# Where did the bubbles go? How to reduce the energy requirements for municipal wastewater treatment.

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**Abstract**
Bubble aeration has been the cornerstone of aerobic biological wastewater treatment for the past 100 years and while it is effective, it is also inherently inefficient with maximum oxygen transfer efficiencies of 40%. Bubbleless-aeration technology has evolved to the point where it is now ready to effectively and efficiently meet the requirements of a wastewater treatment plant. To demonstrate this, a 1000 litre OxyMem Membrane Aerated Biofilm Reactor (MABR), was installed at a municipal wastewater treatment plant, downstream of the primary treatment tanks. The reactor was operated in parallel to the full scale Activated Sludge (AS) plant. The reactor was in operation for 270 days before being upgraded to a larger system. After the initial start-up period, the MABR achieved COD and ammonia removal rates of greater than 75% and 80% respectively with a remarkably low aeration energy requirement. Aeration energy was estimated at 8kg O2/kWhr for the MABR compared to 2.2kg O2/kWhr for the fine bubble diffusers installed in the AS. This is the first time a MABR of this scale has been successfully deployed at a wastewater treatment plant .

**Keywords**
Biofilm; Membrane, Aeration

## INTRODUCTION

After being identified as potential wastewater treatment technology over 30 years ago, the Membrane Aerated Biofilm Reactor (MABR) showed great potential as a viable, low -nergy alternative technology for the biological treatment of wastewaters. By decoupling the gas supply from the buoyancy forces exerted on a bubble, the gas residence time can be extended and therefore the supplied oxygen is provided with more time to diffuse into the reactor. This dramatically increases the Oxygen Transfer Efficiency (OTE), with the possibility of achieving over 90% if so required. Economically another major advantage is the dramatic reduction in the energy required to supply the oxygen for the aerobic processes (Casey et al, 2008). The oxygen containing gas supplied to the internal lumen of the membrane does not have to overcome any hydrostatic head and hence does not need to be compressed, therefore along with the reduced airflow rate due to the improved OTE the reduced gas pressure results in the potential of transferring over 8kgO2/kWh in comparison with 2.2 kgO2/kWh in fine bubble diffusers. (US EPA, 1989). Along with the significant energy savings the MABR has a unique counter diffusion profile of oxygen and pollutants into the biofilm. This unique process advantage protects the aerobically growing biofilm from shock loads and detachment while also allowing for aerobic bacterial processes in an anoxic tank. The simultaneous removal of COD and Nitrogen in a continuously operating tank without out air cycling is unique to the MABR, this potential has been demonstrated numerous times at lab and small pilot scale. (Downing, 2008; Stricker, 2009), while the potential high rates of reaction have also been reported, (Brindle, 1998). The MABR concept has been trialled treating various different wastewaters and at various small pilot scales (Syron, 2007) but has yet to be installed at a full scale as a standalone treatment system.

To continue the MABR development and begin to tackle the scale up challenges a 1000l MABR was built by Oxymem and installed at Severn Trent’s Minworth Sewage Treatment Works. This reactor treated the municipal wastewater post primary settling tanks.

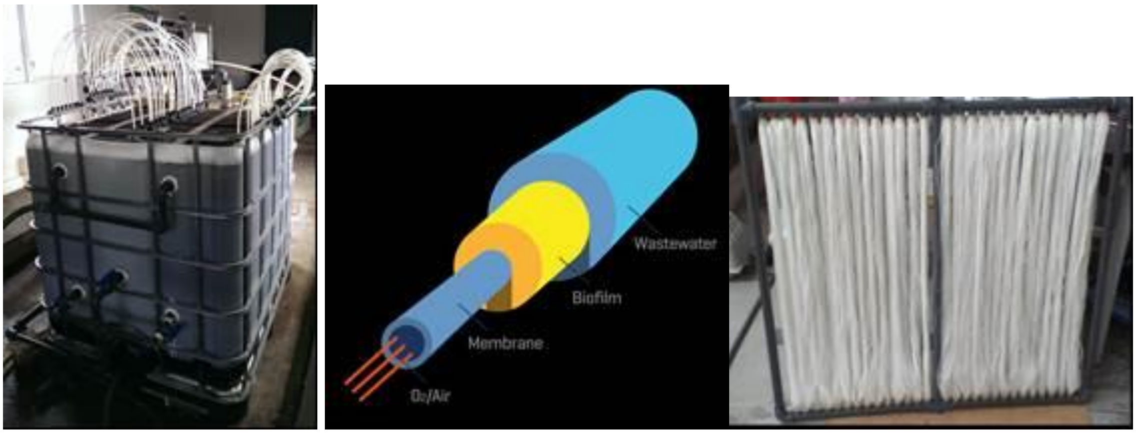


**Figure 1.** A) Photo of the OxyMem reactor on site in Minworth, UK. B) Schematic of biofilm growing on the outside of a hollow fibre aeration membrane, C) OxyMem Membrane cassette.

## Minworth Sewage Treatment

The Minworth Sewage Treatment plant treats the sewage of 1.75 million PE. The Activated Sludge Treatment process at Minworth consists of 7 AS plants each consisting of 4 single pass lanes. The average flow through the Activated Sludge process is over 500,000m3/day, aeration is supplied by 16 blowers in total with a combined air flowrate of over 6 million Nm3/day. The AS plant has recently been upgraded to an enhanced biological phosphorus removal process (University of Capetown configuration) to meet a new effluent phosphorus standard of 1 mg/l. Results from before the upgrade show that the plant consistently meets its target limits with, typical discharge concentrations shown in Table1.

| **AVERAGE Concentrations** | Settled sewage | Final Effluent | |
|---|---|---|---|
| **COD** | 130.3 | 26.0 | mg/l |
| **Nitrate(N)** | 1.9 | 17.9 | mg/l |
| **Nitrite(N)** | 0.3 | 0.1 | mg/l |
| **Ammonia(N)** | 26.9 | 0.2 | mg/l |
| **TN** | 37.1 | 20.9 | mg/l |

Table 1: Average Inlet and Effluent concentrations for Minworth Activated Sludge treatment plant.

## MATERIALS AND METHODS

The 1000litre reactor was built by OxyMem Ltd,in collaboration with University College Dublin, using a non-porous diffusive membrane made of PDMS (Silicone), designed to be both the biofilm carrier and oxygen delivery medium. The PDMS was produced as a hollow fibre membrane with and internal diameter of 300μm and an external diameter of 500 μm. Each fibre was 0.8m in length and they were arranged into bunches of 400. In total the reactor had a membrane specific surface area of $238m^2/m^3$. The reactor was supplied with air from a low pressure blower (Nitto Kokhi) between 100mBarg and 200mBarg. Air pressure and air flow rate were measured at the inlet and outlet of the membrane aeration unit and the oxygen concentration of the outlet gas from the membrane unit was also measured. From these values the mass of oxygen transferred to the unit was calculated. Grab samples of the feed and the effluent from the OxyMem reactor were taken periodically and analysed for COD, $NH_4$, TSS, N-$NO_3$ and N-$NO_2$.

Biofilm control was carried out through an intensive coarse bubble air scour process which varied from 5-15mins and from 2 times a day to every 2 days in frequency.

**Mixing**

Initially mixing was provided by a recirculation pump with a flow rate of 6000l/hr creating a tank turnover time of 10minutes. This regime provided good liquid mixing but due to the drag of the membranes on the liquid flow it did not maintain all the solid particles in suspension. On Day 226 the recirculation pump (550 W) was removed for the system and was replaced with two low energy submersible mixers (2x5W). These mixers provided a continuous liquid movement in the tank while at the same time giving a low TSS concentration in the effluent, TSS in the effluent reduced to less than 30mg/l.

## RESULTS

The 1000Litre OxyMem reactor ran for a total of 9 months from the summer of 2013.The flow rate was gradually increased to a maximum of 120l/hr giving a HRT of 8.3 hours (Day 177). The flow rate was reduced over the Christmas period and subsequently increased to 90l/min. Removal rates of 2g dCOD/$m^2$ day and 0.3g N-NH4/ $m^2$ day were achieved.

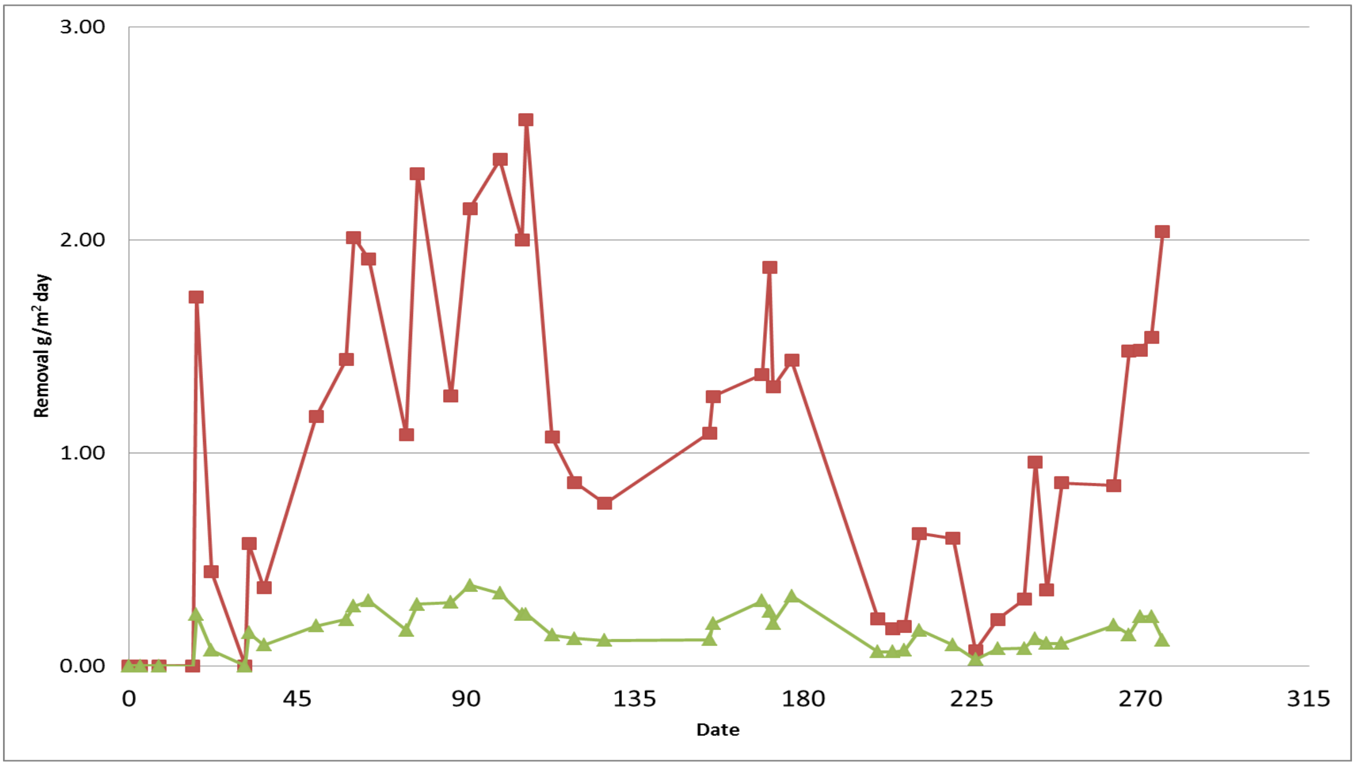


**Figure 2** Areal based removal rate for -■- dissolved COD and -▲- N-NH4 over the course of the reactor Start-up.

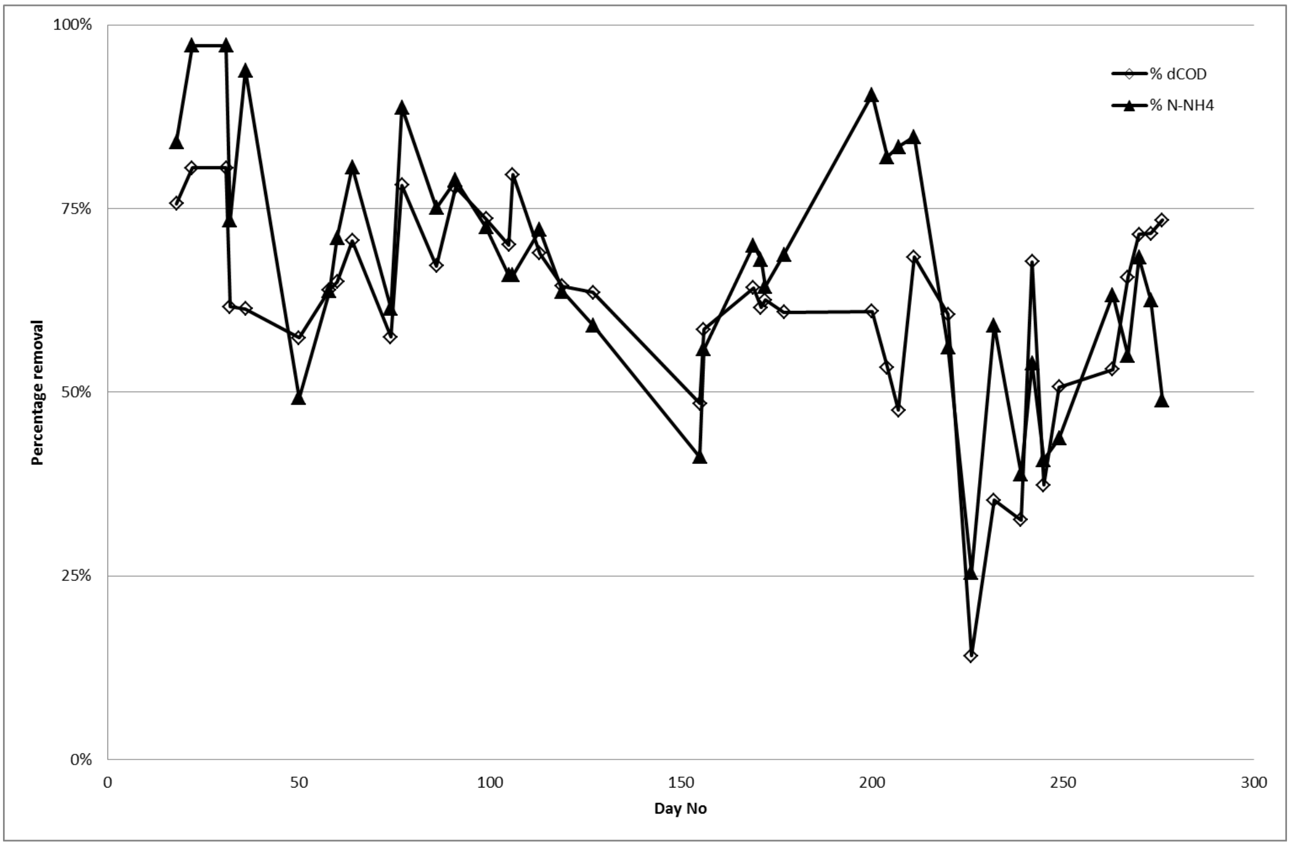


**Figure 3** Removal efficiencies of dCOD and N-NH4 over the course of the OxyMem trial.

## Sludge production

Sludge production of 0.1gTSS/gCOD have previously been reported for the MABR (Stricker et al, 2009). Unfortunately due to the rapid settling which occurred in the Oxymem reactor and the lack of provision for sludge discharge from the bottom, it was not possible to get an accurate measurement of sludge production during this trial. During the operating period where mixing was carried out via the recirculation pump TSS values varied between 50-100mg/l and an accumulation of biomass on the bottom of the flat tank was observed. To maintain some control on the biomass accumulation, an auto drain valve was added to the reactor and this valve was opened during the biofilm control (air scour) event when the reactor and the solids were completely mixed. When the mixing regime was changed effluent TSS values decreased and were consistently below 30mg/l. This suggests that secondary clarification following an OxyMem MABR is not required.

## Simultaneous Nitrification-Denitrification

Due to the unique oxygen profile in the membrane attached biofilm, the bulk liquid remained anoxic through-out the operation of the reactor. This was verified with dissolved oxygen measurements. The anoxic outer regions of the biofilm resulted in almost complete de-nitrification of the oxidised ammonia. During periods of low loading rate the dissolved oxygen concentration in the bulk liquid rose and denitrification ceased. During these periods the ammonia concentration in the effluent reduced dramatically to less than 2mg/l .

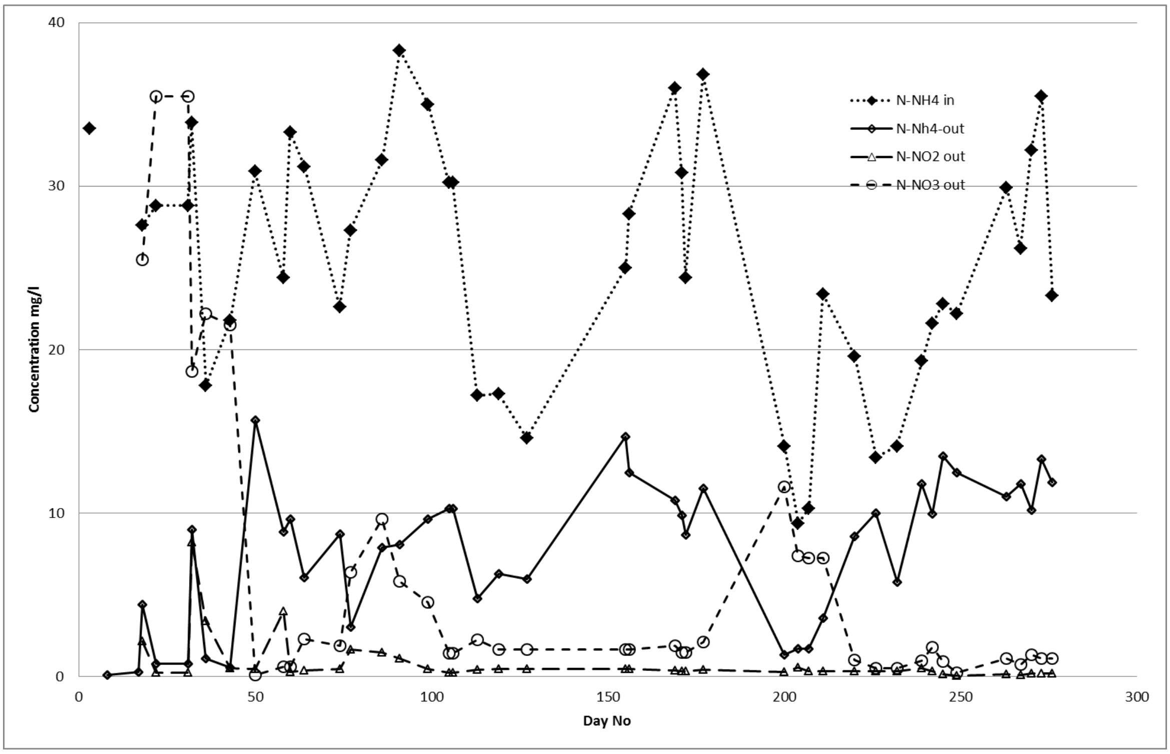


**Figure 4** Concentration of ammonia in the effluent and ammonia, nitrate and nitrie in the effluent over the course of the OxyMem trial.

## Energy Requirements,

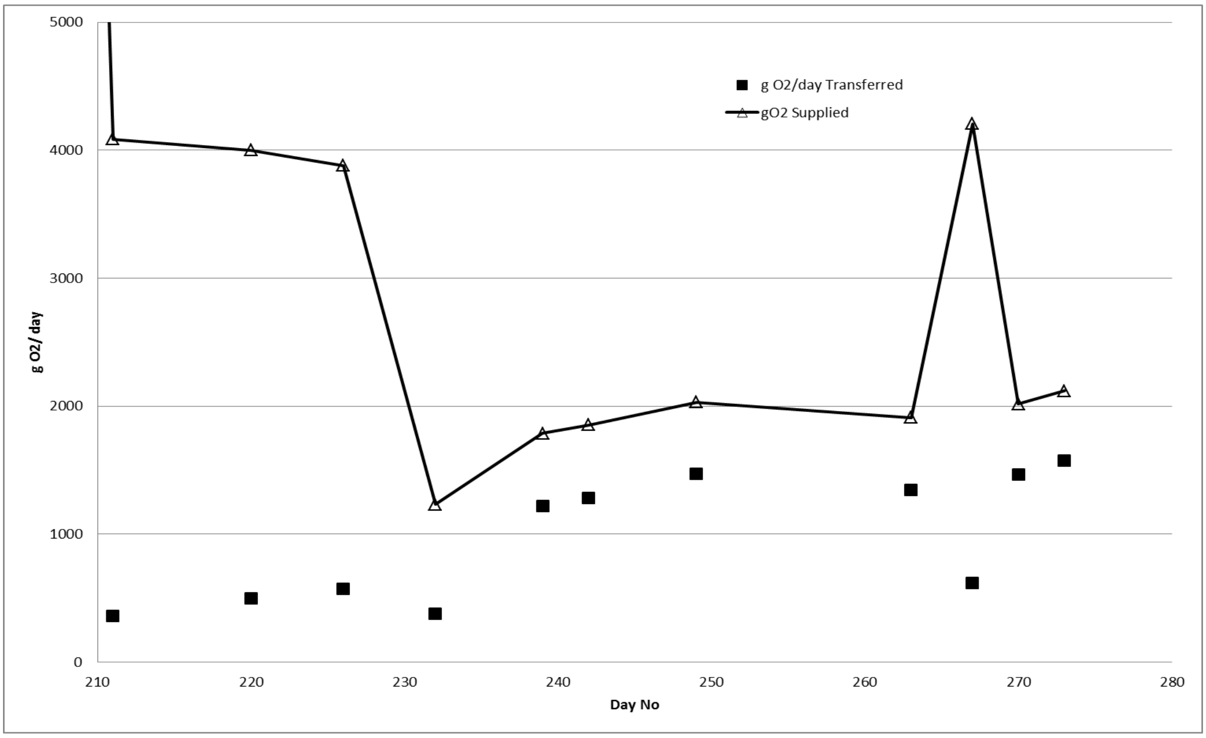


**Figure 5** Plot of the mass of oxygen supplied and the mass of oxygen transferred to the OxyMem reactor.

Initial operational conditions were chosen to maximise the oxygen available for the system and maximise the potential rate of reaction. This was achieved through the provision of an excess of air and intensive mixing. When the air flowrate was reduced to an appropriate range OTE values of over 50% were achieved. The energy required to supply the air from the low pressure blower was 0.6W per L/min. giving an energy requirement of 30W/kg$O_2$ supplied in comparison with 97 W/kg$O_2$ supplied for the existing blowers installed on site.

**Conclusions**

A successful demonstration of an OxyMem MABR was carried out for 9 months in a Municipal Wastewater Treatment plant treating primary effluent. High oxygen transfer efficiencies of over 50% were achieved while at the same time providing effective treatment. As was highlighted in previous studies of MABRs, biofilm control proved to be critical to the continuing stable performance of the MABR. The OxyMem MABR reactor has proven successful at 1000 litres to date and is now being tested on the same site as a two stage MABR of with a total reactor volume of 2.4$m^3$ . Further data needs to be collected to determine the sludge production in the OxyMem unit and further characterise the minimum mixing requirement to achieve effective performance.

Overall the onsite demonstration of the OxyMem unit resulted in a 70% reduction in aeration energy when compared with the existing bubble-based aeration system.

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