Feedback from the Porlock MBR Plant in its 10th Year of Operation:- An Analysis of the Flux, Effluent Quality and Membrane Lifetime Data to date

Authors: Steve Churchouse*, Silas Warren & Mark Floyd

Contents

Steve Churchouse,
SciEng Consultancy Services Bristol BS40 5NN UK,
steve.churchouse@btinternet.com

Silas Warren & Mark Floyd
Wessex Water Services Ltd, Claverton Down, Bath BA2 7WW, UK
Silas.warren@wessexwater.co.uk

Note on the authors,

At the time of installation in 97/98 Dr Churchouse was the commissioning scientist and has acted as a technical adviser on the plant over the period to date. Mr Warren is Wessex Water Process and Commissioning Manager and Mr Floyd the senior technical operator responsible for the plant for much of the past 10 years.

1 Introduction

The submerged membrane bioreactor plant at Porlock in the South West of the UK is the oldest continuously operating full scale submerged MBR plant in Europe[1,2]. The plant is operated by Wessex Water and is now in its 10th year treating domestic sewage for a population of 3800 people. It is sited in a coastal location where disinfection is required and has a treatment capacity of 1907 m^3/d. The works has no primary treatment or grit removal and screening is to 3 mm prior to entering the 4 MBR treatment tanks. Each process tank contains 6 Kubota flat sheet submerged membrane units, giving a combined total of 3600 membrane panels in the plant (2880 m^2 of membrane). Flow through the membranes is by gravity with a maximum head of 1050 mm being available (~0.1 bar).

The plant is unmanned and employs a SCADA system with a PLC that controls plant operation and logs all key instruments and alarms. Key parameters are recorded to a site pc and sent via telemetry to Wessex Water's control rooms and then logged every 15 minutes in a data archive for the plant.

Figure 1: The Porlock MBR treatment plant

2 Methods

Data analysis is time-consuming and made complicated due to the number of extraneous variables and occasional gaps in the data. In addition, rarely are records kept of historical dates of previous operational problems to link with archived data.

Over the 10 years since installation, some minor changes have been made to pipework and instrument calibration that have to be accounted for in the analysis. In addition although the SCADA system records and monitors data every second, archived data is recorded only every 15 minutes. Unfortunately the instrument/physical lag can mean that there is an effective time discrepancy between corresponding data points recorded as the same time, particularly when set-points are changing. This necessitates filtering of the data to ensure scatter is reduced to reveal underlying trends.

Data from 1998, 2003, 2005 and 2007 has been analysed and attempts made to compare the membrane performance under similar conditions. Times when the membrane plant operation was subject to overriding non-membrane related factors have been avoided. These have included tidal seawater ingress, mechanical failures (screens, blowers), excessive MLSS etc. Membrane performance has been compared when aeration has been good, chemical cleans on-time and MLSS within range. This is to ensure we report here on membrane performance rather than extraneous factors.

3 Process Data

3.1 Effluent quality

Being a coastal site, Porlock does not have an ammoniacal nitrogen consent, however, the proximity to a bathing beach has led to a requirement for disinfection. Effluent quality data remains good (table 1) with the average reduction in faecal coliform levels exceeding 5.8 log over the entire period (figure 2). Average treated effluent faecal coliform levels show a show a slight increase from year 5, but this corresponds with a change in the sampling location to the outside final effluent chamber. This necessitates use of sampling poles and an increased risk of contamination and it is believed that this rather than any underlying change in the permeate quality is the likely cause.

In February 2007 SDI tests were carried out on permeate from the plant and an average SDI of 1.50 over 3 sample runs was obtained. This figure is well within the guidelines for use as a feed to a Reverse Osmosis system for re-use applications. This result is a good indicator of effluent quality and lifetime considering that 93.6% of the installed membranes are originals in their 10th year of operation.

Table 1: Porlock effluent quality data from 1998 to July 2007

Parameter	**Number of samples**	**Feed average**	**Permeate average**	**Typical detection limit**
BOD - mgO_2/l	360	226	< 5	6
COD - mgO_2/l	200	424	22	10
Faecal coliforms counts/100 ml	200	12800000	< 21	10
F+ Coliphage virus pfu / litre	80	1540000	< 26	10

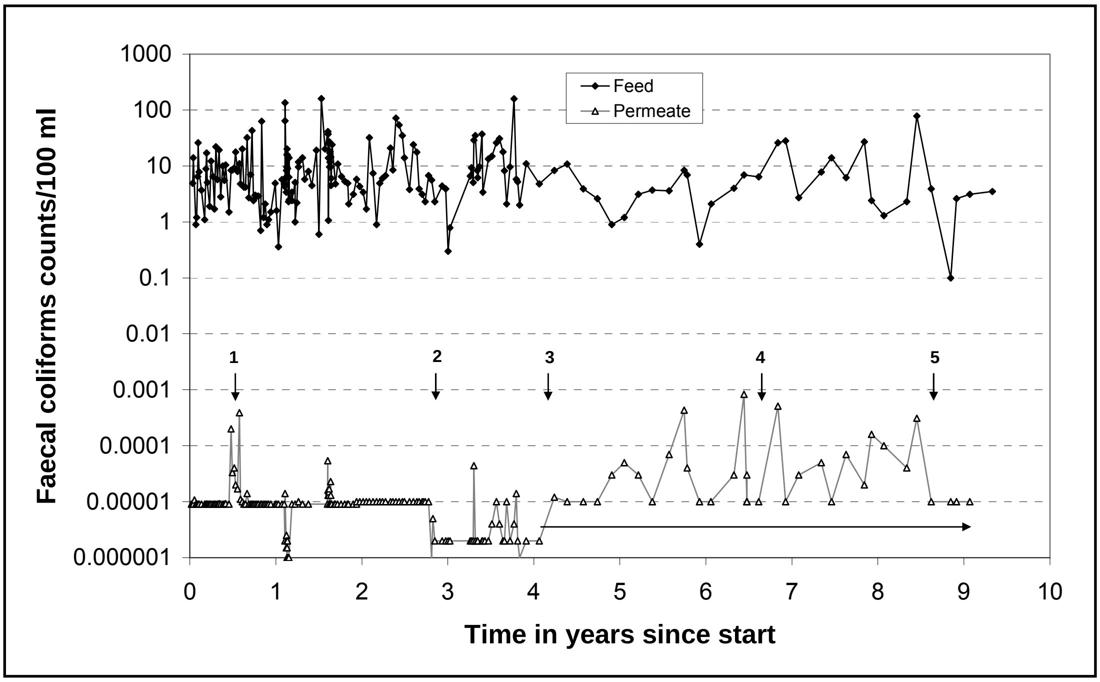

Figure 2: Porlock faecal coliform levels from 1998 to 2007. (1) was later identified as sampling contamination, (2) increased sensitivity sampling period, (3) reduction in sampling frequency to 8 weekly, with all samples from outside final effluent sampling chamber, (4) disconnected permeate tubes found (5) plant overhaul and membrane inspection. Average removal log 5.8.

3.2 Mixed Liquor Suspended Solids

MLSS figures have a long term plant average of ~17200 mg/l with a range of 8000-27000 mg/l. Individual tank values show greater range principally due to uneven distribution of sludge recycle. This has led to difficulties in consistently maintaining MLSS with the target range of 10-18000 mg/l. At times individual tank MLSS figures have exceeded 30000 mg/l. Despite the excessive range, the plant has proved very tolerant of the high MLSS, provided the aeration is maintained. However, if the plant had had an ammoniacal nitrogen consent, maintenance of dissolved oxygen would be more critical and would have required much more careful control of MLSS range.

Typical sludge ages are long and have ranged from 30-90 days, depending on season. F:M ratios are low and have generally ranged 0.02-0.07 kgBOD/kg MLVSS. As a consequence, sludge production figures are low and have been estimated in the range 0.35 – 0.50 kgds/kgBOD.

3.3 Flux rates and permeability over time

A comparison of flux data from 1998 to 2007 shows little detectable deterioration in permeability under comparable conditions and flow rates (figures 3 & 4). Typical membrane permeability's at or above average flow rates following a membrane chemical clean are in the range 350 – 500 l/m^2.hr.bar, declining to around 250 l/m^2.hr.bar when a chemical clean becomes necessary.

Average permeability is little changed, but <u>may</u> have declined slightly overall since 1998. However, if not an artefact, this decline represents an increase in TMP of ~ 100 mm (0.01 bar) over a 9.5 year period or 11 mm per year (0.001 bar). These figures are within the error range (drift) of the transducers over the period. As the plant has never had an acid clean, it is anticipated that much of any loss would be recovered following a more intensive clean.

3.4 Chemical cleaning

Chemical cleaning has a target frequency of twice per year as an in-situ, (in sludge) backwash of sodium hypochlorite. An average interval between cleans of 8 months was recorded over the first 9 years. However the target remains 6 months, with the 8 month figure principally being the result of delays in carrying out the chemical cleans for unrelated operational reasons. Chemical cleans take approximately 6 hrs per tank from taking off-line to re-start, allowing for a 3 hr soaking time. All cleans to year 10 were with sodium hypochlorite (0.5-0.7% w/v as free Cl_2). However chemical cleaning tests have indicated an acid clean would now be beneficial (the Porlock area is generally soft-water).

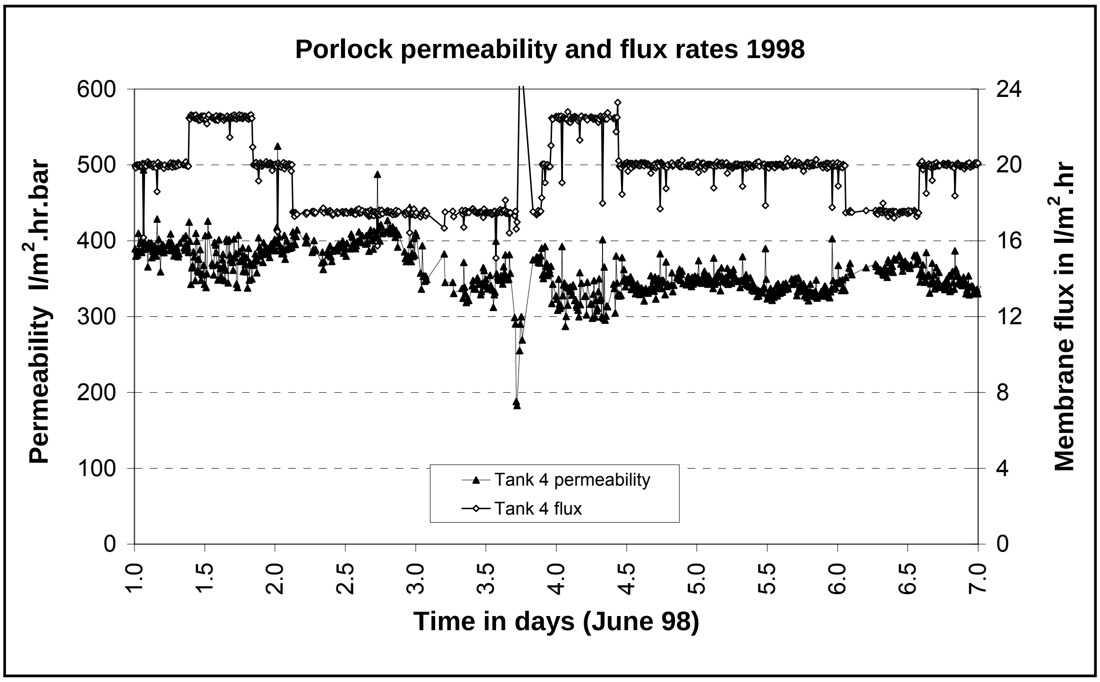

Figure 3: Example membrane permeability and flux data from 1998 after 4 months of operation.

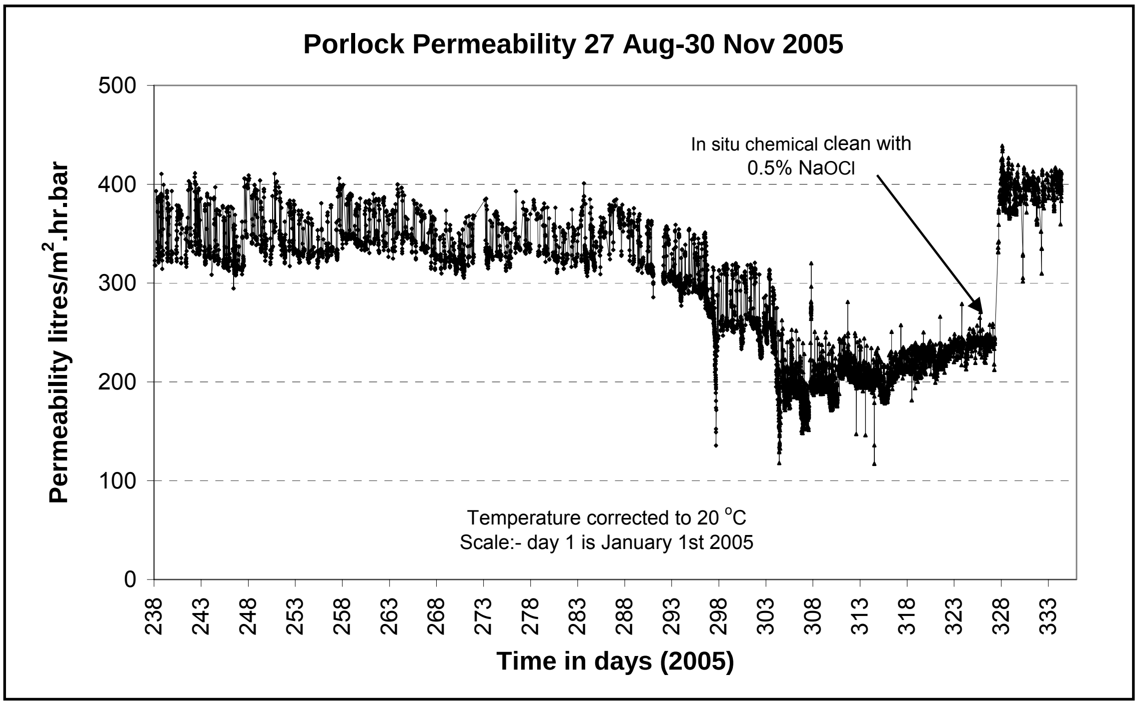

Figure 4: Example membrane permeability decline due to fouling and subsequent recovery following chemical cleaning (2005 data). The previous clean was 8 months earlier. The decline in permeability correlates with increased average daily flows (rainfall) and decreasing temperatures (from 22 to 11.8 ^{o}C).

A typical membrane permeability profile leading up to and post chemical cleaning is shown in figure 4. This shows a good immediate recovery in performance using sodium hypochlorite as the cleaning agent. The rate of permeability and flux decline is affected by many operational factors, but under good operating conditions in the absence of mechanical failures, the strongest correlations are with average flow rates and temperature. Average flow rates are indicative of the length of time the plant will be operating at higher TMP. Operation at as low a TMP as practicable is the key to maintaining long term performance.

4 Maintenance

To the date of this paper, membranes at Porlock have only been systematically removed once in year 9. In year 9 each tank was drained in turn to allow the tanks to be inspected, sludge/grit to be removed and membrane panels hosed clean and inspected.

4.1 Membrane lifetime

Microscopic examination of the membrane surface by SEM showed comparatively little deterioration in surface appearance in comparison to new membranes (figure 5). However, by eye examination of cleaned panels showed some evidence of macroscopic abrasion consistent with long term exposure to grit and screenings. Given the lack of grit removal, and the considerable depth of grit found within the tanks, membrane wear was remarkably slight. To reduce abrasion to the membrane unit housings steel brackets were installed underneath the GRP unit sides in year 9.

Following the first removal and overhaul of the membrane units in year 9, all membrane panels have been checked and damaged ones replaced. To date, a total of 230 panels have been replaced out of the 3600 installed, giving a failure rate of less than 6.4% after more than 9.5 years of operation. Of the

230 failed panels replaced, an inspection identified the following causes of failure:

- 55% holes from debris and grit
- 24% had internal sludge or contamination inside (probably smaller holes)
- 11% were damaged in handling
- 6 % had seals torn or split
- 4% were removed in error (cleanable staining)

The majority of the failures were thus from potentially preventable causes. Given the remarkably low failure rates, it is not anticipated that the plant will need any further overhaul until year 12 or later.

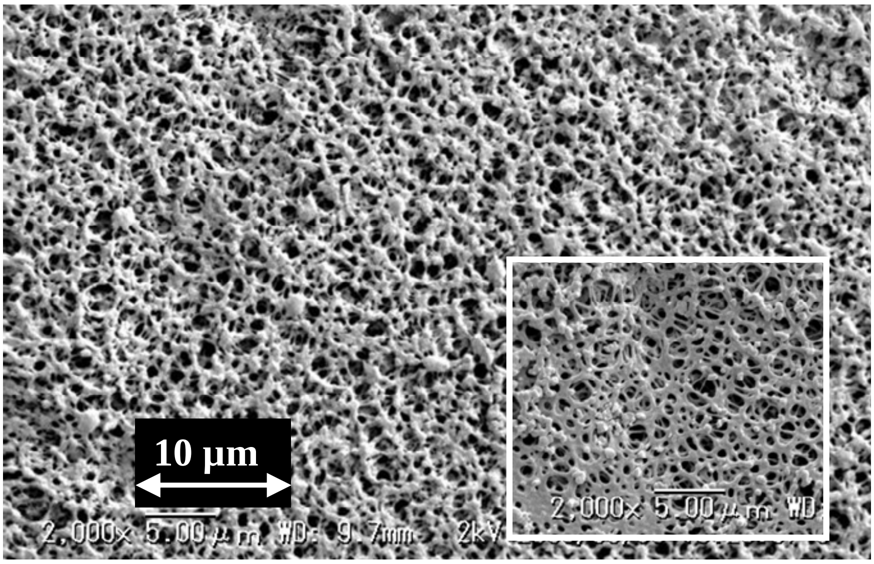

Figure 5: SEM photograph of membrane sheet material after 8 years of operation (inset: new membrane sheet at same magnification). Sample taken before chemical cleaning.

4.2 Operational problems

Overall the plant has performed well over the period with membranes proving exceptionally robust. Operational problems have mostly centred around M&E kit and have included screen and blower failures, grit damage, seawater entry and consequential foaming.

Other than the expected effect of high flows and low temperatures, several operational factors have been identified over the years that have caused flux rates to decline, these include:

- Screenings build up
- Excessively high or low MLSS (< 8000 mg/l or > 24000 mg/l
- Uneven aeration (insufficient diffuser flushing)
- Seawater ingress
- Blower failure
- Delays in chemical cleaning

The main maintenance tasks associated with the membranes on this site are:

- Manual diffuser water flushing to maintain aeration (weekly)
- A visual check on effluent quality and aeration pattern
- MLSS check every 1 – 2 weeks
- Chemical cleaning (target once per 6 months)
- Annual drain down of the tank for a visual check on membrane units and tanks, for signs of screenings, sludge caking or grit build-up.

Full membrane access and hosing off has only been carried out once in year 9. Problems with screen failures and screenings have led to the need to access tanks to remove gross screenings on two occasions.

The key to the longevity and reliability of the Porlock plant is probably

1. Good competent well trained operational staff
2. Maintaining uniform even aeration
3. Low maximum TMP due to hydraulically limited gravity flow

5 Conclusions

Plant effluent quality has been consistently good with little change in quality since start-up. Recent SDI measurements have indicated the permeate is suitable for direct reverse osmosis re-use applications

The plant has caused few operational problems with the majority of site visits being associated with conventional M&E items. All chemical cleans have been with sodium hypochlorite with an average interval of > 6 months. No acid cleans have been carried out to date, although these are planned and may improve membrane permeability further.

Flux data analysis indicates less than 100 mm head TMP increase for average flows over the period. Little discernable difference can be identified in underlying membrane flux performance between 1998 and 2007 once extraneous factors are excluded

Thus far membrane lifetime and robustness has been exceptional with 93.6% of the 3600 membranes being originals that have been in continuous use since February 1998. Of the membranes that have been replaced most were damaged from potentially preventable causes with the greatest number being damaged by debris and grit. Based upon the recent membrane inspection, it is anticipated that the next membrane overhaul will not be until year 12 or later.

References

1. 'Betriebserfehrungen und Planungen fur Membrananlangen mit dem Kubota System in Groβbritannien' 'Design and Operational Experiences of the Kubota Membrane Bioreactor in the U.K' presented at the Aachener Tagung, Siedlungswasserwirtschaft und Verfahrenstechnik, Germany 9th February 2000, associated paper published in 'Membrantechnik in der Wasseraufbereitung und Abwasserbehandlung - Technische Neuentwicklungen und Betriebserfahrungen im In- und Ausland', S.J. Churchouse B12, p1-16, Editors R. Rautenbach, T. Merlin, M. Dohmann, pub. IVT Aachen, ISBN 3-921955-24-6.

2. 'Long Term Operating Experience of Membrane Bioreactors', S. Churchouse and K. Brindle, 9th April 2003. Proceedings of the 4th International Meeting on Membrane Bioreactors for Wastewater Treatment, School of Water Sciences/ Water Biotreatment Club, Cranfield University.

Acronym	Definition
BOD	Biochemical oxygen demand (mgO_2/l)
COD	Chemical oxygen demand (mgO_2/l)
FFT	Full Flow to Treatment
GRP	Glass fibre reinforced plastic
F/M ratio	Food to biomass ratio (kg BOD_{in} / kg MLSS)
MBR	Membrane Bioreactor

Acronym	Definition
MLSS	Mixed liquor suspended solids (mg/l)
MLVSS	Mixed liquor volatile suspended solids (mg/l)
PLC	Programmable Logic Controller
SCADA	Supervisory Control And Data Acquisition
TMP	Transmembrane Pressure in mm water head or sometimes mb