DISCUSSION

5. Discussion

5.1 Inocula Types And Their Efficiencies In The Biodegradation Of Detergent Wastewater.

5.1.1 Efficiency of sewage inocula compared to soil inocula.

The studies on the enrichment of cultures to the wastewater using inocula from sewage and soil sources showed rather unexpected results. The Figs 4.1 to 4.12 generally show that sewage derived cultures perform better than soil inocula in the reduction of MBAS, BOD and COD. This is surprising in view that microorganisms from both sources were expected to consist of active degraders since they had been continously exposed to the detergents. In fact, the microorganisms derived from the soil were expected to have performed better since they were obtained from the river banks in the proximity of the detergent plant and should have therefore been continually exposed to higher concentrations of surfactants. In contrast, the microorganisms from the sewage treatment plant were exposed to lower concentration of detergents of 20 mg/1 MBAS or less.

The better performance of the sewage inocula can be probably explained by the fact that the bacteria were retained over a prolonged period in the treatment plant. The prolonged period would have ensured stable physiological or/and mutational changes to occur in the bacteria such that they are able to degrade the surfactants. Although subjected to similar selection pressures, the acclimatized soil bacteria are, however, faced with the problem of washout. The success of the sewage inocula could also be due to other factors. For instance, Bird (1981) has reported that different microorganisms and different multiplication rates of microorganisms present would also favour one inocula over another.

5.1.2 Acclimatization of the sewage and soil inocula to raw and treated detergent wastewaters.

The results depicted in Figs 4.1 to 4.12, generally showed that the sewage and soil cultures are easily acclimatized to the treated wastewater in comparison to the raw wastewater. This can be explained by the lower number of chemical components and their lower concentrations as well as the lower toxicity of the wastewater after physical-chemical treatment. Physical-chemical treatment resulted in a lowering of the biodegradability index (COD/BOD_5) which is a measure of the ease of breakdown of the organic compounds by the microorganisms. A low biodegradability index of 5 or less means a more easily degradable wastewater (Grutsch and Mallat 1976, Stones 1976 and Crepsi and Sanchez 1980). It was clearly observed that physical chemical treatment of the detergent wastewater under investigation had made the wastewater more amenable to biological treatment. This was demonstrated in the biodegrability index which dropped from 7 to 4 after the treatment.

The raw wastewater used in the studies also contained high concentrations of alkylbenzene sulphonates. These compounds are not only recalcitrant in nature but also toxic to microorganisms due to the physico -chemical effect on bacterial metabolism resulting from the marked reduction of surface tension at the surface of the cell membrane (Manganelli and Crosby 1953, Swisher 1970, Cain 1977). This would explain the long acclimatization period required by the microorganisms and the poor efficiency observed in the reduction of BOD, COD and MBAS.

5.1.3 Effect of different concentrations of sewage inocula.

The use of different concentrations of inocula showed that, for sewage inocula, the 1% concentration was optimal to effect the highest reduction in BOD, COD and MBAS values . The results are as shown in Figs 4.7 - 4.12.

It is believed that there was an optimal number of microorganisms and concentration of extraneous carbon sources present in the 1% inoculum. This allowed for the optimal and rapid usage of the carbon sources by the microorganisms before they were forced to adapt to the alternative recalcitrant detergent wastewater for their carbon. At a 2% sewage inoculum concentration, a poorer efficiency and a slower adaptation was observed during the 60 day period. At this concentration, the increased presence of the extraneous carbon sources and the higher number of cell death increased the carbon source available. This further slowed down the need for the microorganisms to adapt to the new substrate, thus resulting in a poorer reduction efficiency in the given period time. The presence of extraneous carbon sources which are generally rapidly assimilable compouns in sewage have been reported by Higgins and Burns (1975) and Mara (1970).

Gaudy et al (1963), and Stumm-Zollinger (1966) and Harder and Dijkhuizen (1983) reported that catabolite repression of xenobiotic compounds could occur in the presence of rapidly assimilable compounds. This results in a longer period for physiological adaptation to occur since enzyme induction or the presence of the neccessary constitutive enzymes for biodegradation are initially repressed. (Ravin 1952, Dagley and Dawes 1953).

5.1.4 Effect of different concentration of soil inocula.

As shown in Figs 4.7 to 4.12, the reduction of COD, MBAS and BOD increased with increasing inoculum concentrations.

It has been earlier discussed in Section 5.1.1. that the soil microorganisms were probably not properly acclimatized to the detergent wastewater. Therefore, in this case, the presence of the highest number of microorganisms initially will result in more of them adapting to the recalcitrant detergent wastewater subsequently. This would have occured at a 2% soil inocula concentration and after all the extraneous carbon sources were depleted. Coe (1952) and Amberg and Cormack (1957) had, in fact successfully and rapidly developed acclimatized cultures to wastewaters that are difficult to degrade, by increasing the microorganisms concentration initially on a more rapidly assimilable substrate before exposing them to the alternative substrate.

5.2 Isolation And Identification Of Microorganisms

The observed predominance of gram negative microorganisms in the activated sludge tanks was probably due to the source of inocula. The sewage inocula used was mainly human in origin and therfore, the presence of the enteric or coliform microorganisms in the aerated tanks were expected.

Four of the microorganisms isolated were *Pseudomonas aeruginosa*, *Alcaligenes faecalis*, *Citrobacter freundii* and *Proteus vulgaris* and they could utilize the tridecylbenzene sulphonate as the sole carbon source. However, *Escherichia coli*, *Bacillus subtilis*, *Serratia marcescens* and *Nocardia asteroides* did not grow on ABS agar indicating the non-utilization of ABS as their carbon source. As mentioned in Section 2.9, the resistance of alkylbenzene sulphonates to biodegradation is well proven (McGauhey and Klein 1959, McKinney and Symons 1959 and Huddleston and Allred 1963, Mohanrao and McKinney 1964), and it was not surprising that not all the microorganisms isolated utilized the alkylbenzene sulphonates as their sole carbon source. These other microorganisms present probably tolerated the presence of the ABS, or co-metabolized it in the presence of other components or utilized other substrates in the wastewater (Beam and Perry 1974, Horvath and Alexander 1970, Horvath

1972 and Jacobson *et al* 1980).

5.3 Biodegradation Of Detergent Wastewater And A Pure Alkylbenzene Sulphonate Solution By Pure And Mixed Cultures.

5.3.1 Biodegradation of treated wastewater by pure cultures.

The observed breakdown of the treated wastewater by *Pseudomonas aeruginosa* followed by *Alcaligenes faecalis* as summarised in Table 4.1 showed that these two microorganisms have developed enhanced metabolic capabilities to degrade the branched alkylbenzene sulphonate compound. Hardy (1983) and Williams (1978) attributed the success of *Pseudomonas* sp. to the presence of degradative plasmids. *Alcaligenes faecalis* has also been known (Marion 1966) to degrade branched alkylbenzene sulphonates, but to date the presence of degradative plasmids for surfactant breakdown has yet to be reported.

The lower oxygen uptake rate of *Citrobacter freundii* and *Proteus vulgaris* together with the suppression of oxygen uptake at higher concentration of treated wastewater as summarised in Table 4.1 probably indicated that these microorganisms had a lower threshold concentration of toxicity. It could also be due to the broad specificities of the enzymes present which would mean lower efficiency of breakdown of the wastewater.

From Fig 4.16 and 4.26, *Bacillus subtilis*, *Serratia marcescens*, *Escherichia coli* and *Nocardia asteroides* showed similar oxygen uptake rates to the endogenous respiration control or even lower. This probably indicates the non-utilization of the alkylbenzene sulphonate component in the wastewater. However, some authors (Huddleston and Allred 1963, Cain 1977)have reported that these micro-organisms are capable of biodegrading alkylbenzene sulphonates. Therefore, the presence of these microorganisms in the wastewater suggests that they would survive through interactions such as co-metabolism or commensalism.

5.3.2 Biodegradation of treated and raw detergent wastewaters by mixed cultures.

The Tables 4.1 to 4.4, showed that the mixed cultures were more superior than pure cultures in degrading different portions of raw and treated wastewaters which were initially subjected to foaming.

The wide array of enzmes produced by the mixed culture resulted in a more complete breakdown of the alkylbenzene sulphonate molecule since the intermediate degradation products of some of the enzymes were substrates for the other enzymes present. In contrast, pure cultures produced a limited number of enzymes which would result in a incomplete breakdown of the ABS molecule and slow degradation kinetics. It is also probable that for the mixed culture system, there were additional interactions between the microorganisms such as synergism, commensalism and co-metabolism which would result in an increased degradation of the wastewater. (Horvath 1972, Kachholz and Rehm 1977, Kim and Rehm 1982).

Tables 4.2 to 4.4 show that concentrating the ABS in the foam or removal of the ABS in the after foaming portion affected oxygen uptake rates in the treated and raw wastewaters. Therefore, enchanced toxicity of the ABS was indicative in the lowering of oxygen uptake in the foam concentrate while reduced ABS levels in the after foaming portion resulted in the lowering of toxicity and subsequently an increase in oxygen uptake of the microorganisms.

However, toxicity as a reason cannot be given for the lower oxygen uptake rates at lower concentrations of the after foaming portion since the oxygen uptake rates are higher for higher alkylbenzene sulphonate concentrations in the after foaming portion of the wastewater (Table 4.3). This therefore demonstrated that the oxygen uptake rates of the microorganisms were reduced due to a limiting carbon source.

Further findings, as illustrated in Table 4.6 confirmed the fact that at high alkylbenzene sulphonate concentrations in the region of 400 mg/l and above oxygen uptake rates were reduced. At low alkylbenzene sulphonate concentrations of less than 45 mg/l the limiting carbon source was the factor in reduced oxygen uptake rates.

5.3.3 Biodegradation of a pure ABS solution using pure and mixed cultures.

The results of the studies using pure and mixed cultures to degrade the pure ABS solution in Table 4.5 showed similar trends to the results of the experiments discussed in Section 5.3.1 and 5.3.2. However, oxygen uptake rates to the pure ABS solution were higher for the four microorganisms namely, *Pseudomonas aeruginosa*, *Alcaligenes faecalis*, *Citrobacter freundii* and *Proteus vulgaris* and the mixed culture compared to the treated wastewater.

The results in Tables 4.1 and 4.5 for the experiments with similar MBAS concentrations for raw and treated wastewaters and a pure ABS solution also showed that oxygen uptake rates was highest for the pure ABS solution followed by the raw wastewater and then the treated wastewater.

The presence of other components such as fluorescent whitening agents and bleaching agents in the raw wastewater probably suppressed oxygen uptake rates. However, with the treated wastewater, the presence of calcium and aluminium ions probably inhibited oxygen uptake of the microorganisms.

5.4 Effect Of Calcium Hydroxide And Aluminium Sulphate On Oxygen Uptake Of A Mixed Microbial Culture.

As shown in Fig 4.28 , the calcium hydroxide and aluminium sulphate in the ratio of 2:1 inhibited oxygen uptake. Theses results confirmed the previous findings discussed in Section 5.3.3 in which the calcium and aluminium ions were believed to inhibit oxygen uptake in treated wastewater.

The widespread use of low concentrations of lime and and alum in the treatment of wastewater, especially in the mineral precipitation of phosphate, has never been reported to supress microbial growth and activity (Ademoroti 1985, Rebhun et al 1985). However, it is believed that the high concentrations of calcium and aluminium used in the physical-chemical treatment of the detergent wastewater, especially aluminium, inhibited the oxygen uptake of the microorganisms. Mowat (1976) has reported that aluminium concentrations above 20 mg/l could inhibit microbial oxygen uptake while calcium was only inhibitory at concentrations above 250 mg/l (Vashon et al 1982). However, the presence of the two ions also proved to be advantageous and this aspect will be discussed later in Section 5.9.

5.5 Nutrient Addition To The Activated Sludge System.

Figs 4.30 to 4.33 demonstrated that the addition of nutrients in the universally accepted ratio 100:6:1 of C:N:P definitely enchanced biodegradation of the wastewater. The enchancement of biodegradation by the adjustment of C:N:P showed that although there was no shortage of carbon, the effluent was still nutritionally unbalanced. This can be observed in Table 3.1. Addition of phosphate and nitrogen maximised the utilization of the wastewater leading to an increase in microbial biomass. Bates and Torabian (1981) and Greenburg et al (1955) showed that the absence of such nutrients will also cause poor settling and the physiological weakening of the microorganisms.

5.6 Activated Sludge System Without Recycle At Various HRT.

The results of experiments on various HRT as depicted in Figs 4.34 to 4.37 generally show that at long HRT there is a higher reduction in BOD, COD and MBAS. The efficiency associated with long HRT was due to various factors such as the longer contact time between the substrate and the organisms, the decrease in the washout rate of microbial cells with increasing solids retention time and the reduction in the effect of shock loadings. The longer contact time between the microorganisms and the substrate ensured a more complete degradation of the complex long chain ABS compounds. This is important especially in a mixed culture system where the products of one organism are successfully utilized by other organisms leading to complete biodegradation and mineralization of the organic compounds. The longer contact time between the microorganisms and the substrate will also encourage the selection of microorganisms that will utilize the recalcitrant ABS. It should be noted also that the period of time is important in the physiological adaptation of the microorganisms for the induction of non-constitutive enzymes which are specific to the substrate.

A longer HRT is equivalent to a longer SRT which will result in the reduction of the number of cells lost by washout. It will also improve the interaction between the mixed culture microorganisms and it will decrease the washout of the unmetabolised substrate. Lawrence and McCarty (1970) have also reported that SRT of 3 to 14 days are optimal since shorter SRT leads to bulking while longer SRT leads to biological floc breakup. With a longer HRT, the effect of localised shock loadings due to high alkylbenzene sulphonate concentrations can also be averted. This will result in the reduction of toxicity towards the microorganisms.

It is interesting to note in the experiments that the percentage removal of BOD is lower after a 5 day HRT compared to MBAS and COD removals. This indicates that most of the biodegradable components have been utilized during the BOD removal while increasing removals of MBAS and COD indicates removal of the recalcitrant ABS components or its products.

The general increase in MLSS and MLVSS was due to the incorporation of the metabolised carbon into the new cells. However, the fall in MLSS and MLVSS after a 25 day HRT could be due to the low presence of carbon substrate or could be due to the stationary phase of growth of the microorganisms at such long SRT.

Even though the shorter HRTs do not produce effluent with reduced BOD, COD and MBAS, a practical approach to industrial application must be reached in terms of time and economics. The shortest HRT is most preferable and this can normally be achieved by increasing the contact time between the microorganisms and the substrates or by other means.

5.7 Treatment Of The Treated Detergent Wastewater Using 3 CSTR In Series.

From Figs 4.38 to 4.45 it can be concluded that operating 3 tanks in series with each at a 1 day HRT (total of 3 day HRT), provides a higher treatment efficiency than operating a single tank at a 3 day HRT with a similar volume of wastewater. It may be argued that a single completly mixed tank operating at a 3 day HRT would be more suitable in terms of buffering by immediate dilution of inflowing compounds, production of a uniform microbial community with a uniform growth and a uniform distribution of oxygen requirements which will result in a higher degradation of complex compounds (Herbert _et al_ 1956, Erickson and Fan 1968, McKinney 1974, Toerber _et al_ 1974).

However, it was observed that a dynamic state occured after 15 days of operation of the 3 CSTR in series, resulting in higher total removal of BOD, COD and MBAS. The results are shown in Fig 4.38 to 4.45. In fact, in tank number 2 which represented a total HRT of 2 days, the percentage removal efficiency surpassed the efficiency of the single tank operating at a 3 day HRT.

It can be suggested that the removal efficiency improved since the mixed culture present in each tank was different with enzymatic systems optimized to various component of the alkylbenzene sulphonate molecule or the detergent wastewater. The selecton pressure exerted in each tank was different due to the variation in the substrates present. In the first tank, the microoganisms were exposed to the original substrate while in the subsequent tanks they were exposed to the degradation products of the first tank.

The first tank was also believed to contain a culture in the logarithmic phase of growth which would result in the highest rate of reaction towards the substrate. This was indicated by the high viability ratio (MLSS/MLVSS) of 0.8 which essentially meant a system with unlimited carbon source but limiting microorganisms. It should be noted that theorectically the culture can only be 100% viable at a SRT of zero (Grady and Roper 1974).

The biodegradation processes in the first tank could also have resulted in the utilization of the more rapidly assimilable substrates or the components of the recalcitrant detergent wastewater. The intermediate degradation products then flowed into the second tank to be further degraded. The high production of microbial biomass in the first tank also resulted in a dynamic state where some microorganisms, were always retained even at the short HRT.

The reaction rate in Tank 2 was slower due to the limiting carbon source and the viability ratio decreased to 0.72 indicating a higher amount of inert solids. At this stage, the microorganisms are believed to be mostly in the stationary and death phases of growth. In this tank, the values of MBAS and COD decreased further probably because of the degradation of the more recalcitrant components of the detergent wastewater. However, in the case of a single tank operating at a 3 day HRT, the microorganisms would be partial to the more easily assimilate compounds and therefore products which can otherwise cause end product inhibition or both feedback repression and inhibition (Clarke and Lilly 1969, Stadtman 1966) will not occur.

Fencl et al (1964) have from their studies, also described that multi-stage systems are advantageous from a physiological point of view with the ability to increase substrate conversion even if the substrate is toxic.

5.8 Biokinetic Coefficients Of An Activated Sludge System With Recycle.

The concept of recycling microorganisms to the treatment tanks serves many purposes (Andrews 1971, Tyteca et al 1977). Amongst others, the recycling process results in the maintenance of a higher cell concentration, it decreases the critical washout retention time while the potential substrate utilization rate per unit volume increases considerably. This results in smaller aeration tank volumes and a lower HRT for the treatment of the wastewater. These are supported in the present study where the treatment efficiency of the activated sludge system with recycle at a 1 day HRT and 15 day SRT was comparable to the treatment efficiencies of a single tank at a 3 day HRT and three CSTR in series at a total

HRT of 3 days. From Table 4.9, it was found that the treatment of the detergent wastewater using an activated sludge system with recycle at a 1 day HRT resulted in an almost 87 % reduction in BOD.

Table 5.1 shows the biokinetic coefficients for the activated sludge system with recycle treating detergent wastewater in comparison to the published coefficients obtained for various wastewaters. The large saturation constant value K_s of 111 mg/l implies a greater difficulty in achieving low detergent or BOD concentration levels to, for example, domestic sewage. However, it is better than phenol and wastes from plastic processing, palm oil mills and palm oil refineries. The large value of K_s could also indicate the lack of affinity of the enzymes to the substrates present in the wastewater (Stryer 1975). Further it can be suggested that the biodegradation of the alkylbenzene sulphonate components occured through a non-specific enzymatic action.

The yield coefficient Y of 0.54 was low even though nitrogen and phosphates were not limiting. This is one of the lower yield coefficients in Table 5.1. The low coefficient suggested a toxic waste or/and a recalcitrant substrate. Low yield coefficients are also noticeable coefficients for various mixed culture aerobic systems

Wastewater	Y, $\frac{mg}{mg}$	k_d day^{-1}	k $\frac{mg}{mg - day}$	K_s mg/l	θ_c^m day	Coeff.	References
Palm oil	0.8	0.2	0.43	442	7.0	BOD	Chin 1978
Palm oil refinery	0.85	0.016	0.12	510	13	BOD	Chin and Wong 1981
Waste paper	0.76						Eckenfelder 1966
Wallboard	0.78						Eckenfelder 1966
Glucose	0.59		3.3		0.52	BOD	Garret and Sawyer 1952
Skim milk	0.48	0.045	5.1	100	0.42	BOD	Gram 1956
Glucose peptone	0.49		10.3		0.2	BOD	McCarty and Broderson 1962
Domestic sewage	0.67	0.048				BOD	Middlebrooks and Garland 1968
Domestic waste	0.67	0.07	5.6	22	0.27	COD	Benedek and Horvath 1967
Landfill leachate	0.59	0.115	1.8	182		COD	Palit and Qasim 1977
Yeast	0.944	0.102	1.23	554		BOD	Wu and Kao 1976
Plastic processing	0.3	0.079	19.92	161		COD	Sundstrom and Klei 1979
Phenol	0.45	0.19	4.08	245		Phenol	Beltrame et al 1980
Detergent waste - water	0.54	0.048	8.8	111	0.27	BOD	This study

for phenol, a toxic compound, and plastic processing wastes which are known to be difficult to biodegrade.

It can be reported that the decay coefficient value k_d for the detergent wastewater was relatively low while the specific growth rate constant k was high.

In the present investigation, the lowest value of solids retention time θ_c at which process failure occurs is 0.27 day which is comparable to the value for domestic waste as reported by Benedek and Horvath (1967). However, Fig 4.48 shows that longer θ_c values of 15 days are required for higher treatment efficiencies. Chiang (1977) has also reported that systems operated at high θ_c values resulted in an improved effluent quality and an increased process stability. The determination of θ_c is important and numerous authors(Lawrence 1975, Mynhier and Grady 1975, Roper and Grady 1974, Sherrard and Schroeder 1972 and Keyes and Asano 1975) have described θ_c as the far more efficient as well as the most significant parameter in terms of design, operation and control of an activated sludge treatment plant. Compared to other parameters θ_c appears to be more significant than HRT (Sherrard and Lawrence 1973, 1975) more easily measured than the process loading factor U (Metcalf and Eddy 1972) or the F/M ratio (Stensel and Shell 1974, Burchett and Tchobanoglous 1974).

5.9 Oxygen Transfer Coefficients In Detergent Wastewater.

5.9.1 Oxygen transfer coefficients at various air flow rates.

In the present investigation, Table 4.10 showed that the oxygen transfer coefficient k_La into treated detergent wastewater increased substantially with an increasing air flow rate compared to distilled-deionized water which showed a relatively lesser increase in k_La. This is unexpected since many reports (Mancy and Okun 1960, McKeown and Okun 1963, Eckenfelder and Barnhart 1961, Koide et al 1976) have shown that presence of surface active agents in water reduced the k_La value in bubble systems. This resulted in α values of less than 1 as shown in their work, thus indicating reduced oxygen transfer rates. However, in the present work, the k_La value was found to be higher when air flow rates of 1 l/min and above were employed in the undiluted detergent wastewater system. This is probably due to the high concentration of ABS present which exceeded the critical micelle concentration. When this concentration is exceeded there will be an increase in k_La due to the increased interfacial area caused by the formation of smaller bubbles (Mancy and Okun 1960, Eckenfelder and Barnhart 1961). Subsequently α values would also increase with increasing air flow rates but only to a certain point after which it will remain constant. (Stanbury and Whitaken 1984).

The dilution of the detergent wastewater lowered the ABS concentration resulting in a lowering of k_La values. This suggested that the surfactant concentration was below the critical micelle concentration and the adsorption of the large molecules of surfactants reduced the surface tension of water (Meijboom and Vogtlander 1976), reduced the bubble size (Zieminski et al 1967), lowered the terminal velocity of bubbles (Kawase and Ulbrecht 1982) and increased the drag coefficient (Raymond and Zieminski 1971). Accordingly, surfactants were believed to reduce the k_La by depressing the hydrodynamic activity and by offering additional barriers for the passage of gas molecules at the gas-liquid interface.

From Table 4.10, it can be seen that the k_La value is highest for the treated detergent wastewater after foaming in comparison to the distilled-deionized and the undiluted treated detergent wastewater. This suggested the presence of components other than the surfactants which affected the k_La values. The only other significant components present in the treated wastewater that would affect k_La values were the presence of high concentrations of calcium and aluminium ions which would contribute to a high ionic strength. The ions were thought to hinder bubble coalescence (Lessard and Zieminski 1971, Zieminski and Whittemore 1971) thereby suggesting that the enhancement of k_La was directly attributable to the formation of smaller bubbles at higher ionic strength. In addition, it can also be attributed to the surface turbulence of the bubbles which increased in the presence of these salts. The presence of the surfactants in the wastewater actually decreased the k_La value as shown by the k_La value of undiluted treated detergent wastewater compared to the k_La value for the detergent wastewater after foaming, suggesting that the single most important factor which enhanced the k_La value was the salts.

Baars (1955) and Downing et al (1960) have reported that, in comparison to bubble aerators, surface or brush aerators are more efficient in affecting higher oxygen transfer rates into detergent containing water. However, the present study with bubble aerators showed that it is possible to achieve α values greater than 1 in detergent containing wastewater with the the presence of the inorganic salts in the wastewater.

5.9.2 Oxygen transfer coefficients at various pure oxygen flow rates.

Many advantages are expected from the utilization of pure oxygen in the activated sludge system, such as a better oxygen transfer efficiency (Humenick and Ball 1974), a reduction of the gas volume to be diffused (Cohen 1973), a higher dissolved oxygen concentration (Matson _et al_ 1972), an increase in bacterial activity (Stamberg _et al_ 1973), the possibility of treating higher loads (Mueller _et al_ 1973) and reduction in aeration volume (Humenick and Ball 1974).

Tables 4.10 and 4.12 show that the results of the experiments utilising air and pure oxygen to aerate detergent wastewater followed similar trends. However, at a flow rate of 2 l/min, the k_La value obtained by using pure oxygen was two times greater than with the use of air. This was due to the increased oxygen content in the pure oxygen. The saturation dissolved oxygen concentration was also greater by approximately 3 times. Theorectically, however, the saturation dissolved oxygen and the k_La value should be higher than recorded. However, the presence of electrolytes (Zieminski and Whittemore 1971) probably resulted in the lower saturation dissolved oxygen concentration while the low k_La value could be due to the membrance electrode used whose speed of response was not sufficiently fast to keep pace with the rapidly changing dissolved oxygen concentration. (Bennet 1980).

NOMENCLATURE

A	cross sectional area through which diffusion occurs, m^2
ABS	alkylbenzene sulphonates
α	k_La of wastewater/k_La of pure water
BOD	biochemical oxygen demand, mg/l
β	saturation dissolved oxygen concentration in wastewater/saturation dissolved oxygen concentration in pure water
C	concentration of dissolved oxygen in sample, mg/l
C_s	saturation concentration of dissolved oxygen in sample, mg/l
COD	chemical oxygen demand, mg/l
E	activation energy
F/M	food/microorganism ratio
HRT	hydraulic retention time θ, day
k	maximum rate of substrate utilization per unit weight of microorganism, day^{-1}
k'	kinetic constant
k_o	specific growth rate, h^{-1}
k_1	proportionality constant
k_2	proportionality constant
k_d	microbial decay coefficient, day^{-1}
k_L	liquid film coefficient, m/h
k_La	oxygen transfer coefficient, min^{-1}
$k_{T1,T2}$	substrate utilization rate coefficients at temperature T1 or T2 C.
MBAS	methylene blue active substances, (mg/l)
MLSS	mixed liquor suspended solids, mg/l
MLVSS	mixed liquor volatile suspended solids, mg/l

Q_o	influent flow rate, l/day
Q_r	sludge recycle flow rate, l/day
Q_w	waste sludge flow rate, l/day
r	respiration rate of activated sludge, mg O_2 /l/h
R	recycle ratio, Q_r/Q_o
S	effluent substrate concentration or substrate concentration in reactor, mg/l
S_o	influent substrate concentration, mg/l
SRT	solids retention time θ_c, day
SVI	sludge volume index
t	time
T	temperature
V	volume, m^3 or l
x	degradable fraction of biomass
X	microorganism concentration measured as MLVSS, mg/l
X_e	microorganism concentration in clarifier overflow, mg/l
X_r	microorganism concentration in recycle, mg/l
Y	weight of microorganisms newly formed/weight of essential substrate utilized, yield coefficient
θ	HRT, day
θ_c	SRT, day
θ_c^m	minimum SRT, day
θ_t	temperature coefficient