CHAPTER II

THEORY AND APPLICATION

Oxygen Transfer

ECKENFELDER (1966) expressed the oxygen transfer rate based on the two-films theory in concentration units as :

$$\frac{dc}{dt} = K_L \cdot \frac{A}{V} \cdot (C_S - C_L) = K_{La}(C_S - C_L) \ldots . (1)$$

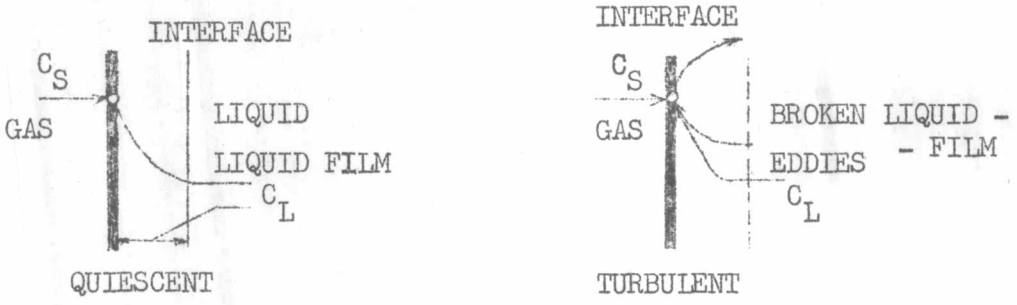


Fig.i Mechanism of Oxygen Transfer

Where :

A = The Total Interfacial Area, ft^2

C_L = The Oxygen Concentration at a Point and at a Time t, mg/l.

C_S = The Concentration of O_2 in the Liquid when Saturated at the Existing Pressure and Temperature, mg/l.

dc/dt = Rate of Change of D.O. Concentration in the Liquid, ppm./hr.

K_{La} = Overall Coefficient for Oxygen Transfer

K_L = The Overall Diffusion Coefficient Based on Liquid Film Resistance, ft^3. of Vol./Sec./ft^2. of Area.

V = The Volume of Liquid under consideration, ft^3.

ECKENFELDER and FORD (1968) explained the determination of mass transfer coefficient under nonsteady state aeration of deoxygenated water that K_{La} is determined from the slope of a semilogarithmic plot of concentration deficit $(C_S - C_L)$ versus time of aeration.

$$K_{La} = \frac{\log (C_S - C_L)t_1 - \log (C_S - C_L)t_2}{(t_2 - t_1)} \cdot 2.3 \cdot 60 \text{ hr}^{-1} \quad \ldots(2)$$

Effect of Temperature on Oxygen Transfer.

The aeration coefficients are influenced by temperature due to the effect on the diffusivity and viscosity. The effect of temperature on the aeration coefficient is usually expressed as follows :

$$K_T = K_{20} \cdot \theta^{T-20} \quad \ldots\ldots\ldots(3)$$

Where:

K_T = Coefficient at temperature T.

K_{20} = Coefficient at 20 ^{o}C.

θ = Temperature Coefficient.

T = Temperature, ^{o}C.

The temperature coefficient, θ has been reported varying from 1.016 to 1.047. Data and formulations have been reported by HASLAM (1924), STREETER (1936) and WILKE (1949). In bubble aeration, temperature also influences the bubble diameter and velocity. It appears that the presence of surface active agents and other substances may also affect the temperature coefficient. Studies on bubble aeration indicated a temperature coefficient

of 1.02. Temperature correlations reported by various investigators are referenced.

Effect of Waste Constituents on Oxygen Transfer.

In order to compare the transfer rate in wastes to that in water, a coefficient α is defined as the ratio of K_{La}, in waste to that in water under specified operating condition. i.e :

$$\alpha = \frac{K_{La}(\text{Waste})}{K_{La}(\text{Water})} \qquad \ldots\ldots\ldots(4)$$

SAWYER and LYNCH (1954) found a variation in α of 0.35 - 1.0 with 50 ppm. of various anionic and non-ionic commercial detergents. Addition of a silicon antifoam to water reduced the absorption rate 35%. Extensive studies by KING (1955) Showed α varying from 0.26 - 0.46 for fresh sewage and from 0.16 - 0.19 for septic sewage.

High mixed liquor solids concentrations in activated sludge processes reduce K_{La} by altering the bulk viscosity of the aerating medium. In the presence of 10,000 ppm. sludge solids, absorption was only 1/5 that was in pure waste GADEN (1956) KEHR (1938) showed a reduction of K_{La} in stream reaeration in the presence of oils, soaps, organic acids raw and treated sewage.

Principles of Biological Oxidation

ECKENFELDER and O' CONNER (1966) explained that when an organic waste comes in contact with biological sludge, BOD is removed by several mechanisms. Suspended and finely divided solids are removed by absorption and coagulation. A portion of the soluble organic matter is initially removed by absorption and stored in the cell as a reserve food. Additional dissolved orgainc matter is progressively removed during the aeration process, resulting in the synthesis of sludge and the production of carbon-dioxide and water. Availability for oxidation decreases as the complexity of the organic compounds increases. Large particles undergo subdivision by hydrolysis prior to oxidation. The rate of BOD removal after initial absorption depends primarily upon the concentration of BOD to be removed and the concentration of sludge solids. The reactions involved in the removal of BOD from solution during bio-oxidation can be interpreted as a 3 phase process.

(i) An initial removal of BOD on the contact of a waste with a biologically active sludge whichis stored in the cell as a reserve food source.

(ii) Removal of BOD in direct proportion to biological sludge growth.

(iii) Oxidation of Biological cellular material through endogenous respiration.

These reactions are illustrated by the following equations.

Organic Matter Oxidation.

$$C_xH_yO_z + O_2 \xrightarrow{\text{enzyme}} CO_2 + H_2O - \Delta H \quad \ldots\ldots\ldots(5)$$

Cell Material Synthesis.

$$C_xH_yO_z + NH_3 + O_2 \xrightarrow{\text{enzyme}} \text{Cells} + CO_2 + H_2O - \Delta H \quad \ldots\ldots(6)$$

Cell Material Oxidation.

$$(\text{Cells}) + O_2 \xrightarrow{\text{enzyme}} CO_2 + H_2O + NH_3 - \Delta H \quad \ldots\ldots\ldots(7)$$

The term ΔH represents the heat of reaction. These generalized equations must be modified for organic compounds containing nitrogen or sulfur.

Equation. (5) is the conventional equation of combustion. If nitrogen is present, it will be oxidized to nitrate; sulfur will be oxidized to sulfate.

Equation (6) represents the synthesis of cell material from organic substrates.

Equation (7) represents the oxidation of cellular. material previously synthesized.

The synthesis of activated sludge as shown by Equation (6) employs ammonia as a source of nitrogen. Equation (5) to equation (7) can be illustrated using lactose sugar as a source of carbon, HOOVER and PORGES (1952). The complete oxidation of lactose is

$$C_{12}H_{22}O_{11} \cdot H_2O + 12\ O_2 = 12CO_2 + 12H_2O$$

The synthesis reaction (equation 6) may be illustrated using 8 sugar units.

$$8(CH_2O) + 3O_2 + NH_3 = C_5H_7NO_2 + 3CO_2 + 6H_2O$$

The cells produced will undergo oxidation (Equation 7)

$$C_5H_7NO_2 + 5\ O_2 = 5CO_2 + NH_3 + 2H_2O$$

The validity of these equations was confirmed by manometric observations.

TAMIYA (1935) has stated that all cell synthesis reactions are exothermic and hence energy is supplied by the reaction. Exact quantitative relations can be determined only by experiment since they will vary depending upon the specific environment.

BOD Removal and Sludge Growth.

The growth of a biological sludge mass in a batch oxidation follows the sigmoidal curve shown in Fig. (ii). This type of growth is followed by all biological populations. The lower portion of the growth curve in concave upward and represents a geometric increase in sludge mass (a - b). This is called the logarithmic growth phase, during which regular and maximum multiplication of the sludge cells is taking place. This growth phase occurs in the presence of an abundant supply of food. The middle portion of the curve is approximately linear (e - f). As the available food supply becomes exhausted, a declining growth phase occurs in which cellular division will be at less frequent intervals (b - c). The upper portion of the curve (b - c) follows a first order reaction. The sludge growth curve becomes asymptotic to a limit which is dependent upon the concentration of available food.

The portion of the growth curve (c - d), following the sigmoidal curve, represents the decrease in sludge mass resulting

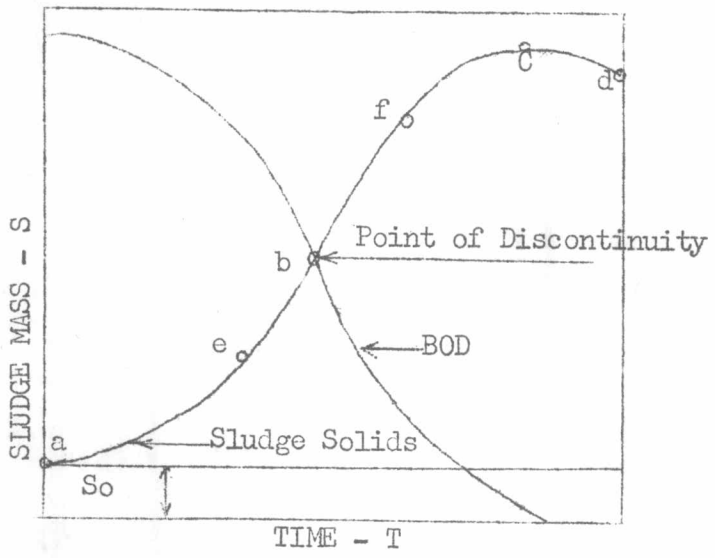


Fig. (ii) BOD Removal and Sludge Growth Relation ships.

from auto - oxidation which occurs after the depletion of the available food. This is often called the endogenous respiration phase of activated sludge. The auto - oxidation rate as the bacterial substrate becomes less available for oxidation.

Lag Phase

In some cases a lag phase may exist in the growth relationship. This will occur when a dissimilar food supply is introduced (i.e, sewage organisms being supplied with industrial wastes). A lag phase of 2 - 5 days to attain full purification capacity was found by SAWYER et.al. (1955) when employing a sludge aerated under starvation conditions for 21 - 22 days.

Initial Removal

In many biological systems a very high rate of removal of BOD is observed immediately after contact of waste with sludge

suspended and colloidal solids are removed by flocculation and adsorption. The magnitude of this high rate depends on the nature of the waste and the characteristics of the sludge. In some cases, this high initial rate exceeds the maximum rate of sludge growth and BOD is stored in the microbial cell. This stored BOD is subsequently oxidized over several hours aeration of the sludge.

It is frequently possible to formulate the initial removal by considering the high initial removal over a short time - interval (10 - 15 min.). In this case, only that portion of the BOD which is removable by biological sludge over the specific time - interval is considered. ECKENFELDER (1959) employed the relationship.

$$-\frac{dL}{dS} = K_i . L \qquad \text{.....(8)}$$

Which integrates to

$$\frac{Lri}{Li} = 1 - e^{-Ki.\ S} \qquad \text{.....(9)}$$

in which

Ki = initial removal rate coefficient.

Li = maximum BOD removable over specified time interval.

Lri = BOD removed over specified time interval.

S = initial biological sludge solids.

Calculation of Organic Removal Rate m by Assimilation

The specific relationship between the fraction removal of organics and the loading intensity for any particular waste can be established with data derived from a batch process. Often it is found that the relation ship approximately.

$$\frac{C}{Co} = 1 - 10^{-mi}$$

Where

C = Concentration of Organics at Time t.

Co = Initial Concentration of Organics.

i = Organic Loading Intensity = Co/ (So.t)

m = Constant

So = Initial Concentration of Activated Sludge

t = time.

A semi - log plot between 1- C/Co and i can be used to establish the value of m.

Bio-oxidation Kinetics

ECKENFELDER and O' CONNOR (1961) also Mc. CABE (1960) from an engineering viewpoint we may consider the various phases of sludge growth and BOD removal to consist of a dynamic relationship between the mass transfer of essential foods into the cell structure, and the assimilation and utilization of these foods for energy and growth. At high concentrations of organic matter the rate of assimilation and the growth rate is independent of the external concentration of organic matter. A low food levels in mixed systems the rate of growth and hence the BOD removal rate are frequently observed to be concentration dependent.

These three phases may be expressed mathematically:
Phase I : The logarithmic growth phase is distinguished by geometric increases in sludge mass, and independent of the concentration of organic matter i.e.

$$\log_{10} \frac{S + \Delta S}{So} = k_1 . t \qquad \ldots\ldots\ldots(16)$$

where:

k_1 = logarithmic growth rate constant for the log growth phase (common logarithmic)

S = the sludge concentration present, p.p.m.

So = the initial sludge mass per unit volume, p.p.m.

ΔS = S - So = the increase in sludge concentration.

Using K_1 as logarithmic growth rate constant for natural logarithmic.

Therefore equation (16) becomes:

$$\ln \frac{S + \Delta S}{So} = K_1 . t \qquad .....(17)$$

Expressed equation (17) in term of BOD removal thus:

$$\ln \left(1 + \frac{a.Ir}{So}\right) = K_1 . t \qquad .....(17.A)$$

where:

a = Fraction of BOD removed for sludge synthesis.

Ir = Quantity of BOD removed, p.p.m.

Phase II : The declining growth phase.

At low concentrations of BOD : the sludge growth rate, and hence the BOD removal rate, will frequently be expressed by a first - order reaction. BOD removed under these conditions can be expressed by the relationship mathematically thus:

$$\log_{10} \frac{Le}{Lo} = - k_2 . t \qquad .....(18)$$

where:

$-k_2$ = Declining growth rate constant for common logarithmic, time $^{-1}$.

Le = Oxidizable BOD remaining, p.p.m.

Lo = Total amount of initial BOD that can be oxidized as a limit of the oxidation process, p.p.m.

Using - K_2 as declining growth rate constant for natural logarithm

Equation (18) becomes :

$$\ln \frac{Le}{Lo} = - K_2 . t \qquad .....(19)$$

Equation (19) is valid for any single oxidation. To compare oxidations, it is convenient to let - $K_2 = K_2' . Sa$.

Phase III : The endogenous respiration phase is characterized by the auto - oxidation of cellular material in the absence of food and can be expressed mathematically as :

$$\log_{10} \frac{S}{Se} = - k_3 . t \qquad .....(20)$$

where:

$-k_3$ = Endogenous respiration rate constant for natural logarithm, time $^{-1}$.

S = The sludge concentration present, p.p.m.

Se = Maximum concentration of activated sludge, p.p.m.

Using - K_3 as endogenous respiration rate constant for natural logarithm.

Equation (20) becomes.

$$\ln \frac{S}{Se} = - K_3 . t \qquad .....(21)$$

Oxygen Utilization

ECKENFELDER and O' CONNOR (1961) showed that for the optimum efficiency, oxygen must be supplied at a rate equal to or greater than its rate of utilization. In the activated sludge process this is usually accomplished by diffusion from air bubbles injected into the liquid sludge mass under turbulent conditions.

Oxygen utilization rate may be defined as the weight of oxygen consumed by a given weight of microbial sludge per unit of time. It is usually expressed as p.p.m.per.hour. In some of the more common are listed below

k_r = mg. O_2/hr./g. sludge.

Q_{O_2} = ml./O_2 hr./g. sludge.

r_r = p.p.m. O_2/hr.

S_a = Sludge concentration, mg./l.

A linear relationship will exist between sludge concentration and oxygen utilization over the range of sludge concentrations usually employed.

$$r_r = k_r . S_a \qquad \text{.....(10)}$$

In very high sludge concentrations (> 10,000 p.p.m) the unit rate of oxygen utilization may decrease due to diffusional resistance. DAWSON and JENKINS (1949). In most cases the specific uptake rate (k_r) will vary inversely with organism size. The most satisfactory index for specific oxygen uptake rate is the surface area per unit volume GADEN (1956).

During assimilation, micro-organisms require oxygen for their synthesis. In addition to the above oxidation, the sludge produced by the asimilation of organic matter is continually oxidized by its own mass. HOOVER and PORGES(1952) have defined this as endogenous respiration. In the absence of available nutrients, cells oxidize their own tissue slowly in order to obtain energy for maintaince. Recent investigations have shown that endogenous respiration also occurs concurrently with synthesis. This oxidation is difined by Equation (7)

The total oxygen requirements of a bio-oxidation system can be defined by ECKENFELDER and O'CONNER (1954) as:

$$\text{lb.}O_2 \text{ / day} = a' \text{ lb.BOD}_5 \text{ removed/day} + b' \text{ lb.MLVSS.} \quad \ldots.(11)$$

where a' = The coefficient, represents that fraction of organics consumed to supply energy for synthesis.

b' = The coefficient, represents the endogenous respiration rate.

The maximum oxygen uptake rate encountered in a waste oxidation system will be related to the sludge growth rate and to the endogenous will be related to the sludge growth relationships shown in Fig. (ii); the maximum uptake rate will be

$$\frac{dO_2}{dt} = \left(\frac{a'}{a}.K_1 + b'\right) S \qquad \ldots\ldots\ldots\ldots(12)$$

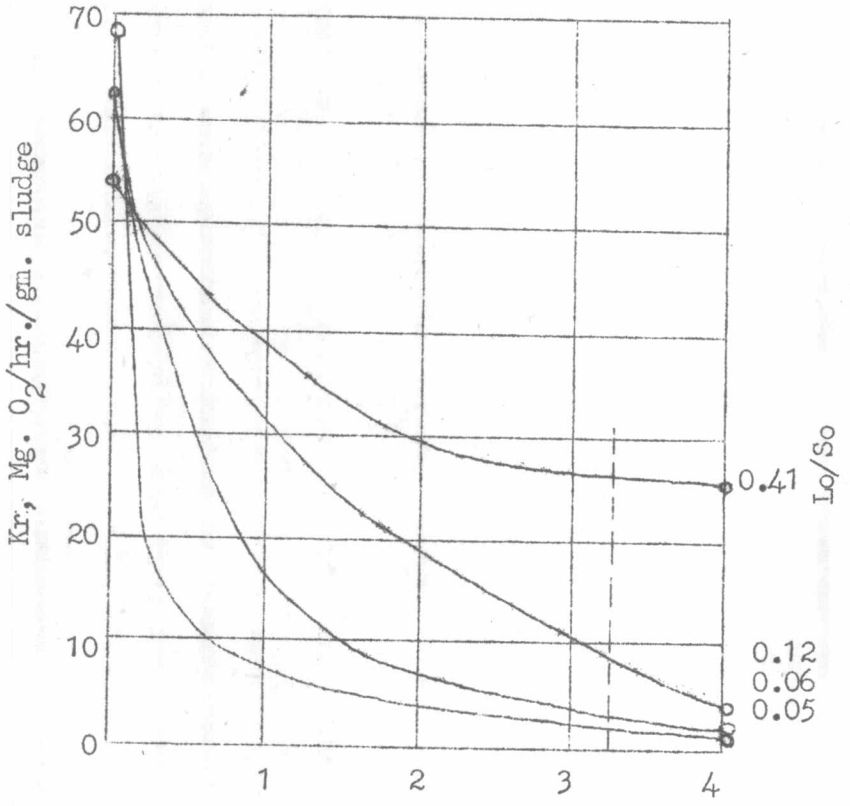
Variation in Oxygen Uptake Rate

In addition to compute the total oxygen requirements for a system, it is important to determine the distribution of the oxygen demand in the aeration tank in order to design the aeration system. As can be implied from Fig. (iii), the oxygen uptake rate will vary with time of aeration as the sludge passes through the various growth phases. Unless the entire occurs in the log growth phase, the growth rate, and consequently the oxygen uptake rate, will decrease along the length of the tank as the BOD to sludge ratio decreases, until the endogenous level is reached.

The oxygen uptake rate will vary with time of aeration as the sludge passes through various growth phases depending on the concentration of sludge employed and the BOD of the waste. If the BOD to sludge ratio (Lo/So) is low, the initial rate will be high since rapid oxidation of the BOD is occuring. Due to the rapid initial removal of BOD under these conditions the uptake rate will decrease very rapidly and approach the endogenous level.

Oxygen Concentration (O_2 DISSOLVED)

ECKENFELDER and O' CONNOR(1961) found that when the oxygen concentration in the mixed liquor is greater than 0.2 - 0.5 p.p.m., the rate of bacterial respiration is independent of oxygen concentration. When the oxygen concentration is below this value, the system becomes oxygen dependent and the rate of BOD removal is decreased.



Time of Aeration, hr.

Fig. (iii). Variation in Oxygen Utilization with Time of Aeration.

Sludge tends to clump, hence to decrease the quantity of oxygen which can be transferred to them by an increase in resistance to tranfer. WARBURG (1950) and PASVEER (1954) defined mathematical relationships for oxygen diffusion into microbial cells which are a function of floc size, diffusivity, oxygen utilization rate and external concentration of dissolved oxygen (driving force). A relationship can be developed incorporating these variables for the case when the entire floc from the surrounding liquid can be approximately by equation (13).

$$\frac{dM}{dt} = \frac{D}{R} \cdot 4\pi R^2 (C_L - C_M) \quad \text{.....(13)}$$

in which

C_L = Oxygen concentration at the cell interface.

C_M = Oxygen concentration within the cell.

D = Diffusivity of oxygen.

dM/dt = Weight rate of oxygen tranfer.

R = Mean floc radius.

[Assuming the floc is spherical, the change in rate with decreasing floc radius is neglected].

The oxygen consumed by the sludge floc will be

$$\frac{dM}{dt} = k_r \cdot \rho \cdot 4/3 \cdot \pi R^3 \quad \text{.....(14)}$$

where ρ is the floc density (1.018 - 1.210)

For steady state condition Equation (13) = Equation (14)

$$k_r \cdot \rho \, 4/3 \cdot \pi \cdot R^3 = \frac{D}{R} \cdot 4\pi R^2 (C_L - C_M)$$

$$R = \sqrt{\frac{3D(C_L - C_M)}{k_r \cdot \rho}} \quad \text{.....(15)}$$

IMHOFF and OTHERS (1971) stated that the air supply to aeration tanks (of the activated sludge process) must be abundant enough to maintain a dissolved - oxygen concentration throughout the tanks of not less than 1 - 1 ½ p.p.m. In high - rate plants, it should be even greater, perhaps upto 3 p.p.m.

Nutritional Requirements

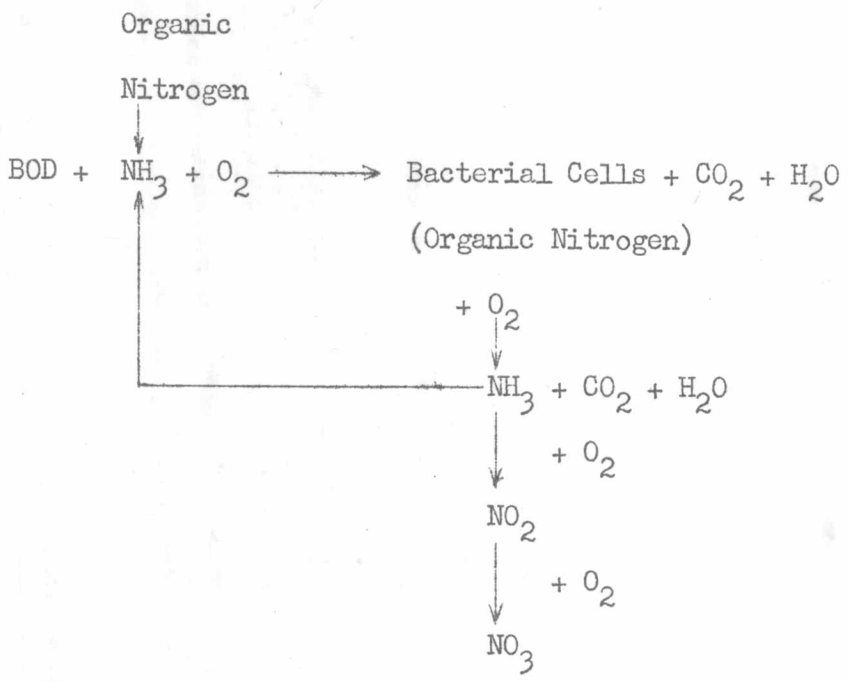
ECKENFELDER (1966) explained that efficient and successful biological oxidation of orgainc wastes requires a mininmal

quantity of nitrogen and phosphorus for the synthesis of new cell tissues. In addition, trace quantities of several other elements such as potassium and calcium are required. These elements are usually present in natural waters in sufficient quantity to satisfy the requirements for bacterial metabolism. Nitrogen and phosphorus, however, are frequently deficient in waste substrates and must be fed as a nutrient supplement to the system to attain optimum efficiency.

Inorganic Nutrient Requirements

Element	Function
Nitrogen	Primarily catalytic
Potassium	Primarily catalytic.
Calcium	Catalytic, bound to cell constituents.
Phosphorus	Uncertain.
Magnesium	Component of chlorophyll.
Sulfur	Constituent of protein.
Iron	Catalytic
Manganese, Copper and Zinc.	Catalytic

The nitrogen cycle in biological waste treatment is :



During sludge growth, nitrogen is utilized for synthesis (a - c) in Fig ii while during the auto - oxidation process (c - d) nitrogen is released back to solution. Some of this nitrogen will be recovered and reused for synthesis.

Nitrogen in the form of ammonia, nitrite and nitrate and some forms of organic nitrogen are available to the organisms for synthesis. The portion of organic nitrogen available varies with the waste. Soluble inorganic phosphorus and most organic phosphorus are available for microbial usage. When a nutritional supplement is required for a biological process, ammoniacal nitrogen and soluble phosphorus salts are generally used since they are most readily assimilable. It is usually not advisable to add nitrates, because they serve as a secondary source of oxygen for the organisms. In secondary settling tanks where the available dissolved oxygen may be

depleted, nitrates are reduced and nitrogen gas is formed, resulting in a floating sludge.

The nitrogen of actively metabolizing sludges will vary from 6 - 15 % and phosphorus from 2 - 5 % on a dry weight basis depending on the growth phase of the system. (After initial removal of carbonaceous BOD, the nitrogen content of the cell may be low. As oxidation and sludge growth proceeds the cell nitrogen will increase to a maximum). SYMONS and Mc. KINNEY (1958) obtained a sludge of 8.2 - 8.7 % nitrogen from the oxidation of sodium acetate when the availability of nitrogen and phosphorus content of 7 % and 1.2 % by weight respectively of the total volatile solids should be maintained.

The nitrogen content of sludges is dependent on the type and nature of the active organisms produced in aerobic waste treatment systems, the concentration of biological valatile solids and the concentration of available nitrogen in the waste. The ratio of microbial mass to total volatile solids will be variable depending on the waste.

The nutritional balance of an aerobic biological system is primarily based upon satisfying the requirements of the cell structure produced by the removal of BOD from a waste ECKENFELDER (1966) revealed that a BOD : N : P ratio of 100:5:1 in a waste will usually insure adequate nutrition. HEUKELEKIAN and MANGANELLI (1951) stated that to prevent nitrogen dificiency affecting in the waste treatment, nitrogen must be added to

satisfy a BOD/N ratio between 17/1 - 22/1. SAWYER (1964) explained that BOD/N ratio required for the activated sludge process was 100 : 5 and also BOD/P ratio of 150 : 1.

According to the works of several workers; a BOD : N:P ratio of 100 : 5 : 1 would be accepted as a design criteria.

Effect of Temperature on Biological Oxidation

ECKENFELDER (1966) stated that the rate of the biological reaction will increase with temperature to an optimum value ; approximately 30 ^{o}C. for most aerobic waste systems. Mc. KINNEY (1958) found that the enzymatic activity of cells was maximum at a temperature of 35 ^{o}C. Mc. CABE and ECKENFELDER (1955) reported that the rate of digestion of organic matter will slightly more than double for every 10 ^{o}C rise in temperature. IMHOFF and OTHERS (1971) showed that temperature affects natural rate of decomposition, which may increase by 4 % per degree centrigrade rise. However, adjustments to temperature are not always direct or immediate, and the effective increase in oxidation rates is seldom more than 3 %.

ECKENFELDER and O' CONNOR (1961) expressed that temperature influences the rate of all chemical and biochemical reactions. In most reactions occuring in the range of optimum biological activity, a two to three fold increase in reaction velocity is experimented for each 10 ^{o}C rise in

temperature.

Formula for Temperature Effects

(i) $\log k_2/k_1 = 0.0368\ (t_1 - t_2)$; 0 - 28 °C.

(ii) $0.0315 = \frac{\log k_1 - \log k_2}{t_1 - t_2}$; WUHRMAN - -(1954)

(iii) $\frac{k_t}{k_{25}}\ ^{o}C \times 100 = 0.71.\ t^{1.54}$; SAWYER and - ROHLICH (1939)

(iv) $k_T = k_{20}\ ^{o}C.\ 1.065^{(t - 20)}$; PHELPS (1944)

Where : k_1, k_2 = Unit uptake rate at temperature t_1 , t_2 in mg. O_2 / hr./gm. of sludge.

Effect of pH on Biological Oxidation

ECKENFELDER (1966) stated that for most processes this covers a range of pH 5 to 9 with optimum rates occuring over the range pH 6 to 8. IMHOFF and OTHERS (1971) explained that bacteria are sensitive to both acidity and alkalinity, and for most bacterial types a neutral medium (pH 7) is optimal. Large sudden changes in pH may be intolerable, but most species can readily adapt themselves within a range of about one or two pH units change ; thus pH 7 - 8 or even pH 6 - 8 may be tolerated, although the reduction in activity with changing pH can be appreciable. ECKENFELDER and O' CONNOR (1961) conducted that a rapid change in pH (for example

a drop in pH from 6 to 5) may decrease the respiratory activity by as much as 75 %.

Toxicity of Biological Oxidation

ECKENFELDER (1966) showed that toxicity in biological oxidation systems may be due to one of several causes

1. An organic substance, such as phenol which is toxic in high concentrations but biodegradable in low concentrations.

2. Substances, such as heavy metals, which have a toxic threshold depending on the operation conditions.

3. Inorganic salts and ammonia which exhibit a retardation at high concentrations.

INGOLS (1955) explained that many substances exert a toxic effect on biological oxidation process. Partial or complete inhibition may result, depending on the substance and its. concentrations. Inhibition may result from interference with the osmotic balance or with the enzyme system. The concentration of a substant which will exert a toxic effect is also influenced by other factors such as food concentration, temperature and the nature of the organisms.

Sludge Bulking

IMMOFF and OTHERS (1971) explained that bulking of the activated sludge results due primarily to the unbalanced

growth of filamentous fungi. The sludge then occupies a large volume, does not settle as readily as usual and tends to rise to the surface and form a scum or floating sludge masses, consequently spoiling the quality of the final plant effluent. An activated sludge in good condition will settle in 30 min. to a concentration of about 1 ½ % solid or more.

ESCRITT (1967) suggested that bulking in the activated sludge is a condition in which the sludge increase in volume to a great extent and very rapidly, rendering final sedimentation difficult and producing a bad effluent. The main cause of bulking at a properly organised works is overloading of the plant owing to works being too small to deal with all flows received. But bulking can be brought about by imperfect operation ; for example, not allowing sufficient air supply or not giving sufficient agitation are detaining sludge for too long peroid in the final sedimentation tanks after inadequate aeration. Too low density of mixed liquor is another cause.

Grease and Fat ; and their Primary Treatment.

SAWYER (1960) stated that the grease in the activated sludge plants often accumulates into "grease balls" which give an unsightly appearance to the surface of settling tanks. The processes are adversely affected by unreasonable amounts of grease which seems to coat the biological forms sufficiently

to interfere with oxygen transfer from the liquid to the interior of the living cells. This is sometimes described as a "smothering" actions.

ESCRITT (1972) found that the waste waters from dairies and creameries are rich in organic matters and very liable to undergo fermentation with the formations of lactic, butyric and other organic acids which give it a particularly objectionable odour.

HARDENBERGH and OTHERS (1961) explained that preaeration is effective in removing oils, greases and fats. A detention period of 10 to 20 min. provided in a tank in which air equipment is installed. Compressed air, applied at rates varying from 0.1 to 0.05 ft^3 / gal. of sewage, agitates the sewage. The agitation prevents settling of solids and the air tends to change the oils, greases and fats to a soapy mixture. This mixture is carried to the surface by the air bubbles, some of which are entrained in it, and may be skimmed off.

Character of Biological Sludge.

The microbial sludge or biological floc employed in bio - oxidation process is a miscellaneous collection of microorganism such as bacteria, yeasts, molds, protozoa, rotifers, worms and insect larvae in a gelatinous mass. Algae will also be present in those area exposed to sunlight.

An excellent compendium of the ecology of activated sludge has been presented by HAWKES (1960). The bacteria are primarily non - nitrifying aerobic spore formers, many of which are of the B. subtilis group. Nitrifying bacteria are primarily Nitrosomonas sp. and Nitrobacter sp.. In most activated sludge process, the sludge appear as zoogleal masses intermixed with filamentous basteria. One of the pricipal forms in the zoogleal mass is Zooglea ramigera which has been defined as a gram - negative, non - spore forming, motile, capsulated rod. Since most bacteria under proper conditions can flocculate, Zooglea ramigera may be a true species, but rather a growth form of many species. Other common forms of bacteria found in activated sludge include Flavobacterium sp., Psuedomonas sp. and filamentous organism, the most common of which is Sphaerotilus natans. The protozoa, stalked ciliates are the most common, including Vorticella sp., Opercularia sp. and Epistylis sp. Free swimming types include Paramoecium sp., Limnotus sp. and Trichoda sp.. Some forms of Flagellata sp. and Rhizopoda are also found. The relationship between the type of protozoa which predominates and the bacterial population seem to depend on the degree of flocculation. In a well flocculated sludge, stalked ciliates and attached forms are common since they feed on the zoogleal mass. With low floccution, free swimming forms dominate. The interrelationship between bacteria and protozoa on treatment efficiency is not well defined. It is generally conceded, however, that protozoa

aid in clarification. ENGLEBRECT and Mc. KINNEY (1957) found that the sludge developed on structurally related compounds possesed similar morphological characteristics and produced similar biochemical changes.

Micro - organism in Dairy Waste Studies

A wide variation in micro - organism population between the assimilative and the endogenous phases was reported by JASEWICZ and PORGES (1956) on dairy waste studies. They found that during the assimilative phase, 74 % of the organisms were of the genera Bacillus or Bacterium while only 8 % of the endogenous sludge was composed of these organisms. The endogenous sludge contained 42 % of the proteolytic organisms Pseudomonas sp. and Alcaligenes sp. and 48 % of the sacchorolytic organisms Flavobacterium sp. and Micrococcus sp.

HOOVER and PORGES (1952) showed that sludge synthesized from dairy wastes to have the general empirical formula $C_5H_7NO_2$. This formula is representative of the statistical average composition of the complex organic compounds constituting cell material. This sludge contain 12.3 % nitrogen and theoretically requires 1.42 oxygen for each gram of sludge completely oxidized. HOOVER (1952) found an empirical factor of 1.25 g. O_2 per g. of dry weight solids for dairy waste oxidation. This equivalent to 1.36 g. O_2 per g. dry weight volatile solids for a sludge of 8 % ash.