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Indian Standard

MECHANICAL SURFACE AERATORS — GUIDELINES FOR EVALUATION AND TESTING

UDC 628·353·3 : 620·1

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Public Health Engineering Sectional Committee, CED 40

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Public Health Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

Gas transfer operations, in particular, aeration, serve a multitude of purposes in water and waste treatment. The principal objectives of aeration, however, are either to add or remove gases or volatile substances from water. In biological processes, surface aerators help to transfer the required oxygen through mixing in the basin and also help to keep the biomass in suspension. The processes that are primarily characterized by the turbulence generated by the mixing devices are as follows:

a) Mixing of raw wastes, return sludge and oxygenated fluid (macro-scale turbulence),

b) Mixing to keep solids in suspension (macro-scale turbulence),

c) Mixing and the resultant turbulence influencing the transfer of oxygen from air bubbles or other inter-facial surfaces into the liquid (micro-macro-turbulence).

d) Transfer of substrate, waste product, oxygen etc, into and from the liquid mass and flocs (micro-turbulence). This is important and is often the rate controlling step in the purification process of activated sludge. If a large number of micro-scale turbulence is generated, then the supply of oxygen is the most decisive step for removal of organics from the treatment plant.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

MECHANICAL SURFACE AERATORS — GUIDELINES FOR EVALUATION AND TESTING

1 SCOPE

1.1 This standard gives guidelines regarding evaluation and testing of single surface aerators. It covers basic equations of mass transfer, characteristics of aeration equipments, oxygenation capacity determination, effects of variables on oxygenation, brief idea about reaeration of deoxygenation, estimation of dissolved oxygen and mass transfer coefficient K_L and overall test procedure for finding K_La oxygenation capacity and oxygenation efficiency.

1.2 This standard does not cover multiple surface aerators.

2 REFERENCES

2.1 Indian Standard IS 3025 (Part 38) : 1990 'Methods of sampling and test (physical and chemical) for water and waste water : Part 38 Dissolved oxygen', is a necessary adjunct to this standard.

3 DESCRIPTION OF VARIOUS AERATION DEVICES

3.1 On the basis of mechanical design, facilities for oxygenation by aeration may be divided into following general classes, namely:

a) *Diffusers* — small orifice diffusers, hydraulic shear diffusers, static aeration devices (includes both porous and non-porous).

b) *Surface Aerators* — rotors (formerly referred as brushes, combs and paddles), cone aeration, updraft aerators, and cavitation type and downdraft types wherein oxygen is supplied by self-induction from a negative head produced by the rotating element.

c) *Static Mixer.*

Table 1 summarizes the characteristics of available aeration equipment.

Bubble aeration with porous and other facilities is basically an aeration device which produces mixing in the activated sludge basin whereas surface aerators of any description are mixers which oxygenate the contents of the aeration basin. From turbulence viewpoint, mechanical surface aerators are more efficient because they produce a lagre number of micro-scale eddies with high intensity. However, the mechanical surface aerators will be effective only for certain depth of the aeration tank.

4 BASIC EQUATIONS OF MASS TRANSFER

4.1 A number of mechanisms have been suggested to represent conditions in the region of phase boundary (Table 2, Fig. 1). The expressions of mass transfer for various modes are different due to variations in basic assumptions. Parameters like 's' and 't_0' are difficult to evaluate for surface aerators and therefore, film theory is often employed to give an overall mass transfer coefficient (K_La) since solubility of oxygen is low in water. It has been observed that the transfer of oxygen from a gaseous into liquid phase takes place in three distinct stages, namely:

a) The oxygen molecules are transferred from air to the liquid interface establishing a saturated oxygen layer at the interface in milliseconds.

b) The oxygen molecules pass through by liquid of about three molecules thick by a process of molecular diffusion which is a relatively slow process.

c) The oxygen is diffused into the body of liquid by further diffusion and convection.

4.2 All devices utilize the first stage. Diffusion control of oxygen transfer in the second stage and surface renewal have different relative importances depending on the type of aeration device. In diffused aeration systems, oxygen transfer from the interface to the body of liquid is governed principally by the process of molecular diffusion and hence is very much affected by surface impurities in the liquid. In surface aeration, the shearing action of the impeller creates new interfaces coupled with a high degree of induced turbulence, mass transfer of oxygen is governed by surface renewal.

4.2.1 Shorter the time of exposure, the greater is the rate of mass transfer. Maximizing oxygen flux would be expensive in both the cases. Decreasing the time of contact for diffused aeration requires increasing mixing at the gas liquid interface. Shallow tanks and high volumetric rates of air are needed in diffused aeration systems. In surface aerators, decreased time means more turbulence and hence more power input. Optimal conditions with respect to power consumption puts a practical limit on transfer rate in both cases.

4.2.2 The effect of some of the operating variables on oxygen transfer rate are given in Table 3.

5 DETERMINATION OF OXYGENATION CAPACITY

5.1 The three most commonly accepted techniques to determine oxygenation capacity/efficiency for standardization of aeration equipment are:

a) Non-steady state of re-aeration of deoxygenated pure water in a test tank,

b) Steady state evaluation in an activated sludge basin, and

c) Non-steady state evaluation in an activated sludge basin.

Table 4 compares the various methods for determining mass transfer coefficient for the evaluation of oxygenation capacity and efficiency.

Table 1 Characteristics of Available Aeration Equipment

(*Clause* 3.1)

Equipment Type	Equipment Characteristics	Process Where Used	Advantages	Disadvantages	Reported Oxygen Transfer Efficiency kg of O_2/hr/kw
(1)	(2)	(3)	(4)	(5)	(6)
Diffused Aeration					
i) Porous diffuser	Produce fine or small bubbles made up of ceramic plates or tubes, plastic wrapped cloth tube or bag	Large conventional activated sludge process	High oxygen transfer efficiency, good mixing, maintain high liquid temperature varying air flow provides good operational flexibility	High initial and maintenance costs prone to clog, not suitable for complete mixing	0·53-0·91
ii) Non-porous diffuser	Made in nozzle, valve orifice or shear types, they produce large coarse or large bubbles. Some made up of plastic with check valve design	All sizes of conventional activated sludge	Less-clogging. Maintains high liquid temperature, low maintenance cost	High initial cost, low oxygen transfer efficiency, high power cost	0·55
iii) Static	Produces high shear and entrainment as water in mixture is forced through vertical cylinder containing static mixing elements, cylinder construction is metal, plastic or polyethylene	Primary aerated lagoon application	Low maintenance, high liquid temperature	Ability to adequately mix aeration basin contents is questionable	1·22-1·33
Mechanical Aeration					
i) Radial flow slow speed	Low output speed, large diameter turbine	All sizes of conventional activated sludge and aerated lagoons	High oxygen transfer efficiency, high pumping capacity	Some icing in cold climates	2·43
ii) Axial high speed	High output speed, small diameter propeller	do	Good oxygen transfer efficiency, high pumping capacity	do	1·59-2·13
iii) Brush aeration	Low output speed	Oxidation ditch	Moderate oxygen transfer efficiency	do	1·68/m
iv) Turbine aeration	Units contain a low speed turbine and provide compressed air in sparge ring	Conventional activated sludge	Good mixing, moderate oxygen transfer efficiency	Require both reducer and compressor	1·035-1·59

NOTE — Other type of equipments such as pump aerators, submerged turbine aerators, air/oxygen injectors, if available, may also be added.

Table 2 Comparison of Mass Transfer Models

(*Clause* 4.1)

Theory	Properties of Liquid Surface	Type of Diffusion	K_L	Remarks
(1)	(2)	(3)	(4)	(5)
i) Film	Stagnant	Steady	D/L	Easy to determine mass transfer coefficient
ii) Penetration	Renewal of surface, constant time of exposure of fluid elements to surface	Unsteady	$2\sqrt{D\pi\ tc}$	Only average value of tc can be known. Its exact value is not known
iii) Surface renewal	Renewal of surface, frequency distributions for time of exposures to gas phase	Unsteady	$\sqrt{DS}$	S difficult to determine
iv) Film/surface renewal	Stagnant and continuously renewed surface depending on degree of turbulence	Steady and/or unsteady	$\sqrt{DS}\ \coth\ \sqrt{SL^2/D}$	Both S and L are difficult to determine
v) Film/penetration	Same as film and penetration	Steady and/or unsteady	$D/L\left(1+2\sum_{n=1}^{n=\infty} exp\ \frac{(-n^2\pi\ 2Dt)}{L^2}\right)$	Difficult to determine S and L

K_L = Liquid film coefficient. D = Diffusivity. L = Liquid film thickness. tc = Contact time. S = Surface renewal rate.

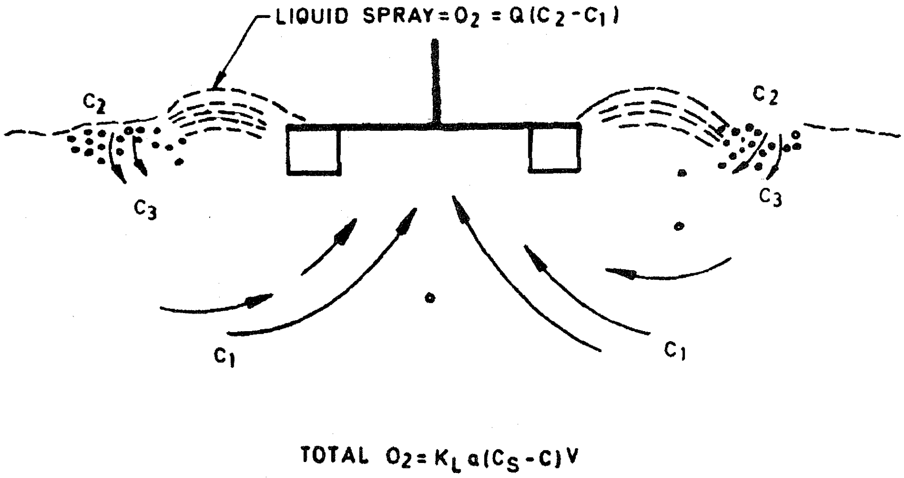


FIG. 1 SCHEMATIC OF GAS TRANSFER INVOLVED IN A SURFACE AERATOR

5.2 Non-steady state aeration of deoxygenated tap water by an aeration device is the most common method employed for determining oxygen transfer rates. In this case there are five different methods to evaluate the value of the overall mass transfer coefficient and these are summarized in Table 5. The absolute value of the overall mass transfer coefficient cannot be determined by any of the above methods. Exponential curve fitting is a slight improvement in the analysis of overall mass transfer coefficients over the log-deficit technique because the value of Cs need not be taken into consideration. However, for standardization and comparison purposes of aeration performance, the log-deficit technique can be used. It is simpler and can be easily reproduced. In this case actual experimental values of Cs should be used instead of assumed values from literature for calculating overall mass transfer coefficient (K_La). However, the value of Cs has to be determined in any case for determining the oxygen transfer rate in the field scale $\left(\beta = \frac{Cs \text{ waste water}}{Cs \text{ tap water}}\right)$. Therefore, this method can be used in all experimental analysis. Moreover, the values of mass transfer coefficient determined by this method are slightly lower than determined by other methods from this category. This may result in slight over design of an aeration system which is a built-in risk factor.

Table 3 Effect of Some Operating Variables on Oxygenation

(*Clause* 4.2.2)

Increase in Operating Variable	Resulting Physical Change	Effect on Equation Variable	New Effect on Oxygenation
(1)	(2)	(3)	(4)
i) Temperature	Diffusivity, D increases but film thickness and Cs decreases	$K_{L}a$ increases Cs-C decreases	Negligible if $C < 3$ mg/l decreases if $C > 3$ mg/l
ii) Circulating velocity	L decreases, bubble size decreases hence inter-facial area increases	$K_{L}a$ increases	Increases
iii) Aeration rate O_2 Partial pressure	A increases, L decreases Cs increases	$K_{L}a$ increases Cs-C increases	Increases
iv) O_2 Demand	O_2 is removed from solution faster than C decreases	Cs-C increases	Increases
v) Height of water	Bubble size path is longer and Cs increases but there is proportionally less surface removal and surface formation	$K_{L}a$ decreases but (Cs-C) increases	Decreases
vi) Soluble inorganic	D and Cs both decrease	$K_{L}a$ and Cs-C both decreases	Decreases
vii) Submergence	Film thickness decreases A increases	$K_{L}a$ increases	Increases up to a level of 10-15 cm from the top level of surface aerator and beyond that it decreases

Table 4 Summary of Mass Transfer Calculation Methods

(*Clause* 5.1)

Method	Assumption	Advantages	Disadvantages
(1)	(2)	(3)	(4)
i) Non-steady state aeration of tap water	Complete mixing, constant temperature	Simple and rapid method, good control of variables	Independent alpha determination, all conditions must be reproducible
ii) Steady state aeration of tap water	Complete mixing, constant temperature	Same as above except smaller volume of water can be used, as $K_{L}a$ evaluation accuracy is dependent on volume. No transient methods are required	Evaluation of small aerators only, because high flow rates are required to obtain good accuracy. Impracticable for evaluation at large scale units
iii) Activated sludge state field conditions	Complete mixing, no significant microbial change during test period	$K_{L}a$ is made under actual field conditions	Difficult to control variable during test period. Respiration factor sometimes difficult to correctly evaluate
iv) Activated sludge-non-steady state field conditions	Substrate composition load and tank conditions do not change during test period		

Table 5 Comparison of Non-Steady State Methods for Reaeration of Deoxygenated Water
(*Clause* 5.2)

Method (1)	Equation (2)	Remarks (3)
i) Direct analysis	$\alpha \rightarrow dc/dt$ = rate of oxygenation, for $dc/dt = K_L a\, C_S - K_L a C$ $\alpha \rightarrow K_L a\,(C_S - C)$	Plot dc/dt *versus* C, slope $= K_L a$ Y-axis intercept = max rate of oxygen transfer
	where K_L = liquid film coefficient; a = interfacial area per unit volume; So $K_L a$ = overall mass transfer coefficient	Exact values of dc/dt difficult to evaluate except using a computer
ii) Exponential curve fitting	$C = C_S [1 - \exp (- K_L at)]$ where t = contact time	$K_L a$ is independent of DO concentration time and space $K_L a$ is independent of DO concentration
		A least square non-linear analysis to be used for calculating $K_L a$ and C_S. Illustrative example is given at Annex A
iii) Rapid estimate (time constant method)	$C = C_S [1 - \exp (- K_L at)]$	Same as in (ii) but the value of C_S should be known to get 63·86% and 95% saturation level of DO
iv) Log-deficit method	$K_L a = \dfrac{ln (C_S - C)_1 - ln (C_S - C)_2}{t_2 - t_1}$	Value of C_S should be known. Non-linearity of plotted data means incorrect use of C_S
v) Linearized transformation method	$C (t + h) = Cte^{- K_L ah} + C_S (1 - e^{- K_L ah})$	The simplest and accurate method C_S need not be known

5.3 A review of testing procedures employed by manufacturers and professional organisations given at Table 6 indicates that data (concentration *versus* time) are normally truncated above 70-90% and under 10-20% of saturation value. The truncation below 10-20% is mainly done to avoid errors resulting from improper mixing of the deoxygenating chemical (sodium sulphite) with the aeration tank tap water. Initial mixing of the deoxygenating chemical can cause erratic and unreliable data generation at the beginning of the test unless extreme care is taken to optimise the testing condition. At the upper end (above 70% saturation DO concentration) as the value of dissolved oxygen concentration approaches its saturation, the value of overall transfer coefficient cannot be determined exactly ($K_L a \rightarrow \infty$). From this analysis the log deficit method is still by far the simplest and can be used without hesitation. Moreover, in an actual activated sludge system dissolved oxygen in the aeration tank is desired to be kept in the range of 1 to 2 mg/l which is certainly less than 70% of the saturation value. Therefore, using the entire data including at the upper end is of no use and that is why one is certain of getting higher values of oxygen transfer rates if other method described in Table 6 are used.

Table 6 DO Cut Off — % Cs

Organization	DO Cut Off — % Cs	
	Lower	Upper
Yeomans	10	70
Emico	10	80
Welles	—	75
Rexord	20	90
Mix-equipment	20	90
ASME	20	90
PEMA	20	80
WPCF	10	70

6 IMPORTANT CONSIDERATION IN EVALUATIONS OF OXYGENATION RATES

6.1 Sodium Sulphite Addition

Before the experimental run begins, the dissolved oxygen (D.O.) level in the test basin is reduced to zero, or below zero level, by the addition of sodium sulphite and a cobalt salt acting as a catalyst. The sulphite reacts with dissolved oxygen and the resulting sulphate remains as inert dissolved material which does not take any part in the further reaction.

The method of sodium sulphite addition can effect the measured dissolved oxygen uptake. The aerator to be tested is usually used to distribute the sodium sulphite throughout the aeration basin. This means that it is operating when the chemical is added and therefore dissolving the sodium sulphite instantaneously and uniformly at all points in the basin, but since it is impossible, one has to attempt to approach this condition within the limits of practicality. The conditions to be observed are:

i) Completely pre-dissolve the chemical in water and do not add any solid residue. If solids are added, they may be dissolved slowly and possibly, locally only. The test result as a consequence will be inconsistent and inaccurate.

ii) Add the chemical in significantly excess quantity so that there is sufficient time for its distribution throughout the basin before it is used up by the proceeding aeration. Sodium sulphite requirements are based on the mean system saturation and normally, 1·25 times the astoichiometric requirement is used. Tests have been conducted using 95 to 200% of the stoichiometric quantity without affecting the oxygen transfer rate results.

iii) Add the chemical in such a manner that its distribution throughout the tank by the surface aerator is facilitated. This can be achieved by adding the solution at several, perhaps four points (one feed line for each quadrant) at location of high velocities.

iv) Strong evidence has indicated sodium sulphite values above 2,000 mg/l increases oxygenation capacity, probably due to reduction in surface tension with an increasing interfacial area thus increasing mass transfer coefficients. Moreover, an increase in oxygenation capacity also results from increasing cobalt concentrations beyond 1·5 mg/l.

v) Fresh tap water should be used after every six test runs because there is a possibility of sodium sulphate build up in the aeration tank.

6.2 Dissolved Oxygen Concentration

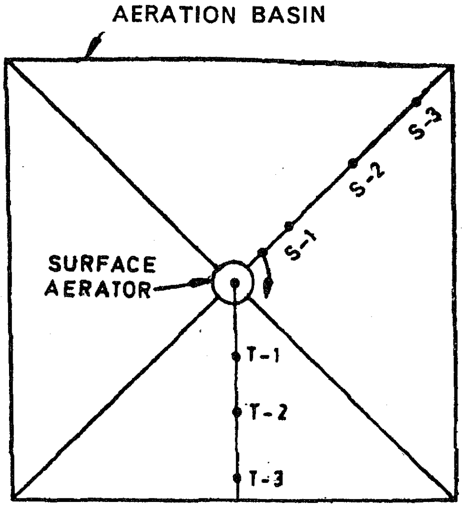
The Winkler titration method and its modification gives results which will depend on water for the determination of dissolved oxygen [*see* IS 3025 (Part 38)]. Dissolved oxygen can also be measured by a dissolved oxygen probe-meter.

The calibration of an oxygen meter using membrane type sensors can be undertaken in mg/l or percent saturation level. However, percentage saturation requires only compensation of membrane permeability for temperature changes whereas if read out is in required mg/l compensation must also be made for solubility changes in temperatures, dissolved solids and atmospheric pressure. Percent saturation is more clearly related to the ideal state of biological process than concentration of dissolved oxygen.

During an aeration/agitation process, size distribution or bubbles of oxygen is produced from large macromolecule to the molecular dimension of oxygen in the aeration basin. The Winkler titration method can entrap oxygen molecules from all sizes of bubbles whereas the oxygen meter can read out what has passed through its membrane. Therefore, there is a possibility of discrepancy between these two systems of measurements. A lot of judgement is required before calibrating an oxygen meter. Excess cobalt chloride in test water may also interfere in (DO) determination by Winklers method. For surface aerators, it is often assumed that water depth does not affect (DO) saturation. *Cs* value which may, or may not be the case as there are very fine bubbles entrained in the aeration basin which travel large distance downwards and finally are released upwards near the top of the water surface. Moreover, it is difficult to estimate the exact value of (DO) saturation. Similar difficulties also arise while measuring the actual (DO) concentration in the turbulent field in the aeration basin.

6.3 Methods of Estimating Mass Transfer Coefficient

The methods listed in the previous sections have some drawback or the other. The simplest and accurate method is the Linearised Transformation Method which can be used provided the system conditions can be reproduced easily. It would be an ideal situation if the exponential curve fitting method is used. However, the difference in values calculated from various methods is not more than 15 percent. During the non-steady aeration of tap water, the dissolved oxygen concentration continues to increase with time, it is suggested that atleast three station points in one quadrant of the aeration basin should be chosen, namely, the first near the aerator, the second midway on the diagonal and the third one near the extreme end of the diagonal. At each station point, at least three depth water samples should be taken at different depths, simultaneously (Fig. 2).



LEGEND

Sampling Stations	*Depths*
T-1	1* + 1† + 1‡
T-2	1 + 1 + 1
T-3	1 + 1 + 1
S-1	1 + 1 + 1
S-2	1 + 1 + 1
S-3	1 + 1 + 1

*15 cm from top WL.

†Mid-depth of aeration basin.

‡15 cm from bottom of aeration basin.

FIG. 2 SAMPLING LOCATIONS IN AERATION BASIN FOR SURFACE AERATOR EVALUATION

It is important that the average of all the (DO) concentration from nine samples is not to be made. Rather, calculate the mass transfer coefficient at each station and depth point separately. The average of the individual mass transfer coefficients obtained from several stations and depth points is then taken. The DO concentration by itself is not important. It is the mass transfer coefficient which is a parameter in the oxygen transfer calculations.

For actual wastewater systems, two factors, namely, alpha α (K_La wastewater/K_La tap water) and Beta β (DO saturation in wastewater/DO saturation in tap water) should be determined separately for evaluating the performance of the aeration device in the field.

A declared oxygenation efficiency (OE) of 1·5 kg O_2/kW/h and an alpha factor of 1·0 leads to exactly same power consumption as an efficiency of 2·0 kgO_2/kW/h modified by an alpha factor of 0·75, although at first sight, the latter might appear to be more efficient aerator.

6.4 Time Period

As the test proceeds a response curve is generated by each (DO) probe. Measurements should be recorded atleast every 10 seconds cycling from the first to the last probe consecutively. At the completion of the test, the response asymtotic concentration should be compared with initial DO saturation value of each probe to verify the final DO saturation value and probe calibration.

If DO probes are not available, a simple sampler rod with BOD bottles fixed at three heights could be used having inlet and outlet arrangements for water and air at a differential head of about 0·10 m respectively. The water inlet tube should nearly touch the bottom of BOD bottle. Air outlet tube is projected outside the BOD bottle, thereby minimizing any kind of mixing of water with air bubbles. It can be used at 30 seconds or longer time intervals. For quicker and faster measurement oxygen DO probe is a must, provided its response period is fairly good. Moreover, the DO probe of an oxygen meter registers only molecular oxygen that has gone into the solution. But with a BOD bottle sampler rod, oxygen from even minute air bulbbes can be fixed.

6.5 Temperature Coefficient

It has been observed that the value of the Arrehenius constant (θ) for mass transfer of oxygen has three distinct values in the range of 5-45°C using a surface aerator. The exact value of the temperature coefficient should be used.

$$\theta = 1{\cdot}024,\ 20 > T \geqslant 5$$
$$\theta = 1{\cdot}028,\ 35 > T \geqslant 20$$
$$\theta = 1{\cdot}031,\ 45 > T \geqslant 35$$

where T is temperature in °C.

6.6 Basin Configuration

For a given diameter of surface aerator, D, the dimensions of an ideal test basin should be between 4 to 5 D (length/width), the water depth should be 1·5 to 2·0 D. It would be advisable to have either a square tank or a circular tank of equivalent dimensions with baffles. If it is desired to operate the unit as a facultative activated sludge process, the circle of influence can be increased from 5 D to 10 D units depending on the thickness of the aerobic zone required in the treatment plant.

6.7 It is also found that oxygenation efficiency (OE) decreases with increase in basin volume. However, oxygenation capacity (OC) tends to increase with increase in area of influence for a given water depth.

6.8 No simple type of aerator is ideal for all conditions. The efficiency (OE) of the aerator in transferring oxygen is obviously important but a high oxygenation capacity (OC) is of no value if obtained at the expense of inadequate stirring and mixing. The load on aeration device is rarely constant at the value the designer originally evisaged and, therefore, the efficiency over a range of input process conditions is likely to be more important than efficiency at a particular designed point.

6.9 The efficiency of an aeration device tends to reduce with reduced loads or with increasing load beyond optimum value. This reduction in efficiency shall be taken into account whenever water levels vary considerably. However, increase in submergence or rotational speed may result in more oxygen transfer than is required, therefore, resulting in wastage of power. For high loading rates, power requirements may be determined by oxygen requirements rather than mixing conditions. However, reverse may be true for other mixing system of activated sludge process. It has been observed that 1 to 7·7 W/m³ of specific power is required to disperse the oxygen molecules throughout the aeration basin. However, additional expenditure of power is required to disperse biological suspended solids in aeration basin, that is, 5-20 W/m³ at 10·5 m (keeping same flow velocity of 10-15 cm/s). Power input is generally regarded as a poor criterion since a number of combinations of impeller diameter, rotational speed and submergence can result in the same power consumption with markedly different mixing characteristics. However, in systems with similar geometrics, this parameter can still be very useful.

6.10 Sometimes the water in the tank may have a greenish tinge. It is suggested that the extent of production of oxygen due to photo-synthetic micro-organisms may also be calculated using the light and dark bottle technique.

6.11 The overall aeration system performance is a function of oxygen transfer efficiency and mixing and both must be considered when evaluating aeration equipment. Oxygen transfer is influenced by the testing procedures employed and methods of analysis used to interpret the raw data. Mixing is influenced by the aeration system geometry of the test facility. A comparison of mass transfer coefficient values for various sample points throughout the test tank will reveal whether or not the volume of fluid is being mixed uniformly. If the mass transfer coefficient value is nearly constant throughout the tank, uniform mixing is occurring.

7 TEST PROCEDURE

7.1 To start the test, the aeration basin is filled with tap water and its temperature and DO determined under the test conditions. Cobalt chloride is added to achieve a cobalt ion concentration of about 0·5 mg/l. Technical grade sodium chloride is used to completely deoxygenate the test water. Normally, 1·25 times the stoichiometric requirement (7·9 mg/l of Na_2SO_3 for each mg of DO present) is used.

As the test proceeds, a response curve (concentration *versus* time) is generated at each sample point. There should be at least three station points with DO measurement at three depths. A tank of 13 m × 13 m × 10 m should have minimum of three sampling stations.

A plot of oxygen deficit ($Cs - C$) *versus* time (t) on a semilogarithmatic graph paper is drawn. The value of overall mass transfer coefficient is calculated by using the expressions:

$$K_La\,(T) = 2{\cdot}303\ \frac{\log (C_s - C)_1 - \log (C_s - C)_2}{(t_2 - t_1)} \quad ...(1)$$

$K_La\,(T)$ is converted to standard condition of 20° C by using Equation 2.

$$K_La\,(T) = K_La\,(20)\ \theta^{T-20} \quad ...(2)$$

The value of 'θ' to be used under different conditions of water temperature is given earlier. K_La values obtained from various sampling points are averaged out to determine the effective mass transfer coefficient for the earlier systems.

Oxygenation capacity (OC) surface aerator under standard condition can be calculated by Equation 3:

$$OC_S = K_La\ C_SV \quad ..(3)$$

To determine the oxygenation efficiency (OE), the efficiencies of gear/belt and motor are necessary. Manufacturers of gears/belt and motor provide the efficiency of their products at various loading conditions. Gross power consumption (P_g) by the entire aerator assembly can be recorded by a watt/watthour meter and necessary corrections for efficiency can be incorporated into the gross power consumption to determine the net power consumption (P_n) as indicated in Equation 4:

$$P_n = P_g \times \eta_g \times \eta_b \times \eta_m \quad ...(4)$$

Therefore oxygenation efficiency (OE_s) can be found by the following expression:

$$OE_s = OC_s/P_n \quad ..(5)$$

It is necessary to know both gross and net power consumption of the surface aerator assembly.

For wastewater other than water, Alpha/Beta determinations are pre-requisite for evaluation of oxygenation capacity. A test model of 0·020 m³ capacity with similar configuration to proto-type fitted with 0·10 diameter surface aerator is used. If the wastewater is of biodegradable nature, oxygen uptake rate (γ) is to be calculated. In this connection, a one-litre wide mouth bottle filled with bio-degradable wastewater and fitted with a DO probe is used. The wastewater is saturated with DO to begin up. After that a plot of DO concentration with time is plotted. The slope of this curve determines the oxygen uptake rate (γ)r. Using the expression as given below, rate of change of DO with DO concentration is plotted. The slope of the curve will determine the overall mass transfer coefficient (K_La). From the intercept ($K_La\ Csw - \gamma$), the value of DO saturation (Csw) can be found out if the value of r determined above is used as defined under the actual field conditions:

$$\frac{dc}{d_t} = (K_LaC_s - \gamma) - K_La\ C$$

To determine alpha (α), it is necessary to determine L_La of wastewater and tap water separately under identical conditions and rates of K_La wastewater to K_La tap water defines alpha(α).

After knowing Csw and alpha as per the field conditions, oxygenation capacity under field conditions (OCf) can be determined provided oxygenation capacity (OCs) using tap water has also been done as explained previously. The oxygenation efficiency divided by power gives oxygenation efficiency OE_f:

$$OC_f = OC_s \frac{(C_{sw} - C)}{9{\cdot}12} .\alpha\theta^{T-20}$$

$$OE_f = OC_f/P_{nf}$$

For toxic wastewater or wastewater which does not contain microbial biomass, test procedure remains the same as defined for tap water.

where

C, C_1, C_2 = DO concentration in the aeration basin at any time, at time-t_1 and at time-t_2 respectively, mg/l

C_s = Saturation DO concentration at 1 atm and 20° C (9·12 mg/l)

C_{sw} = Saturation DO concentration under actual field conditions, mg/l

K_La (T), K_La (20) = Overall mass transfer coefficient, at any temperature — T and at 20°C respectively, h^{-1}

V = Liquid volume of the aeration basin, m^3

η_g, η_b, and η_m = Efficiency of gear, belt and motor respectively

γ = Respiration rate, mg/l/h

P_n, P_{nf} = New power consumption under standard and field conditions respectively, kW

OC_s, OC_f = Oxygenation capacity under standard and field conditions respectively, kgO_2/h

OE_s, OE_f = Oxygenation efficiency under standard and field conditions respectively, $kgO_2/kW/h$

ANNEX A

(*Clause* 5.2 and *Table* 5)

ILLUSTRATIVE EXAMPLE

The assessment of K_La by the simple method of incremental increase in time from the non-steady state reaeration experiment is presented in Fig. 3. Since the DO values are available at an interval of two minutes, the value of h is also considered as two minutes. The basic experimental data is presented in Table 7.

The line of best fit has been obtained both by graphical as well as least square method. The line of best fit by eye judgement drawn on this figure shows the values of K_La and C_s to be 0·111 min (base e) and 8·0 mg/l respectively. The line of best fit obtained by least square method show these values to be 0·118 min (base e) and 7·795 mg/l respectively. The non-steady state reaeration of tap water is shown in Fig. 4 based on the data indicated in Table 7.

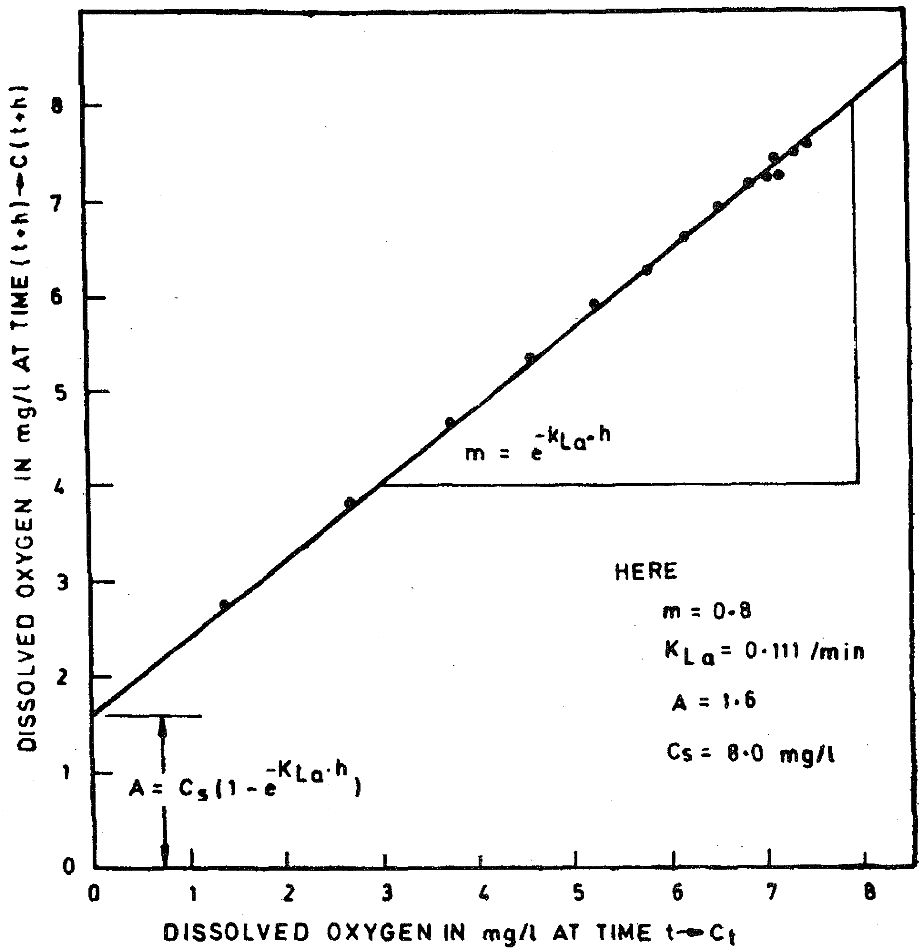


FIG. 3 METHOD OF DETERMINATION OF K_La

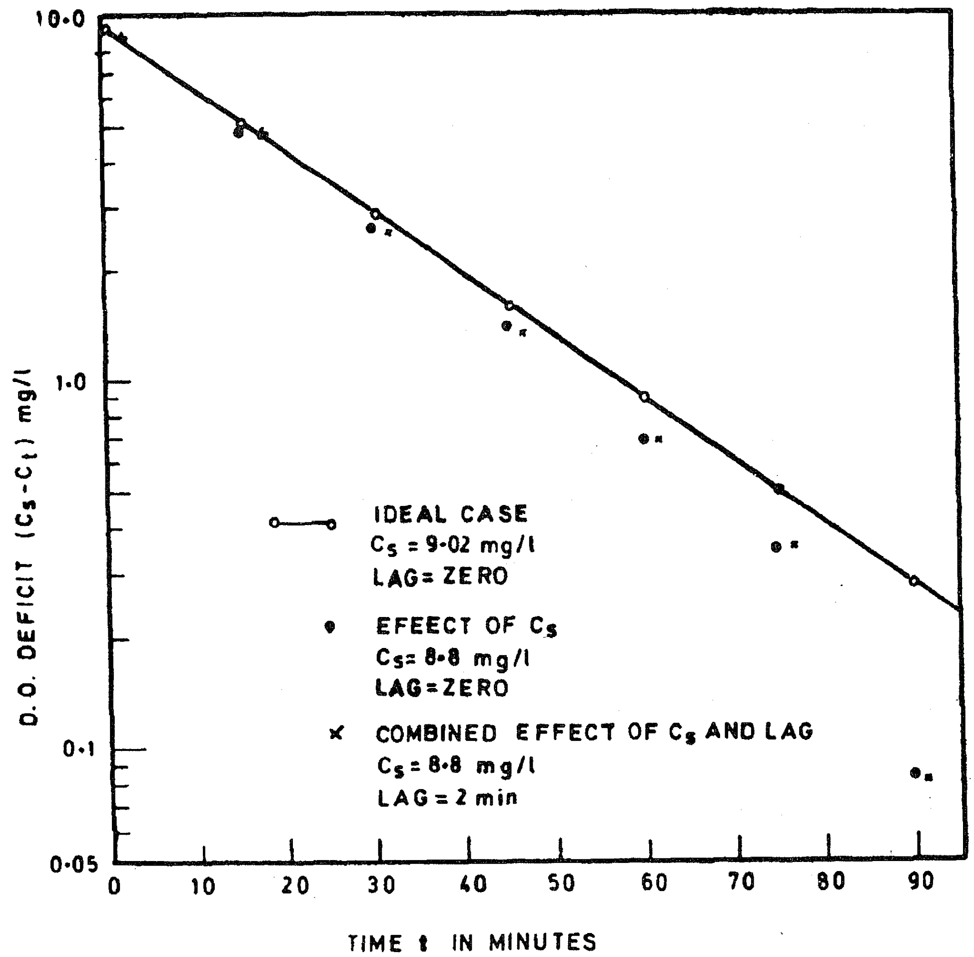


FIG. 4 EFFECT OF LAG TIME AND C_S ON DETERMINATION OF K_La

Table 7 Non-Steady State Reaeration Data

Time in Minutes	DO Concentration in mg/l
1·8	1·39
3·8	2·73
5·8	3·80
7·8	4·62
9·8	5·32
11·8	5·87
13·8	6·24
15·8	6·58
17·8	6·91
19·8	7·13
21·8	7·20
23·8	7·23
25·8	7·41
27·8	7·48
29·8	7·56

Comparison of Results

Table 8 shows the values of K_La and C_s obtained by the incremental increase method, non-steady state re-aeration of tap water and non-linear programming techniques.

The above table shows that for all practical purposes there is hardly any difference in the values of K_La obtained by different methods. The simplicity of the method and the elimination of the use of computer renders this method far more useful than any other techniques presently adopted for the assessment of K_La value.

Conclusions

1) The importance of assessment of K_La for a water or waterwaste water system from laboratory or plant studies is emphasized.
2) Simple method of assessment of K_La has been suggested. The method eliminates the use of computer and also does not need the assessment of saturation D.O. concentration of the wastewater under any temperature condition of the experiment.
3) The results obtained by this method are practically the same as obtained by methods using non-linear programming techniques.
4) The elimination of computer work and simplicity of method renders the method far more useful than any other techniques presently adopted.

Table 8 Comparison of Results

Parameter	By Graphical Method	By Numerical Least Square Curve Fitting	Non-Linear Programming Techniques
$K_L a$/min (base e)	0·111	0·118	0·118
C_S in mg/l	8·0	7·795	7·8

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