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Biological Aerated Filters

BAF 2

Cranfield University
12th June 1996

Organised by:
The School of Water Sciences, Cranfield University

In conjunction with The IChemE Water Subject Group

Editors – Professor Tom Stephenson and Dr Bruce Jefferson

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2nd Symposium on Biological Aerated Filters (BAF2)
12 June 1996

Following the success of the first BAF symposium held here in 1993, Cranfield University's School of Water Sciences is holding a second one day symposium on Biological Aerated Filters.

Over the last three years there has been a great deal of work on the development and optimisation of what has become one of the leading processes in wastewater treatment. The aim of this second symposium is to introduce recent work carried out in this field, bringing together many of the world's leading exponents of BAF technology and its application.

BAF2 represents an ideal opportunity to update your knowledge of these developments.

BAF2 Programme

9:30 Registration and coffee

10:25 Chairman's morning introduction

10:30 Trouble shooting and optimisation of BAF systems.
A Smith, Thames Water

11:00 Pilot scale comparisons of floating/sunken media and up/downflow BAFs.
A Mann, School of Water Sciences, Cranfield University.

11:20 Combined treatment of dairy and municipal wastewater in BAFs.
Howard Rundle, Tetra (Europe) Ltd.

11:40 North European experience of BAFs.
P Sagberg, Veas, Norway.
(to be confirmed)

12:00 The Poole Harbour wastewater treatment works.
P Brewer, Wessex Water Engineering.

12:30 Lunch

2:00 Chairman's afternoon introduction

2:10 The moving bed biological aerated filter
T Stephenson, School of Water Sciences, Cranfield University

2:30 Operational trials of different proprietary Lamella and BAF systems.
F Budge, Halcrow Consulting Engineers and D Gorrie, Grampian Regional Council.

3:00 Aeration optimisation in biological aerated filters.
P Pearce, Thames Water.

3:30 Operating performance and future development of the Biobed system.
A Cantwell, Brightwater Engineering.

4:00 *Close of Meeting and Tea*

The School of Water Sciences

The School of Water Sciences is the UK's only academic centre to specialise in process technologies for water and wastewater treatment. The school has considerable experience in research and development, working with many of the world's leading water companies and organisations concerned with water and effluent treatment. This experience ensures that the school if well positioned to offer consultancy and research and development related to these process technologies. The School has particular expertise associated with biotechnological applications including BAFs.

In addition to research and development and consultancy, the School of Water Sciences is recognised as a leading centre for the training of process technologies with funding from the EPSRC and approval of its programmes from the IChemE and CIWEM.

BAF and the biotechnology short courses have been developed to advance the understanding and implementation of these technologies.

School of Water Sciences

AERATION OPTIMISATION OF BIOLOGICAL AERATED FILTERS

Peter A Pearce -
Thames Water Utilities, Group R&D, Spencer House, Reading.

1 Introduction

Aeration costs account for a large proportion of the total running costs of biological aerated filters (BAFs) which are in themselves an energy intensive form of treatment process. Optimisation of oxygenation efficiency is therefore an obvious goal as small improvements in operating efficiency will yield significant savings in energy consumption.

This paper will deal with the oxygen transfer characteristics of a downflow BAF using mineral media. Clean water and operational performance are compared over a range of hydraulic and organic loadings and a range of air flow rates. Alternative aeration devices and aeration procedures were also evaluated but will only be discussed in summary in this paper.

2 Test Procedures

The pilot scale BAFs used in this study were 0. 5m diameter circular section columns with a media depth of 2.0m. Sampling ports were situated at 0.25m vertical intervals and projected into the media bed. The media specification used throughout the testing is shown in Table 1.

Table 1 Media Characteristics

Mean Geometric Size	3.3mm
Porosity	45.5%
Bulk Density	1327kg/m^3
Shape	Highly angular

Clean water test procedures were unsteady state determinations of mass transfer coefficient (KLa, h^{-1}) Oxygenation capacity (0c, KgO_2/h) and oxygen transfer efficiency (OTE, %) . The results are standardised to zero dissolved oxygen concentration, 760mm Hg atmospheric pressure and 20°C. A limited number of tests were performed with 5mg/1 anionic detergent added to the test water. The method is the standardised test using sodium sulphite to deoxygenate the test water prior to re-aeration and follows in principle the method proposed by the American Society Of Civil Engineers (ASCE).

Certain modifications were made to allow the test to be performed on BAFs. These concerned sulphite addition and probe calibration. The detailed test method has been reported elsewhere (Lessar 1993) The only aeration device tested under cleanwater conditions was the coarse bubble sparge grid described above. .

Operational testing on the BAF units utilised the steady state off gas analysis method. The mass balance calculation procedure used is the inert gas mole fraction method as outlined by Redmon *et al* (1989). This method gives operational values of OTE and Oc which can then be corrected to standard conditions for comparison to clean water results. Certain modifications were made to the test procedure to accommodate the testing of BAFs. The detailed test method has been reported elsewhere (Harris 1994).

Theoretical power requirements were calculated from air flowrate, supply pressure and compressor efficiency and combined with the Oc determinations to give oxygenation efficiency (Oe, KgO_2/Kwh) . These can be standardised to give SOe at conditions of zero dissolved oxygen and $20^{o}C$.

All results for KLa are based upon empty bed reactor volumes (EBV)

3 Results

3.1 Cleanwater Tests

The cleanwater tests showed that the SOTE increased at lower airflow rates and that the imposition of a counter current liquid velocity increased SOTE. The SOTE was highest at the lowest air velocity tested (5m/h) in all of the downflow conditions ranging from 17.2% at 1m/h liquid velocity to 12.6% at 3m/h liquid velocity. In the absence of a downflow liquid velocity the static column SOTE peaked at the medium air velocity tested. (10m/h). SOTE for a given air velocity was highest at a downflow liquid velocity of lm/h for the lowest and highest air velocities (5&15m/h) and at 2m/h for the mid range air velocity of 10m/h and the static tests.

The increase compared with a static bed (zero liquid velocity) was most significant at 5m/h air velocity.

The detergent added tests were performed over the full range of air velocities and at a downflow liquid velocity of lm/h. They gave a significant improvement to SOTE and KLa resulting in a simulated alpha factor of 1.1 at 5m/h and 1.3 at 10 and 15m/h based on SOTE. The OTE trends can be seen in figure 1.

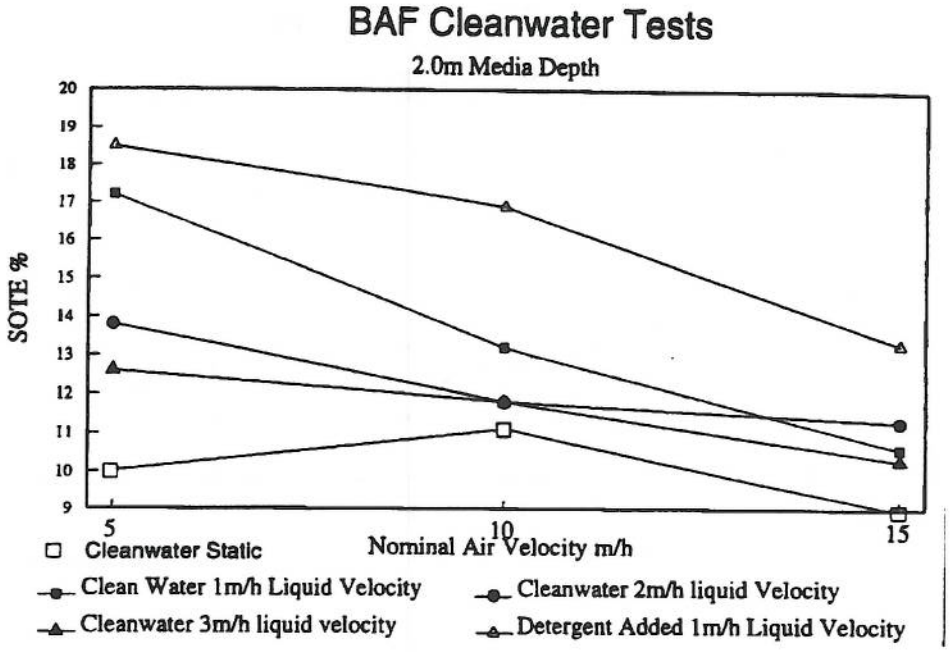

Figure 1

3.2. Operational Tests.

Operational tests were performed under steady state conditions over a slightly extended range of air flows compared with the cleanwater tests and at organic loadings of 1.0,1.7 and 2.3 KgBOD/m^3/d. An alternative aerator comprising 9 fine bubble diffusers was also tested.

SOTE was calculated for cleanwater comparison. The trends were similar with SOTE being inversely proportional to air velocity. The trends with organic loading showed SOTE increasing with organic loading. SOTE for all loads is shown in figure 2 with cleanwater values for reference.

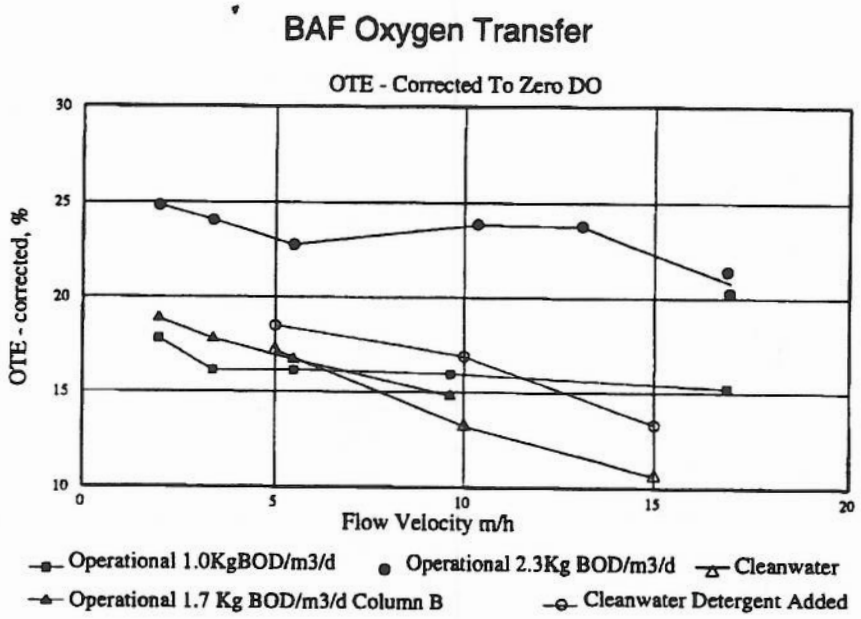

Figure 2

The increase in SOTE and apparent KLa (KLa_{app}) with organic loading gave SOTE values 1.3-2.2 times greater than cleanwater values. At the lowest organic load the increases were smaller at 1.1 to 1.7 times greater.

The term apparent KLa is used as increases in the operational oxygen transfer over clean water conditions are likely to be due to factors other than the bulk liquid phase mass transfer coefficient - Kla. The coefficient may not have increased operationally but the larger value of apparent KLa comprises true.

KLa plus an additional operational coefficient.

Compared with the optimum cleanwater values (1m/h downflow liquid velocity) the (α factors are 1.1 - 1. 2 at the low organic load, 1.1 at the medium organic load and 1.3 - 1.6 at the high organic load.

Table 2 shows the range of α values based on SOTE at the 3 organic loadings compared with the range of cleanwater values.

Table 2 SOTE based α Factors. Operational SOTE vs Cleanwater Range

Nominal Air Velocity m/h	1.0 kgBOD/m^3/d Organic Load	1.7 kgBOD/m^3/d Organic Load	2.3 kgBOD/m^3/d Organic Load
5	1.1 -1.7	1.1 -1.8	1.3 - 2.2
10	1.2 -1.4	1.1 -1.4	1.4 -1.7
15	1.2 -1.5	1.1 -1.3	1.6 -1.9

Operational OTE is more strongly influenced by air velocity than is the SOTE. Figure 3 shows the trends of OTE versus air velocity at the three organic loadings. Below 7m/h OTE increased markedly accompanied by a fall in the average DO concentration in the column. Above 10m/h air velocity OTE was largely unaffected by further increases in air rate.

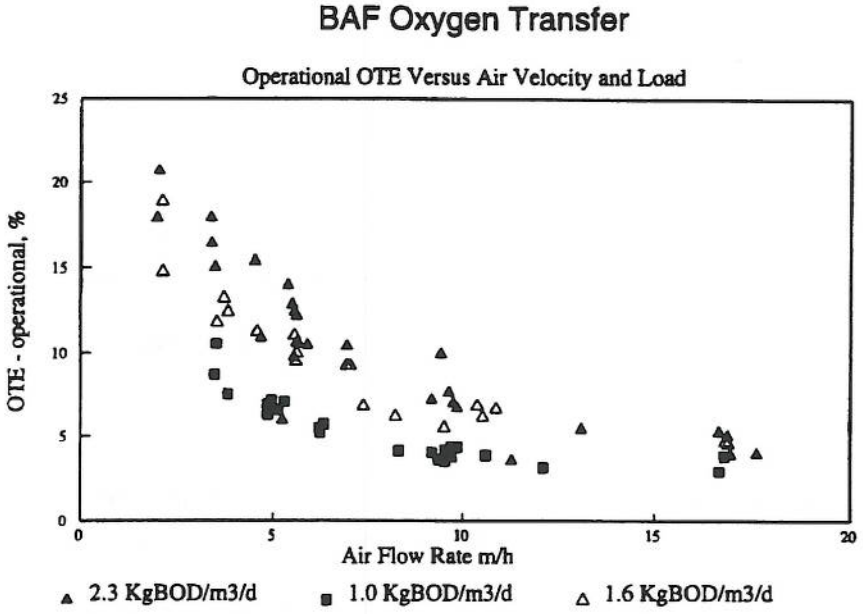

Figure 3

The diffusers showed no improvement in OTE operationally except at the very lowest air velocities of 2-3m/h. The diffusers consistently held a lower average DO concentration in the column and therefore SOTE values were consistently below those obtained with the sparge grid.

Effluent ammonia values increased at each of the loadings when the air rate was reduced below 5m/h. The increase in effluent ammonia concentrations as air flow was further reduced was most marked at the highest organic load. Figure 4 shows the effluent ammonia trends versus air rate.

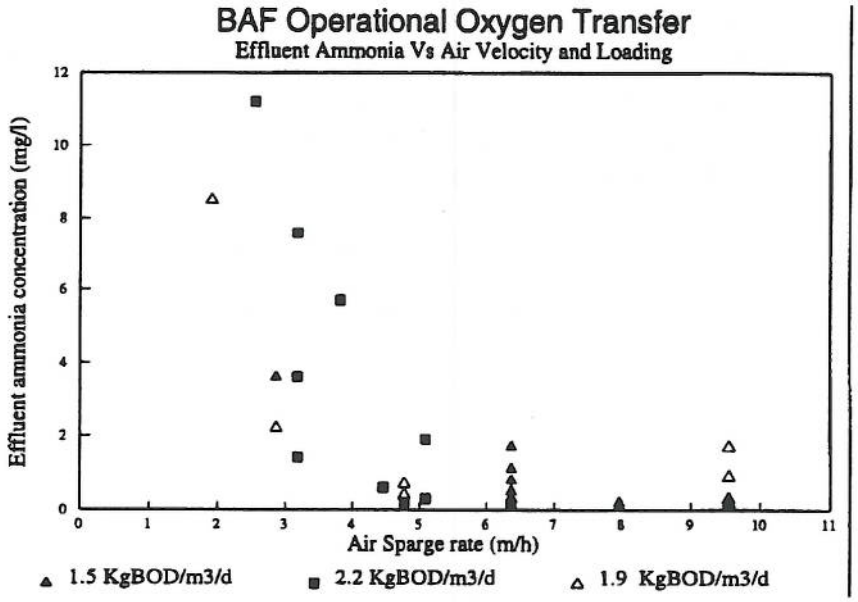

Figure 4

Oxygenation efficiency (Oe) trends are directly proportional to those found for OTE as the aeration device and liquid depth is constant throughout.

At low organic loadings Oe is around $1.0KgO_2/Kwh$ above air velocities of 10m/h. As the OTE increases at lower air rates the Oe improves to 2.0 at 5m/h and 2.4 at 3m/h. Due to the high DO concentrations maintained in the column SOe values are significantly higher at 4-5.5.

At medium organic loading the Oe is increased to around 2. 0 at 10m/h and 3.0 at 5m/h. SOe is similar to the low loading values.

At high organic loading the Oe is further increased especially at the lower air rates. Oe is 2.0-3.0 at 10m/h air velocity and 3.0 to 5.0 at 5m/h air velocity. This further increases to 5.5 at very low air rates (2-3m/h) . The corresponding SOe values are higher than at the lower loads though there is a significant amount of scatter on the data. Figures 5 and 6 show the trends in Oe and SOe for the high and low organic loads.

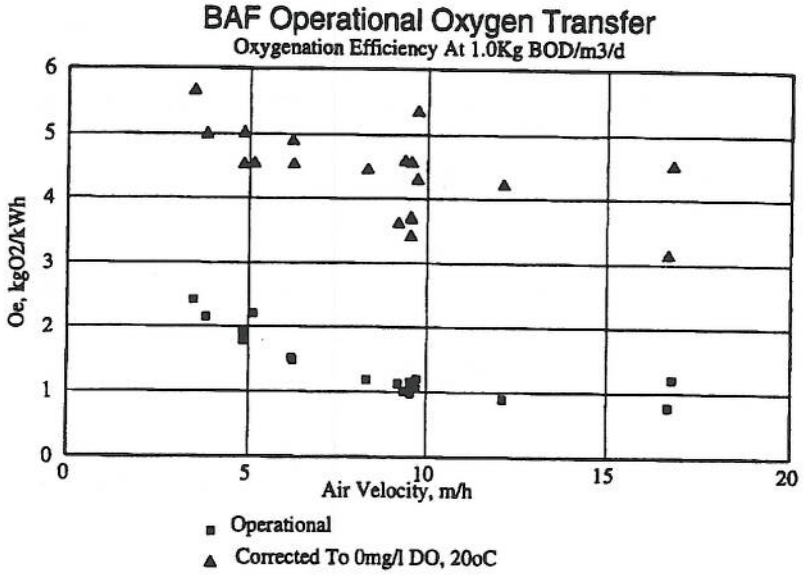

Figure 5

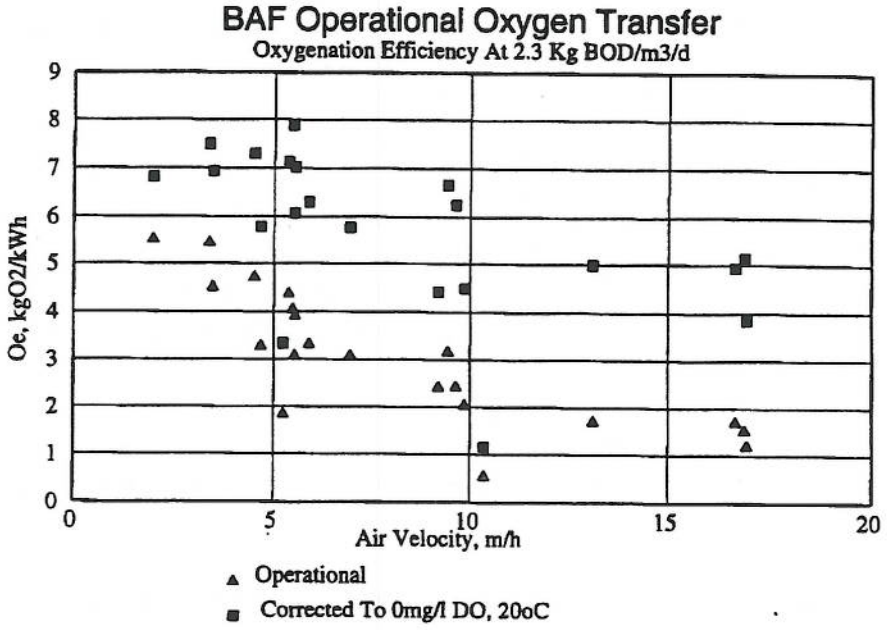

Figure 6

4 Discussion

The cleanwater tests performed on the BAF units have provided a useful benchmark for assessing the operational oxygen transfer characteristics and mechanisms of BAFs. The clean water tests show the degree of oxygen transfer due to purely physical mechanisms in the absence of biomass.

The influence of a small counter current liquid velocity is large at low air flow rates and decreases as the air rate is increased. The countercurrent liquid velocity will reduce the rise rate of air bubbles in the BAF and may increase the resistance to air flow by blocking some of the routes otherwise available to air flow or by reducing their effective size.

On operational BAFs a phenomena known as air blinding can occur when high air rates preclude the downward passage of water. The same process may work in reverse under normal operating conditions ie the downward liquid flow will impede the upward flow of air.

The fact that further increases in hydraulic load do not increase oxygen transfer may be due to a critical countercurrent air/water velocity being exceeded when the air starts find preferential routes up through the bed. The channelling of air through preferential paths is probably responsible for the decrease in SOTE at higher airflows under any conditions of hydraulic load.

Practically, the clean water tests are difficult to perform. Several times the stoichemetric amount of sodium sulphite is required to maintain zero DO in the test water to account for the large amounts of oxygen transferred into the test liquid as it is pumped into the BAF from the backwash grid.

DO probes were buried in the BAF at six locations near the centre of the column. As the tests progressed it was found that several of these probes intermittently gave very low KLa values and were very slow to respond to deoxygenation and re-aeration. This indicated that air flow up the columns was not even and that by moving an individual probe a few centimetres its output characteristics would change.

This supports the belief that conditions in the media bed are not only plug flow in a vertical plane but that local conditions could significantly vary in a lateral plane.

The addition of 5mg/1 anionic detergent (manoxol OT) to the test water improved SOTE significantly with the simulated α factor increasing with air flow rate. This phenomena must be purely physical though not related to bubble size (which is controlled by media voidage). The mechanism may be due to wetting phenomena outweighing any physical transfer hindrance caused by the surfactant film at the gas/water interface. It is of interest that the detergent added clean water tests gave similar SOTE values to the operational medium and low organic loads.

The operational improvement of SOTE over clean water conditions has been documented previously (Reiber and Stensel 1985, Lee and Stensel 1986, Canzioni 1989) and has been attributed to interfacial oxygen transfer(direct from gas phase to biofilm) , operating in parallel with the conventional bulk liquid transfer mechanism. The increases in SOTE found in the above studies are 2-2.5 which are higher than the increases found in this study.

At the organic loading rates used in this study liquid velocities ranged from 0.4 -0.9 m/h. SOTE based α on optimum cleanwater conditions (1m/h liquid velocity) are only 1.1 - 1. 2 at low loadings, 1.1 at medium loadings and 1.3 - 1.6 at high loadings. SOTE based α on static cleanwater conditions ranged from 1.4 - 1.7 at low loadings, 1.3 - 1.8 at medium loadings and 1.3 - 2.2 at high loadings. The optimisation of cleanwater SOTE has given rise to a large variation in SOTE based a values. This and the low organic loadings employed may explain the lower α values found in this study.

There is however a definite trend towards improved SOTE with increasing organic loading which is attributed to interfacial transfer.

The fact that a part of the overall oxygen transfer process is not via the bulk liquid makes correction of OTE values to SOTE and Oe to SOe difficult. After correction the data shows more scatter than the clear trends of OTE and Oe versus airflow and loading.

This mechanism also makes bulk liquid DO measurements inappropriate for DO and process control as bulk liquid DO may not be the controlling factor in overall oxygen transfer.

Ammonia breakthrough in the effluent at low air rates occurred concurrently with average BAF bulk liquid DO concentrations of 3-5mg/1. These DO concentrations are well above rate limiting concentrations for nitrification in suspended growth systems.

Due to the potential errors caused by correcting OTE and Oe to zero DO, together with the observation that high bulk liquid DO concentrations are required for complete nitrification the operational value. % of OTE and Oe are the most important observations.

Whether due to physical or biological phenomena OTE and therefore Oe can be seen to increase markedly at low air rates (below 7m/h) . If the BAF can operate at air rates in the 4-7m/h range then power costs can be halved compared to operating in the 10-15m/h range. Practically this range of air flows may only be available for lightly loaded BAFs operating in combined carbon/ammonia oxidation mode or non nitrifying units both of which need to have a media depth of 2.Om or less. Many BAF installations have media depths of 3.5 - 4.Om to reduce plant footprint. These potential energy savings will not be available on such deep beds.

The oxygen transfer characteristics found here are also only likely to be applicable to BAFs operating with a similar media type as the oxygen transfer characteristics of pelletised media or that with larger voids may be different.

If operation at lower air rates is possible, dependant upon loading Oe can be improved from 1.0 - 2.0 to 3.0 - 5.0 KgO_2/Kwh.

Comparing this data to a small number of tests performed on full scale BAF units suggests that at full scale air rates of 4-7m/h are insufficient to maintain complete nitrification. If this is the case then it may point towards the optimisation of air distribution on full scale installations. Good air distribution is easy to attain in 0.5m diameter columns but may be less so on full scale units. Small increases in OTE will produce large energy savings on an inefficient aeration system. If OTE can be increased from 3% to 5% then process air requirements can be reduced by 40%

5 Conclusions

Aeration rate and hydraulic load are both important parameters in determining oxygen transfer efficiency in cleanwater conditions.

In operation, further improvements to oxygen transfer efficiency are observed increasing with increasing organic loading. This is further evidence to support the theory of enhanced transfer due to direct oxygen transfer into the biomass.

The operational increases are smaller than have been noted elsewhere. This may be due to the relatively low organic loads applied to the BAFs and also to the optimisation of clean water transfer efficiency.

Where process oxygen demands are relatively low significant energy savings may be realised by operating at air velocities below 7m/h. These benefits are not available at higher loadings or at media depths greater than 2m.

6 Acknowledgements

Thanks are due to Samuel Harris and Alex Lessar who undertook the testing in partial fulfilment of their MSc at Cranfield University.

7 References

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