steady state process conditions. The method (ASCE,1996) employs measurement of the oxygen partial pressures in the influent atmospheric air and the emergent air stream (offgas) from the surface of the aeration tank, under controlled conditions of pressure, temperature, humidity, flow rate and carbon dioxide content. Carbon dioxide and water vapour are stripped from both streams, thus eliminating the associated partial pressure influences. The residual oxygen concentration in the emerging air stream at the surface of the aeration tank is measured. The difference between the oxygen concentration in the influent and emergent air streams provides a direct measurement of the oxygen transfer efficiency (OTE) of the aeration system.

With carbon dioxide and water vapour removed from the influent and offgas air streams, the mole ratios (MR) of oxygen to inert gases are as follows:

influent air                                   $MR_{ia} = \dfrac{0.2095}{1 - 0.2095} = 0.265$

offgas                                         $MR_{og} = \dfrac{0.2095 \, DO_{og}}{1 - 0.2095 \, DO_{og}}$

where $DO_{og}$ is the DO probe reading for the offgas stream, expressed as a fraction of its reading for the influent air stream. The field oxygen transfer efficiency is then calculated as follows:

$$\text{OTE}_f = 1 - \frac{\text{MR}_{og}}{0.265} \qquad (13)$$

The equipment required for the execution of the offgas test includes (a) a floating collection hood for the generation of an offgas stream, (b) a stripping column for the removal of carbon and water vapour, (c) a DO meter. A recommended procedure for carrying out the test is presented in a set of Standard Guidelines published by the American Society of Civil Engineers (ASCE, 1996).

The $\text{OTE}_f$ value is determined for a representative number of sampling points over the aeration tank surface and are averaged to give a mean value for the system as a whole.

By also measuring the mixed liquor DO concentration, C, the standard oxygen transfer efficiency under process conditions $\text{SOTE}_{PW}$ can be calculated as follows:

$$\text{SOTE}_{PW} = \text{OTE}_f \left( \theta^{20-T} \right) \left( \frac{\beta \, C^*_{\infty 20}}{\tau \Omega \beta \, C^*_{\infty 20} - C} \right) \qquad (14)$$

## 4. FACTORS AFFECTING DIFFUSED AIR SYSTEM PERFORMANCE

The performance of fine bubble diffused air systems under process conditions is affected by many factors, the more significant of which are:

- basin geometry and diffuser placement
- diffuser density and air flow rate
- diffuser performance characteristics
- mixed liquor contaminants, particularly surfactants
- diffuser fouling

### 4.1 Basin geometry and diffuser placement

The air bubble stream emitted from a submerged diffuser exerts an air-lift pumping effect on the surrounding liquid, generating a pattern of vertical circulation, which has an important influence on oxygen transfer. The nature of this circulation is determined by the tank shape and the diffuser placement.

Where the diffusers are clustered on one side of a tank, a vertical bulk liquid circulation is created, which provides a mixing input to the entire tank. This circulation, however, reduces the bubble contact time and hence has a negative effect on oxygen transfer efficiency.

Where the diffusers are uniformly distributed over the tank floor area, the air-lift pumping effect is minimised, thus maximising air bubble/water contact time and oxygen transfer efficiency.

Diffused air systems are also used in looped channel aeration tanks (e.g. oxidation ditch), where the primary mixing input is typically provided by a slow speed propeller device, which generates a horizontal circulation velocity that is sufficient to keep the activated sludge in suspension. It has been reported (Gillot et al., 1998) that oxygen transfer efficiency is enhanced under such conditions, relative to transfer in the absence of an horizontal flow velocity.

Tank depth is also a significant factor in relation to diffused air system performance. From reported studies in the depth range 2m - 12m (Popel & Wagner, 1994, Fred, 1998), the influence of diffuser submergence on oxygen transfer efficiency can be approximated as follows:

$$SOTE_{D_s} = SOTE_4\left(\frac{D_s}{4}\right)^{0.75} \tag{15}$$

$$SSOTE_{D_s} = SSOTE_4\left(\frac{4}{D_s}\right)^{0.25} \tag{15a}$$

where the subscripts $D_s$ and 4 refer to diffuser submergences of $D_s$ (m) and 4m, respectively. These empirical correlations are illustrated graphically on Fig 2.
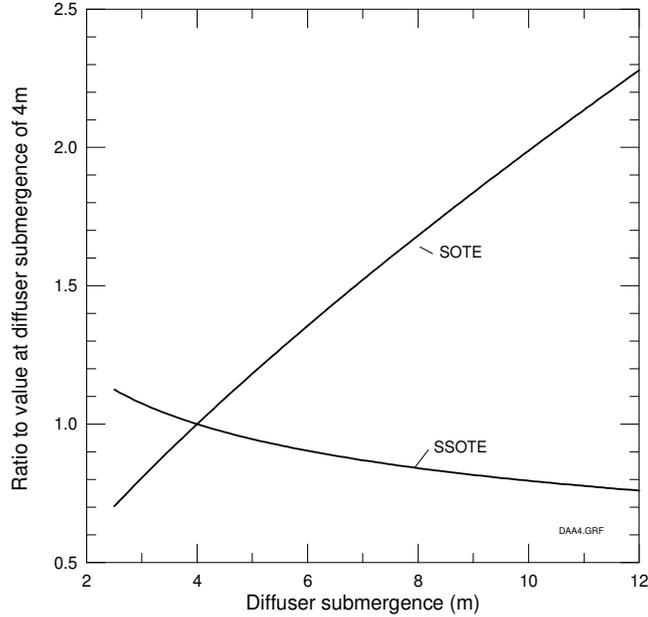


**Fig 2**            **Influence of diffuser submergence on oxygen transfer efficiency**

### 4.2 **Influence of diffuser density and air flow rate**

The efficiency of oxygen transfer has been found to increase with increasing diffuser density (diffuser density is defined as the ratio of the diffuser surface area to the tank floor area). The efficiency of oxygen transfer has also been found to decrease with increasing air flow rate. The typical magnitude of these factors is illustrated graphically on Fig 3.

### 4.3 **Influence of mixed liquor contaminants**

As already outlined, the oxygen transfer coefficient $k_La$, for mixed liquor operation, is found by multiplying the clean water $k_La$ by an empirical factor, $\alpha$, which is typically within the range 0.35-0.8. Surfactant residues have been identified as the primary category of contaminants, which have an adverse effect on the performance of diffused air systems. The addition of surfactants to water reduces surface tension, reducing bubble size and hindering bubble coalescence. This results in a larger bubble/water interface area and greater hold-up of bubbles in the liquid column, both of which significantly increase the air/water interface area. However, this positive effect is more than offset by the negative impact of surfactant accumulation at the bubble surface. The net result is a significant reduction in $k_La$ (Wagner & Popel, 1996)
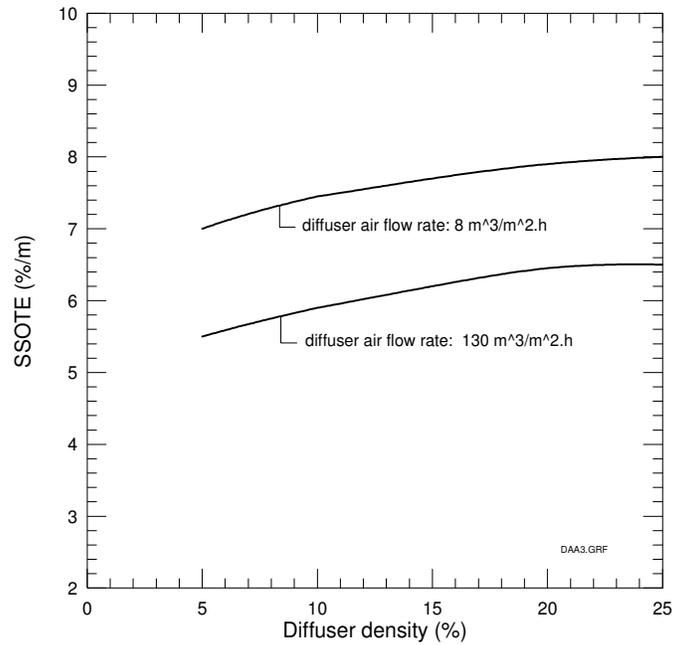
**Fig 3**       **Influence of diffuser density and air flow rate on SOTE**
(flexible membrane diffusers, 4 m submergence)

From a brief review of $\alpha$-factor measurements at wastewater treatment plants, it would appear that measured $\alpha$-values fall mainly within the range 0.35 - 0.8 (USEPA, 1989; Groves et al., 1992). It has been found that the magnitude of $\alpha$ is strongly influenced by sludge age. For carbonaceous processes, operating at sludges ages less than 8 days, the value of $\alpha$ is generally in the range 0.35 - 0.55. For nitrifying processes, with sludge ages in the range 10 -12 days a value in the range 0.5 - 0.8 may be expected. The increase in $\alpha$ with increasing sludge age would appear to be due mainly to the increasing extent of biodegradation of surfactants with increasing sludge age. Thus, in nitrifying plug flow reactors, there is, typically, a gradient in the $\alpha$ value, increasing from a low value at the inlet end, where the oxygen demand is highest, to a high value at the outlet end, where the oxygen demand is lowest. The highest overall $\alpha$ value is likely to be obtained in completely mixed systems with a high sludge age.

### 4.4 Diffuser fouling

All fine bubble diffusers are susceptible to accretion of biofilms and/or deposition of inorganic precipitates that can alter the operating characteristics of the diffusers (USEPA, 1989).

The effects of fouling are two-fold (a) clogging of the pores in the case of rigid materials, such as ceramics, and (b) surface blinding, which adversely affects bubble formation and bubble size.

Pore-clogging may be due to adhesion of particulate material derived from the air side or precipitated material, such as metal hydroxides and carbonates, coming from the liquid side. The reduction in effective pore volume may actually improve oxygen transfer efficiency initially, but it eventually gives rise to increased head loss and increased energy consumption. Air-side fouling can be eliminated by the use of air filters and corrosion-resistant air distribution materials. Experience would appear to indicate that a 95% removal of particles $\geq$ 1 micron should be sufficient to prevent air-side clogging of rigid pore diffusers.

Biofilm and/or chemical precipitate accretion on the surface of diffusers can enlarge the pore apertures at which the air bubbles are formed, by effectively creating a new boundary at the surface of the biofilm, thereby increasing bubble size and reducing oxygen transfer efficiency.

The manifest effects of diffuser fouling are increased fluid flow resistance and possibly increased flow variation between diffusers. A variety of cleaning procedures have been applied (USEPA, 1989). They include high-pressure hosing to remove surface biofilms and acid-gas purging to eliminate pore clogging.

It should be noted that flexible membrane diffusers, while not having the durability of rigid pore diffusers, are less prone to fouling problems.

## 5. ENERGY EFFICIENCY OF DIFFUSED AIR SYSTEMS

The energy efficiency of aeration systems is quantified by the parameter, SAE, the standard aeration efficiency:

$$SAE = \frac{SOTR}{P_w} \tag{16}$$

where $P_w$ is the power input, in this case taken to be the wire-power (i.e. electrical power input). SAE is readily determined in conjunction with the standard clean water SOTR determination, by noting the blower electrical energy consumption over the test duration. $P_w$ can be expressed in terms of the adiabatic blower power and the combined blower/motor efficiency, $\eta$, as follows:

$$P_w = \frac{1.014\ Q_{a(m)}T_l}{\eta}\left[\left(\frac{p_2}{p_1}\right)^{0.283} - 1\right] \tag{17}$$

where $Q_{a(m)}$ is the intake air flow (kg/s), $T_1$ is the absolute temperature (K) of the intake air, $p_1$ and $p_2$ are the absolute pressures of the intake and compressed air streams, respectively.

The SAE is a function of the combined efficiencies of the air delivery and oxygen transfer processes. Two generic types of air blower are in general use for activated sludge aeration, positive displacement blowers and centrifugal blowers. Positive displacement blowers can be used for water depths up to 10m, while high-speed centrifugal blowers can be used for water depths up to 15m. While the latter type of blower has a greater energy efficiency than positive displacement blowers, it is not suited to small-scale applications i.e. where the required air flow is less than ca. 3000 $Nm^3$/h.

The SAE value for fine bubble diffused air systems typically falls within the range 3 - 4 kg $O_2$/kWh.

## 6. DETERMINATION OF REQUIRED OXYGENATION CAPACITY

Aeration systems are designed to maintain dissolved oxygen in the activated sludge mixed liquor at or above a specified lower limit concentration. This lower limit value is typically 1 mg/l for non-nitrifying processes and 2 mg/l for nitrifying processes. In the interests of energy efficiency, the operating dissolved oxygen concentration in activated sludge processes is generally maintained close to the lower limit value. For example, at a diffuser submergence of 3m and a mixed liquor temperature of 15 $^o$C, the power input required to maintain a DO concentration of 4 mg/l is 50% higher than required to maintain a DO concentration of 1 mg/l.

Because water has such a low capacity for oxygen storage the oxygen input of the aeration system must effectively match the uptake of oxygen through microbial respiration. The rate of microbial respiration is directly related to the rate of substrate oxidation, which in turn is dependent on the sludge age at which the activated sludge process is operated, the mixed liquor temperature, the influent wastewater load and its composition.

The process oxygen demand is made up of two components, a carbonaceous component, which is BOD-dependent, and a nitrogenous component, related to nitrification/denitrification processes.

Fig 4 shows the typical variation of the specific carbonaceous oxygen demand with sludge age and process temperature. As may be expected the carbonaceous oxygen demand has a positive correlation with both of these parameters.
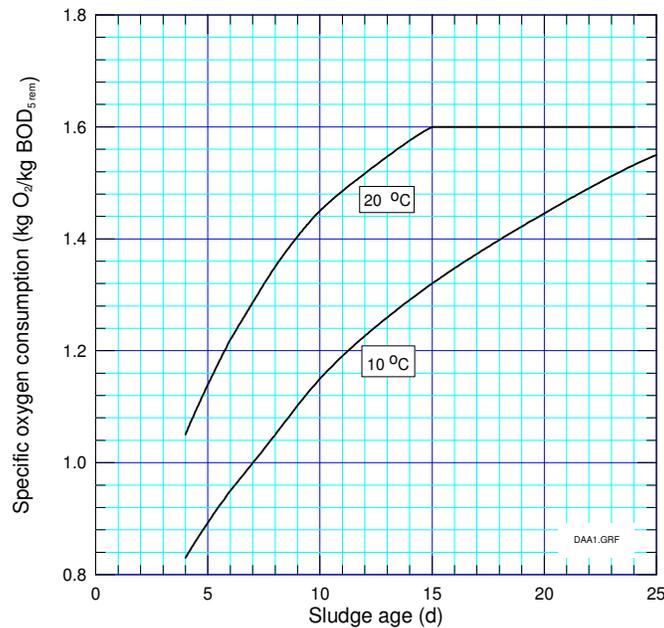


**Fig 4**                         **Specific carbonaceous oxygen demand**
(ATV, 1991)

The onset of nitrification brings a step-change in the process oxygen demand of activated sludge processes. Each unit mass of ammonia nitrogen converted to nitrate requires an input of 4.3 units of oxygen. Likewise, denitrification reduces the process oxygen demand, each unit mass of nitrate nitrogen reduced to gaseous nitrogen is equivalent to an input of 2.8 units of oxygen. In the typical annual temperature range of Irish municipal wastewaters (8 to 20 $^{o}$C), nitrification is likely to be well established at sludge ages of 8 days and over.

Based on the foregoing correlations, the computed range of average process oxygen demand (APOD, kg $O_2$/PE.d) for the commonly used spectrum of activated sludge processes is plotted in bar chart format on Fig 5, based on an assumed typical municipal wastewater composition ($BOD_5$:N =5) and an operating temperature of 20 $^{o}$C. The selected sludges ages of 5 ,10 and 25 days relate, respectively, to non-nitrifying, nitrifying and sludge-stabilisation activated sludge processes. The computed APOD values assume complete nitrification and 95% denitrification for the nitrifying and denitrifying processes, respectively. As may be seen from an inspection of the bar chart, the APOD ranges from 44 kg $O_2$/PE.d, at a 5-day sludge age with primary sedimentation, to 135 kg $O_2$/PE.d at a sludge age of 25 days, without primary sedimentation.

Due to influent load variation, the process oxygen demand varies diurnally and from day-to-day. In particular, it is important to define the maximum process oxygen demand, which, in turn, determines the required oxygen transfer of the aeration system. In the absence of definitive data on influent load fluctuation, the maximum process oxygen demand (MPOD) can be evaluated by applying recommended default handbook peak load factors to the APOD values for C and N (determined by the ratio of the maximum 2-hour load to the 24-hour average load). Fig 6 shows recommended (ATV, 1991) peak factors for the carbonaceous and nitrogenous components of the total oxygen demand. It will be noted that the recommended peak load factor for nitrogenous respiration is greater than that for carbonaceous respiration. Both peak load factors tend to decrease with increasing plant scale.
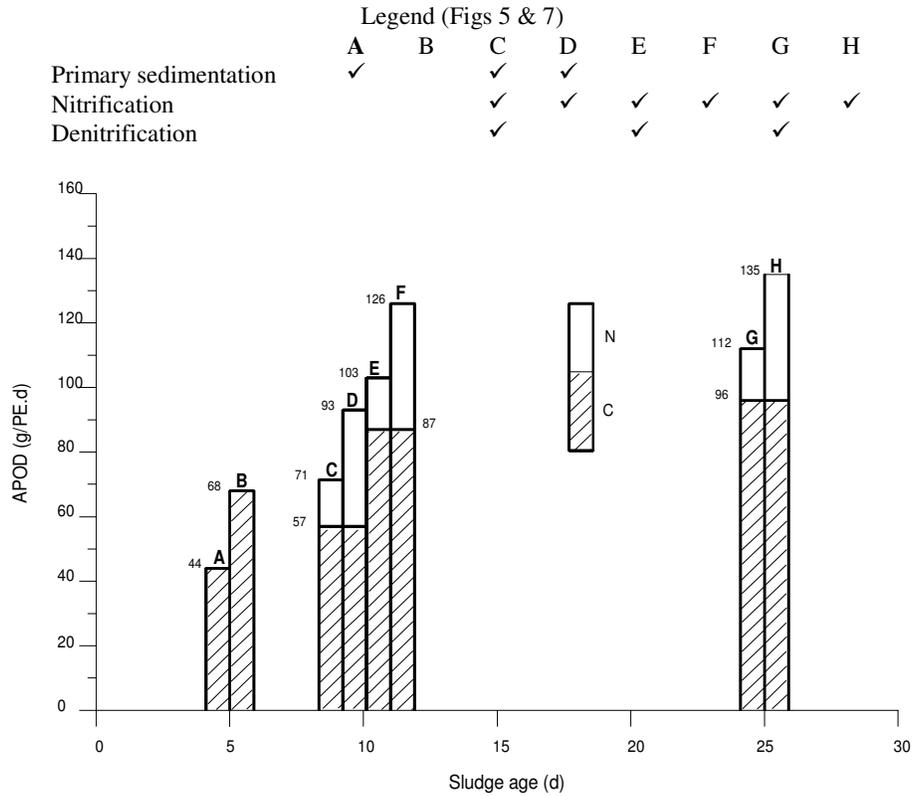
Legend (Figs 5 & 7)

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Primary sedimentation | ✓ | | ✓ | ✓ | | | | |
| Nitrification | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Denitrification | | | ✓ | | ✓ | | ✓ | |



**Fig 5**              **Computed average process oxygen demand (APOD)**
              unit PE: 60 g $BOD_5$/d, 12 g N/d; Temp. 20 $^{\circ}$C .
              Primary sedimentation assumed to remove 35% of BOD
              and 15% of N.

Assuming the MPOD value is based on a process temperature of 20 $^{\circ}$C, the required aeration system SOTR is then calculated as follows:

$$\text{SOTR} = \frac{\beta\, C_{\infty(20)}}{\beta\, C_{\infty(20)} - C}\left(\text{MPOD}\right)\frac{1}{\alpha} \qquad (18)$$
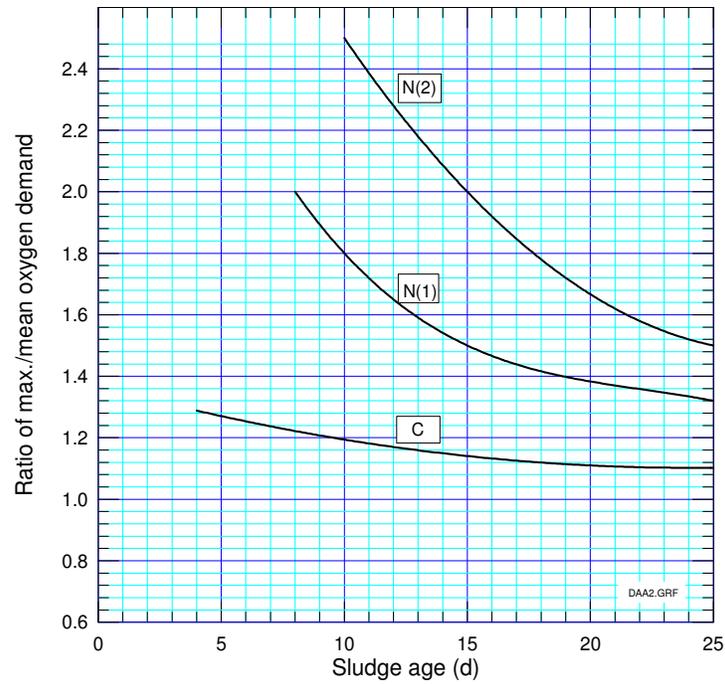
**Fig 6**          **Influence of load fluctuation on oxygen demand**
C carbonaceous; N1 & N2 nitrogenous
N1 > 100 000 PE  PE;  N2 ≤ 20 000



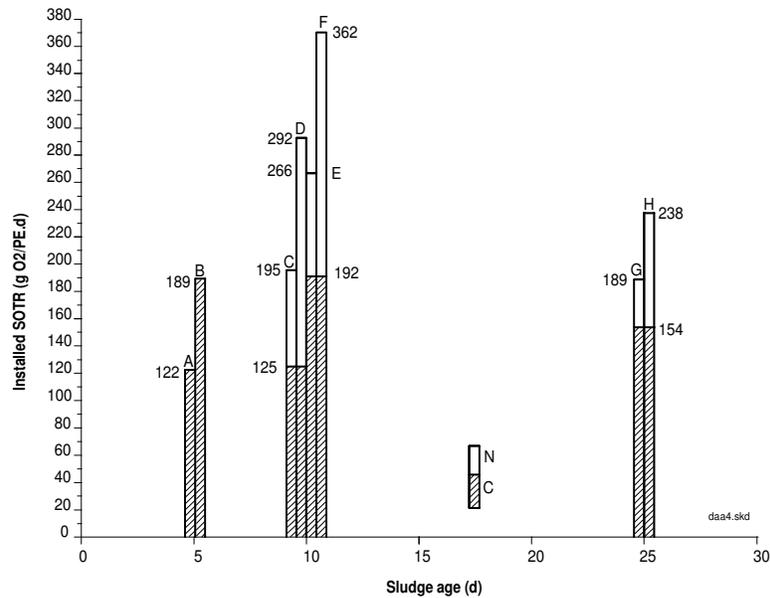**Fig 7**          **Installed SOTR as a function of sludge age**
assumed α-values:          $\alpha_5 = 0.5$
                           $\alpha_{10} = 0.65$
                           $\alpha_{25} = 0.75$

where C is the operating mixed liquor DO concentration, generally taken as 1 mg/l for carbonaceous processes and 2 mg/l for nitrifying processes.

Fig 7 shows design SOTR values, based on the APOD values in Fig 5 (temp. 20 $^{\circ}$C) and peak load factors taken from Fig 6 (the nitrogen-related peak load factor used was based on curve N2 on Fig 6 i.e. PE $\leq$ 20 000). The DO concentration was taken as 1 mg/l at the sludge ages of 5d and 25 d, and as 2 mg/l at the 10d sludge age. The diffuser submergence was taken as 4m. The assumed $\alpha$-values are given in the footnote to Fig 7.

The data presented in Fig 7 serve to highlight the very significant impacts of both $\alpha$ and peak load factors on the design SOTR for diffused air aeration systems. The nitrogen peak load factor (refer Fig 6), in particular, exerts a very significant influence at a sludge age of 10 d., while the combination of low $\alpha$-factor and carbon peak load factor exerts a significant influence at the lower sludge age of 5 days. It will be noted from Fig 5, however, that the **average** process oxygen demand at a sludge age of 5 days is in the range 50%-60% of the average process oxygen demand at a sludge age of 25 days.


## 7.  CONCLUDING COMMENTS

Aeration systems are usually the single largest consumer of energy at wastewater treatment installations, typically accounting for 30% to 50% of the total electrical energy consumed. In general, it is also true that the annualised capital cost of aeration systems is very substantially less than the annual cost of the electrical energy consumed. In consideration of these facts, it is clear that careful attention to aeration system design, including blower selection, can yield a significant energy/cost saving, particularly at large wastewater treatment works.

Fine bubble diffused air systems are probably superior to all other commercially available systems in terms of their energy efficiency in oxygen transfer to clean water. However, under activated sludge process conditions, the oxygen transfer efficiency of diffused air systems is adversely affected by wastewater contaminants, particularly surfactants. It is important that a realistic evaluation of this adverse affect is made during the design process, taking all the factors, discussed earlier in this paper, into account.

The availability of efficient flexible membrane diffusers, which have an acceptable operating life and a significantly better resistance to bio-fouling than their rigid counterparts, represents a significant development in diffused air technology, that is likely to lead to a greater use of fine bubble diffused air systems at small to medium sized wastewater treatment plants.


**References**

American Society of Civil Engineers:   Standard Guidelines for in-process oxygen testing, ASCE-18-96, 345 East 47th. St., New York, 10017-2398, 1996.

American Society of Civil Engineers:   A Standard for the measurement of oxygen transfer in clean water, ANSI/ASCE 2-91, 345 East 47th. St., New York, 10017-2398, 1993.

ATV:    ATV-Standard A131, Dimensioning of Single Stage Activated Sludge Plants upwards from 5000 Total Inhabitants and Population Equivalents, Abwassertechnische Vereinigung e.V., Postfach 1160, Markt 71, W-5205 St. Augustin 1, Germany, 1991.

Casey, T J:  Unit Treatment Processes in Water and Wastewater Engineering, John Wiley & Sons Ltd., Chichester, 1997.

U.S. Environmental Protection Agency:   USEPA Design Manual, Fine Pore Aeration Systems, EPA/625/1-89/023,  Cincinnati, Ohio, 1989.

Gillot, S, Capela, S and Heduit, A:    Alpha factor and in-process efficiency in horizontal flow aeration basins, Proc. Aeration Conference, Rome, 1998.

Groves, K P, Daigger, G T, Simpkin, T J, Redmon, D T, and Ewing, L (1992)    Evaluation of oxygen transfer efficiency and $\alpha$-factor on a variety of diffused aeration systems, Water Environment Research, Vol. 64, pp. 691-698.

Popel, H J and Wagner, M:    Modelling of oxygen transfer in deep diffused-aeration tanks and comparison with full-scale data, Wat. Sci. Tech., Vol. 30, No. 4, pp. 71-80, 1994

Wagner, M and Popel, H J:    Surface active agents and their influence on oxygen transfer, Wat.    Sci. Tech., Vol. 34, No. 3-4, pp. 249-256, 1996.