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Scaled-up trials with a gravity-driven ultrafiltration unit in France

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Report within WP2.5: Compact Units for Decentralised Water Supply.

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Title
Scaled-up Trials with a gravity-driven ultrafiltration unit in France

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Abstract

The study aims at validating the point-of-use investigations on long-term gravity-driven ultrafiltration for a scaled-up system, which could produce drinking water for a community of 100-200 inhabitants using natural surface water. Eawag, KWB and Opalium conceived a membrane-based small-scale system (SSS) which can operate without crossflow, backflush, aeration or chemical cleaning. Equipped with a biosand filter as pretreatment, it is designed to be robust, energy-sufficient (gravity-driven) and run with restricted chemical intervention (only residual chlorine). The containerised unit (10’) requires to be fed with raw water at a 2 m-height (energy-equivalent to ~8Wh/m3). As sole operational requirement, the membrane reactor is simply to be drained (i.e. emptied) on daily to weekly basis to superficially remove the material retained by the membrane and accumulated in the module. Otherwise, the system, which is only driven by a 40 cm differential pressure head (i.e. 40 mbar), is totally self-determined and autonomous.

This report details the validation tests performed at Veolia Water Research Center in Annet-sur-Marne (France) from January to August 2009 : the gravity-driven UF compact unit showed promising results in regards to flux stabilization and flow capacity. Although early investigations take place in winter, an initial flux stabilization to 2.5 lmh is observed, which is below the reference results from the Eawag lab tests (i.e. 7-10 lmh, at 20 ± 2°C). However, the “scaled-up” system can benefit from a weekly drainage which seems to enhance the flux to 4-5 lmh, and thereby, the unit is to produce more than 4 m3/d, which is consistent with the design target of 5 m3/d. Moreover, the increase of the drainage frequency (to 3 times/week) along with warmer temperatures – leading to a better membrane permeability and biological activity - contribute to a further enhancement to 5-7 lmh. This is particularly relevant for South Africa, for which decentralized water supply is a burning issue and where the unit is to be further tested from November 2009.

The investigations also highlighted the critical performance of the biosand filter as pretreatment. More than the UF step – whose membrane integrity was confirmed with bacterial analyses, the pretreatment step needed more frequent (i.e. monthly) O&M requirements. Therefore, the pretreatment necessity will be further assessed in South Africa where high turbidity peaks could represent an extra challenge for the unit.

1 Introduction

As it may be neither economically nor technically viable to set up a reliable water network in developing countries or in rural areas, decentralised water supply stands as one of the greatest challenges in the forthcoming years. In these regards, membrane processes seem promising as they efficiently remove pathogens and offer a modular design that enables flexibility in terms of flow capacity reduction. With regards to the Millennium Development Goals, novel decentralised water systems should be robust, low-cost and as independent as possible from chemical and energy requirements and they are expected to enter the market within the next years [1].

Within the European project TECHNEAU (www.techneau.eu), a research group aims to develop a low-energy ultrafiltration (UF) unit for small drinking water applications. The Swiss Federal Institute of Aquatic Science and Technology - Eawag - performed lab work on long-term gravity-driven membrane filtration at a point-of-use (POU) scale. These investigations have enabled to design and build a scaled-up unit (dimensioned for 5 m^3/d) to be tested in real environments firstly in France and, in a second time, in South Africa.

This study presents the results of the tests, which are performed under controlled conditions in Annet-sur-Marne, France, on Marne river water in order to ensure the technological reliability of the compact unit. The focus is set on the process features of the unit (flow capacity) in function of periodicities of mechanical cleaning (drainage) and intermittent operation. These investigations will demonstrate if UF membrane systems can be operated without chemicals and energy, and stand as (cost)-effective options for decentralised water supply.

2 Materials and Methods

2.1 Description of the Unit

The small-scale system (SSS) is based on a gravity-driven UF process developed by Eawag, which enables operation without crossflow, backflush, aeration or chemical cleaning. Eawag, KWB and Opalium conceived a membrane-based SSS, which could treat up to 5 m^3/d of natural surface water – enough to satisfy drinking water needs for a community of 100-200 inhabitants. The unit only needs to be fed with raw water at a 2 m-height.
Compacted in a 10 feet-long maritime container, the unit is composed of (see **Erreur ! Source du renvoi introuvable.**):

- A biological sand filter, as pre-treatment, which enables the elimination of the turbidity and significantly improves the membrane permeability as the biological layer ("Schmutzdecke") on the sand surface consumes some of the raw water constituents and thereby contributes to the reduction of the organic fraction [2]. The sand filter is supposed to operate with a velocity of about 0.1m/h.

Table 1 - Characteristics of the biosand-filter

Filtration surface	2.25 m2
Filtration velocity	0.1 m/h
Sand size	0.3 mm
Sand + Gravel Thicknesses	600 +100 mm
Sand Volume	1.35 m3
Water table level above media	500 mm

- a flat-sheet UF module (area : 40m²), whose long-term operation can produce a stable flux (about 7 -10 lmh was observed at POU scale at lab temperature) over months, although no maintenance is performed [2]

Table 2 - Membrane Characteristics

Membrane Supplier	A3 Water Solutions GmbH
Nominal MWCO	150 kDa
Membrane material	PES
Gap between membrane sheets	8 mm

- a storage tank for residual chlorination to avoid recontamination of the treated water.

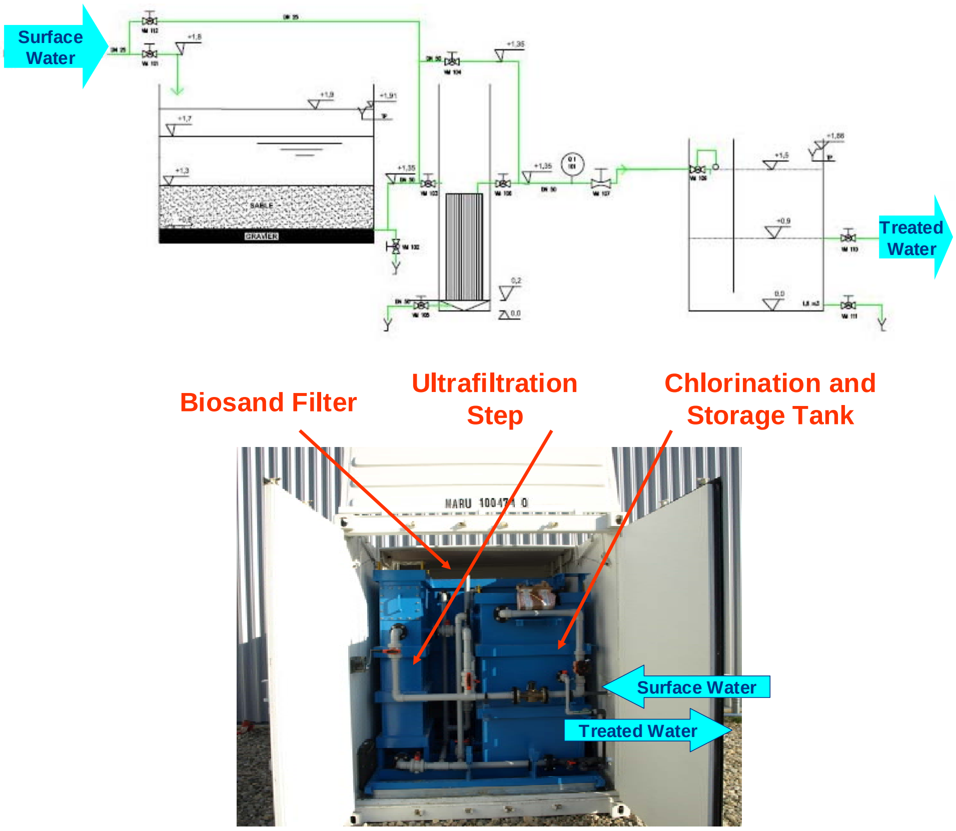


Figure 1 - Process Instrument Diagram and Photo of the compact unit

As sole operational requirement, the membrane reactor is simply drained (i.e. emptied) once to several times per week in order to remove the superficial material retained by the membrane and accumulated in the module. Moreover, the operating rate (number of hours/days) can also vary. Apart from those two control parameters, the system, which is only driven by max. 40 cm differential pressure head (i.e. 40 mbar), calculated as maximum difference between water level in membrane reactor and in permeate, is totally self-determined and autonomous.

2.2 Site for Trials

The unit is installed at the Anjou Recherche - Veolia Water Research - facilities in Annet-sur-Marne (France) and is fed with Marne river water. As presented in Table 3, the water quality of the Marne River is consistent with the ranges of water qualities on which Eawag made its lab tests (Chriesbach water and Chriesbach water mixed with wastewater [3]), in regards to organic content and turbidity. Therefore, the “scale-up” challenge is relevant and results with the Eawag POU investigations with a membrane area of 25 cm^2 could be compared.

Table 3 - Marne River and Chriesbach water qualities

	Marne River (at Annet-sur-Marne) Average (Min-Max)	Chriesbach water	Chriesbach water mixed with 15% wastewater
Organic Content (mg/L)	TOC : 2.7 (0.9 – 7.7)	DOC : 2 - 3	DOC : 10-15
Turbidity (NTU)	23 (3.3 – 258)	0.3 – 1 (peak 300)	30 -40

2.3 Action Plan

The report presents the trials performed in Annet-sur-Marne from November 2008 to August 2009. Initially, different operating conditions were to be tested in order to put progressively the unit under more constraints (i.e. increase the operating rate - 12, 18 and 24 hours/day – and decrease the drainage frequency of the membrane reactor).

The initial phase (from Day 1 to Day 21 – Nov 2008) consisted in by-passing the UF step in order to let the biological activity build in the slow biosand filter. After a 3 week-operation, the UF step was sequenced back in the process train. However, preliminary values of outlet flux were very low (1 – 2 lmh) and showed that the unit presented some unexpected head loss. Due to these hydraulic setbacks which required constructive modifications of the system and the hostile/freezing winter conditions, the unit could only be run properly from Mid-January 2009 (Day 62) and a reschedule of the phases with different operating conditions took place:

- Until the end of January 2009, the unit run 12h/d and no drainage was performed.
- During the two following weeks, the unit run continuously and no drainage was performed.
- From Mid-February, the unit has run continuously and a drainage was organized from once to 3 times / week

The chlorination step was not implemented in this study. As the unit is autonomous, the monitoring tasks simply include the general visual control of the unit, the recordings of the temperature and the volume flow rate (a mechanical flow meter is included in the unit) and the measurements of the oxygen content and the turbidity in the inlet, after the sand filter and after the UF step. From Mid-January to the beginning of March 2009, data were collected 2 to 3 times/day every weekday, but after the apparent stabilization of the system, the measurements took place only 3 days/week. Data for the raw water were directly read from on-line instrumentation of the water plant, whereas data for the waters sampled after the sand filter and after the UF step were measured by portable probes (for oxygen content and turbidity).

If not specified as corrected values, the flux/permeability results that are presented in the study are actual flux measurements at ambient temperature.

A correction at 20°C, based on the variation of the water viscosity [4] was also considered for complementary discussions.

From June 2009, complementary sampling for the raw water, filtered water and permeate were performed on a weekly basis in order to analyse the organic content (Absorbance UV at 254 nm, DOC) and the bacterial removal rates.

2.4 Commissioning and hydraulic issues

Some permeability tests with clean water were made in order to identify the causes of the initial head loss (Dec 2008). Indeed, the low flux (1-2 lmh) measured in the outlet may be explained by an insufficient pre-conditioning of the new membrane (possible need of a chemical wetting to enhance the membrane porosity) or a head loss due to the connectors and the piping of the unit. In a first step, it was decided to let the membrane filtration run continuously on longer periods (several hours), at the highest head pressure (1m in this case, as it is a gravity system) in order to ensure that the whole membrane surface was wet. As observed in Figure 2, the permeability (corrected at 20°C) did not evolve steadily although an initial increase from 80 to around 250 l/(m².h.bar) was observed in the first 20 operating hours.

Before suggesting any chemical wetting of the membrane, the next option was to release any air that would be stuck in the module (without the use of any pump). Therefore, a tube connected to the air was added on the permeate tube, in the membrane reactor (see Figure 2), in order to ensure that any air bubbles could be released on the permeate side. Moreover, the addition of this pipe removes a pinch on the flexible permeate tube which could have caused significant head loss as well. Once the tube was fixed, a corrected permeability of 300 – 350 l/(m².h.bar) was observed, which is consistent with tests made at lab scale with a membrane sample from the same manufacturer (A3 Water Solutions GmbH).

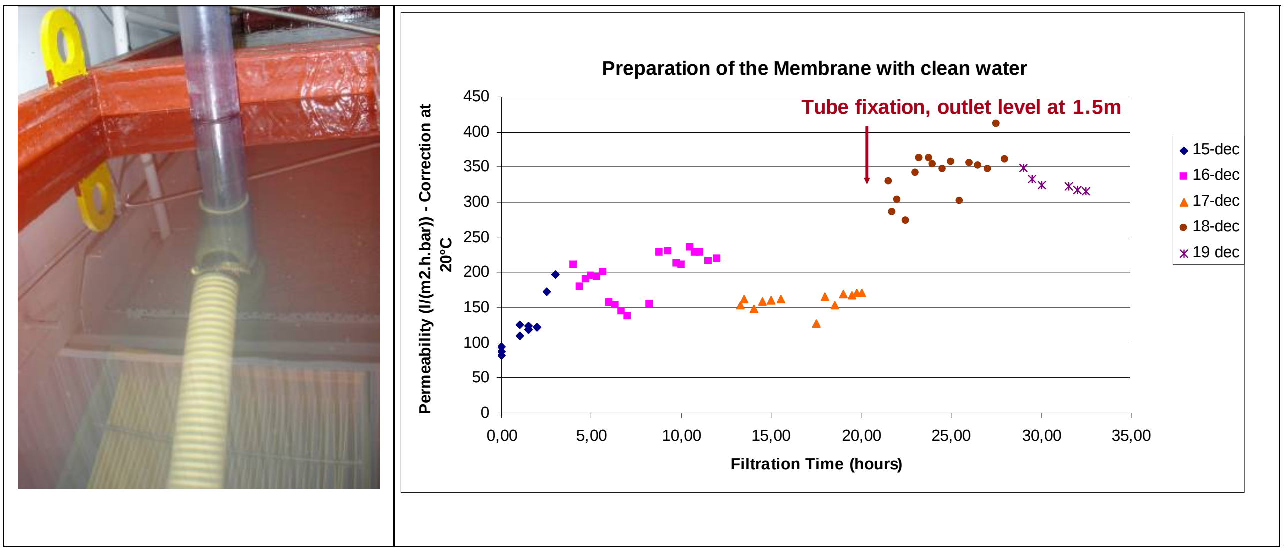


Figure 2 - Permeablity Tests with the membrane before and after the addition of an open-air tube on the permeate pipe

3 Results and Discussion

The main objective of the study is to validate the results observed at lab scale for gravity-driven ultrafiltration point-of-use systems for a containerised membrane-based unit, which is designed to produce around $5m^3/d$ of drinking water. The investigations were mainly focusing on the flow capacity of the system and on the optimisation of its operating conditions in order to match that target.

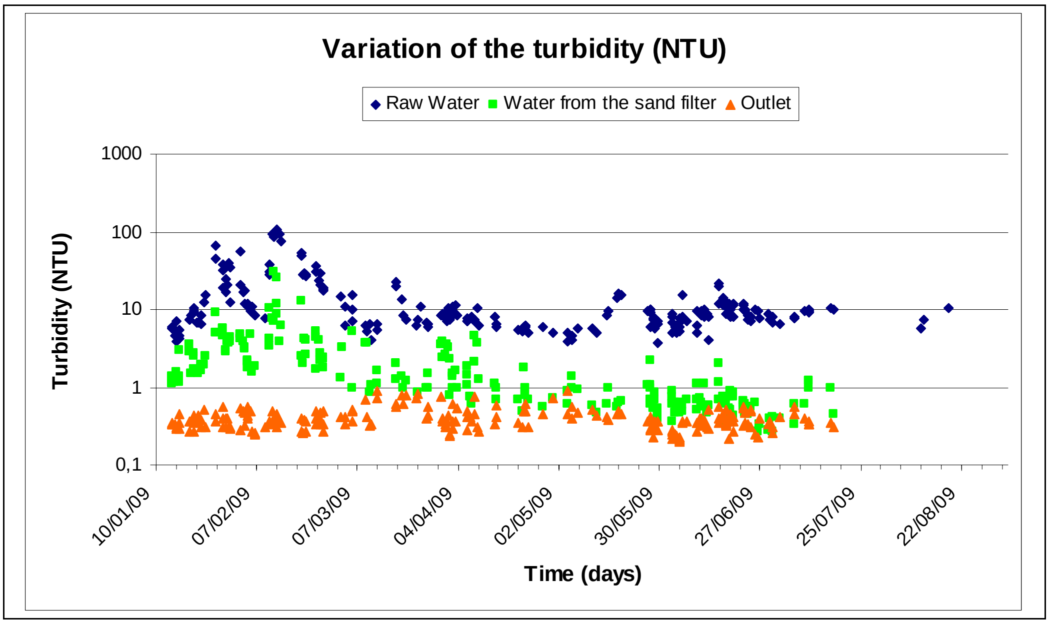
Before looking at the flux stabilisation process itself, it is suggested to better characterise the water quality of the different types of water during the investigation period (January – August 2009)

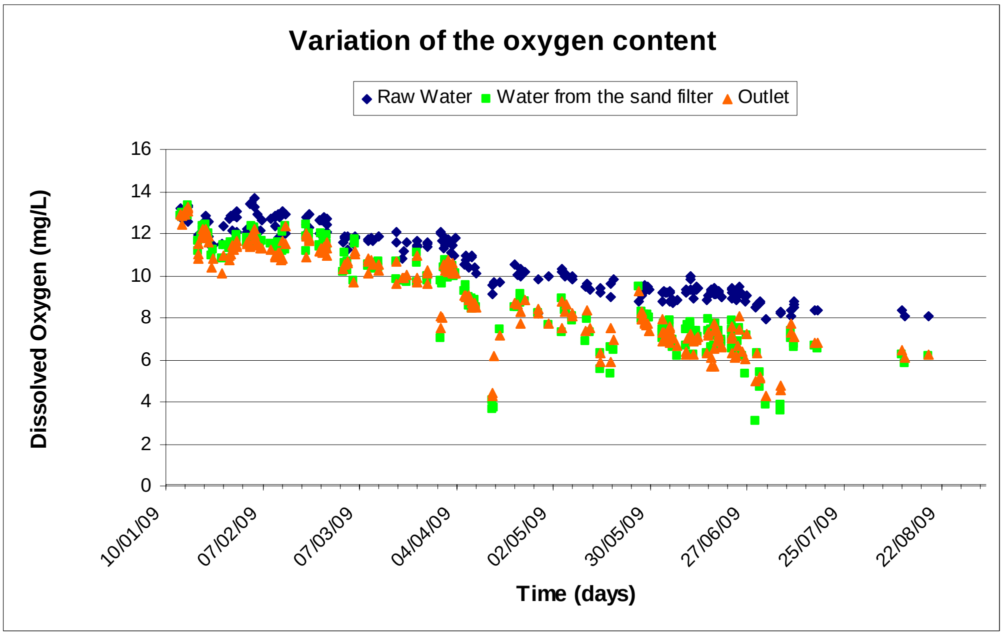
3.1 Water Quality

3.1.1 *Daily Monitoring*

An overview of the data collected from the daily operation of the unit is here presented via graphs and tables 4 and 5, which explicit the variations of the following physico-chemical parameters : temperature, the turbidities and the oxygen contents for raw water, filtered water and permeate.

Table 4 - Daily Monitoring : Variations of the turbidities, the oxygene contents and the temperature





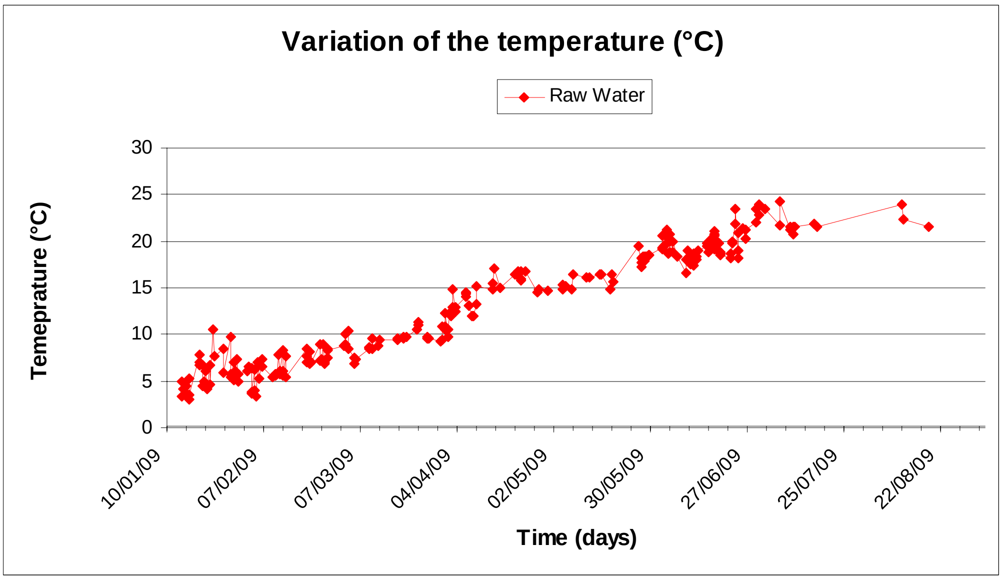


Table 5 - Daily monitoring: min/max/average results

	Surface Water			Filtered Water		Permeate	
Parameters	Temperature	DO	Turbidity	DO	Turbidity	DO	Turbidity
Units	°C	mg/L	NTU	mg/L	NTU	mg/L	NTU
Min value	3.1	7.94	3.74	3.11	0.27	4.27	0.2
Max value	24.2	13.7	105	13.3	30	13.2	0.88
Average value	12.8	10.7	14.7	9.2	2.1	9.04	0.39

3.1.2 Organic Characterisation

Several complementary analyses on the raw water, filtered water and permeate were performed in order to characterize the organic content at the end of the trials (June-August 2009) after stabilisation of the biological processes and with a temperature range from 16.6 to 23.5 °C. From Figure 3, it can be seen that a fraction of the organic content is consumed in the sand filter. However, it is difficult to differentiate the organic content in the filtered water and in the permeate (i.e. treated water) based on the results on UV absorbance at 254 nm and DOC content. It is then recommended to look more specifically at BDOC for future tests (relevant for South Africa).

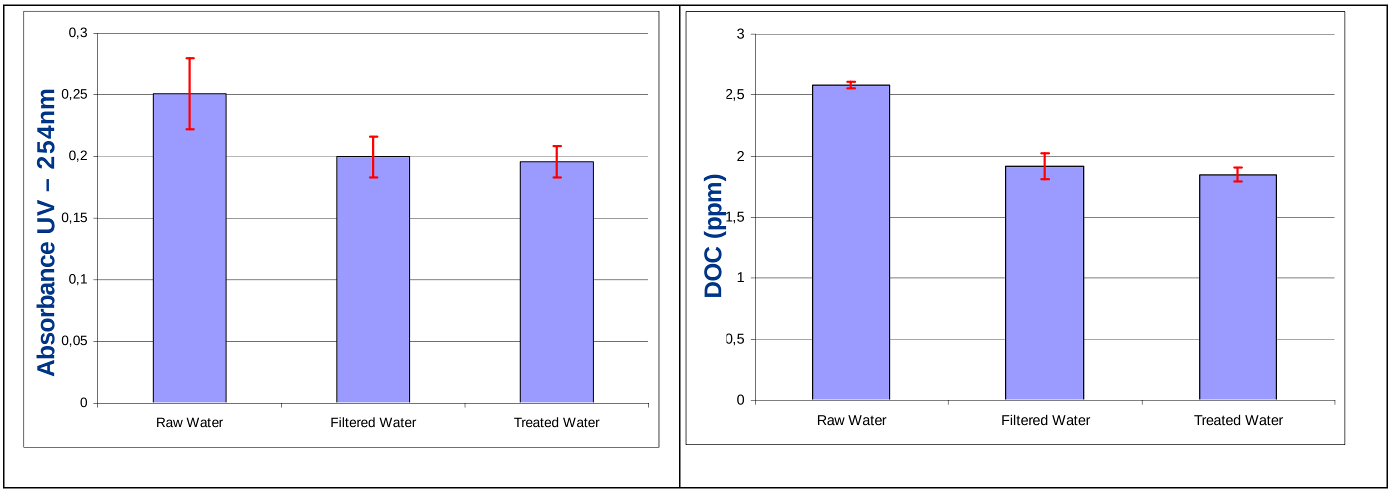


Figure 3 - Organic Characterisation

3.1.3 *Bacterial Analyses*

Bacterial analyses were performed to check on the membrane integrity, which is confirmed by the results illustrated in Figure 4 that shows that no *Spores, Coliforms, Enterocoques* and *E.Coli* were detected in the permeate, and in agreement with the nominal molecular weight cut-off of 150kDa. However, a risk for regrowth is clearly highlighted in Figure 5, where colony counts at 22°C and 37°C are comparable in the permeate and in the filtered water. This result validates the need for residual chlorination in the overall system. Alhtough not implemented in Annet-sur-Marne, the chlorination step would then be set for the South African trials for a short period in order to assess the demand. The removal efficiency of the sand filter is rather low with up to 2 log-removal regarding coliforms.

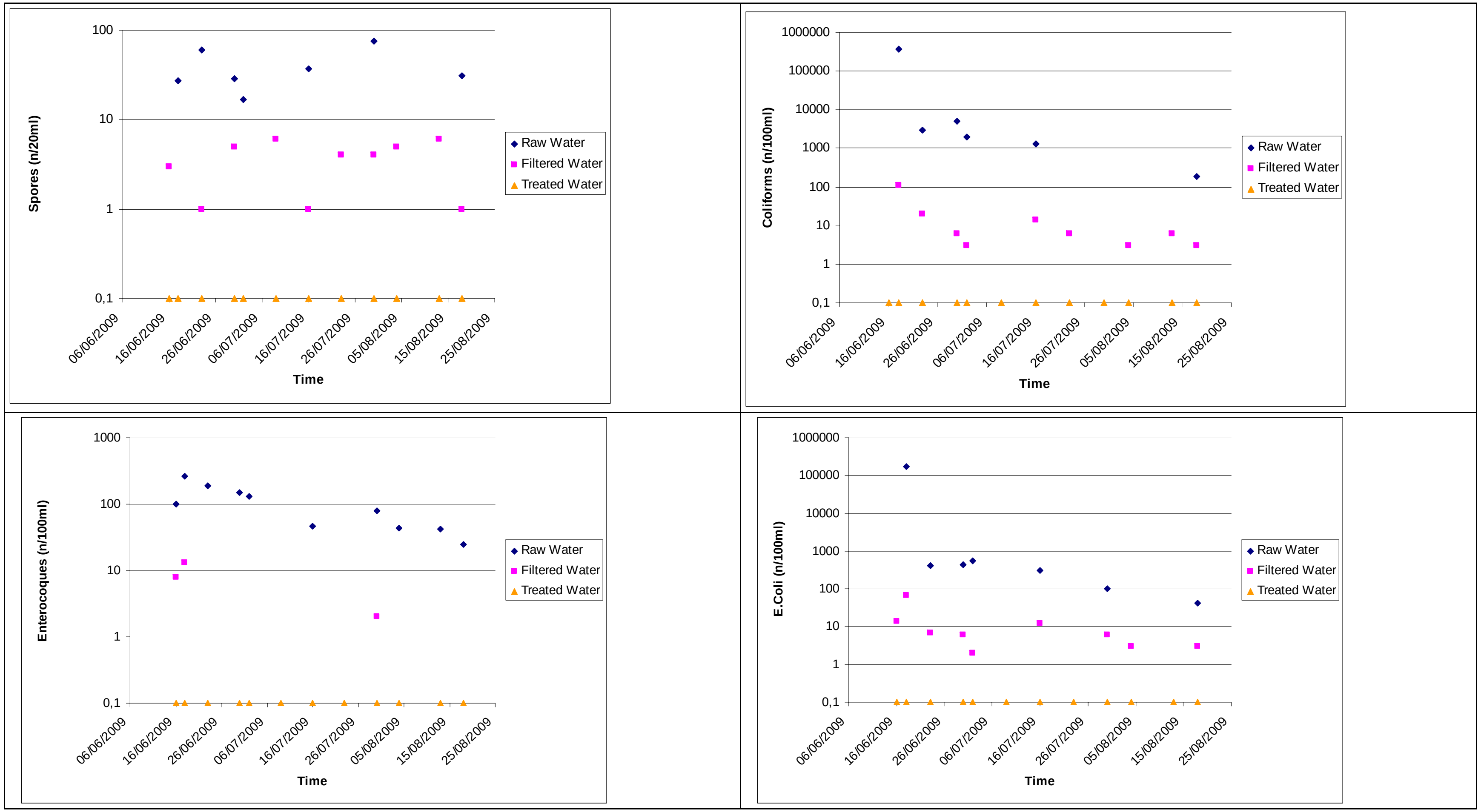
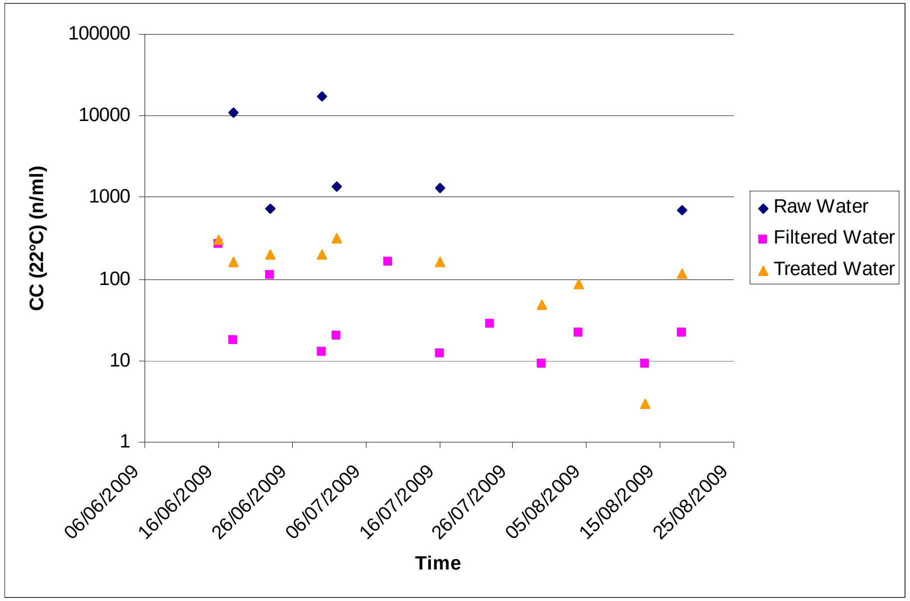


Figure 4 - Bacterial Analyses. Results for Spores, Coliforms, Enterocoques and E.Coli.



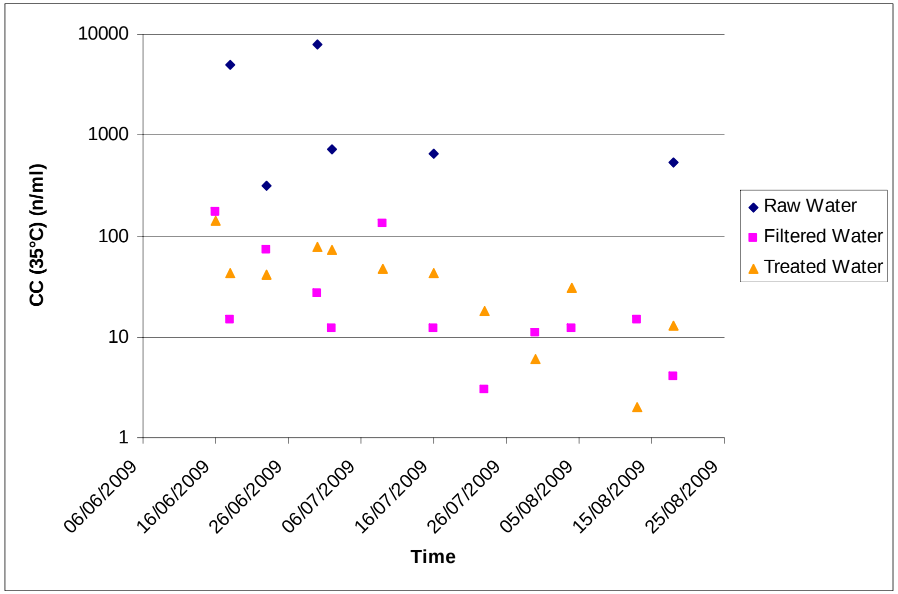


Figure 5 - Colony Counts at 22°C and 37°C

3.2 Flux Stabilization

Influence of the intermittent operation and of the turbidity feed

From Mid-January 2009, the process unit was running with the biosand filter and the UF step in winter conditions (temperature range : 3.1 – 10.5°C). *Figure 6* shows that the flux stabilizes to around 2.5 lmh (compared to 7-10 lmh for Eawag lab conditions at 20°C ± 2°C), in 20 days. The stabilization curve seems here slightly different than the one expected from the Eawag lab tests as the decrease of the flux is slower in the first 10 days than in the next 10 days. This is probably due to the fact that the unit was only running half-time on the first 10 days and thereby the flux was enhanced (also observed at Eawag lab scale). Another option is that the membrane reactor had to cope with higher turbidities (>5 NTU) in the next 10 days, which could also have lead to some flux reduction.

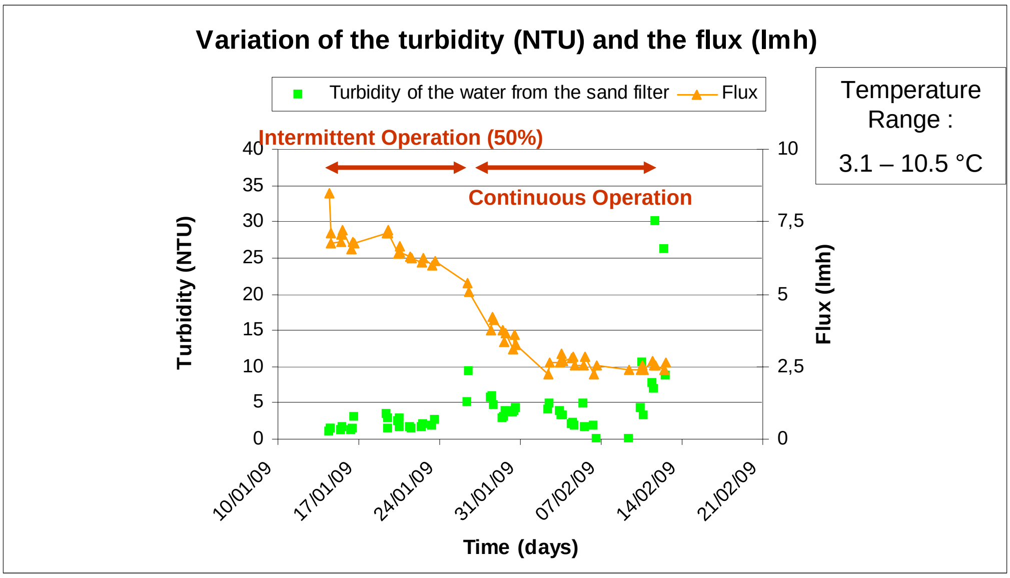


Figure 6 - Flux variation in regards to intermittent operation and turbidity feed

Influence of the drainage frequency

Once the flux has stabilized for more than 10 days, a weekly drainage (event labelled as "D") took place. This should lead to the removal of the accumulated material which is not attached to the membrane surface, facilitating the stabilization of the fouling layer and preventing the increase of its thickness. From Figure 7, the first drainage event (D1) enables a flux enhancement from 2.5 to 6 lmh.

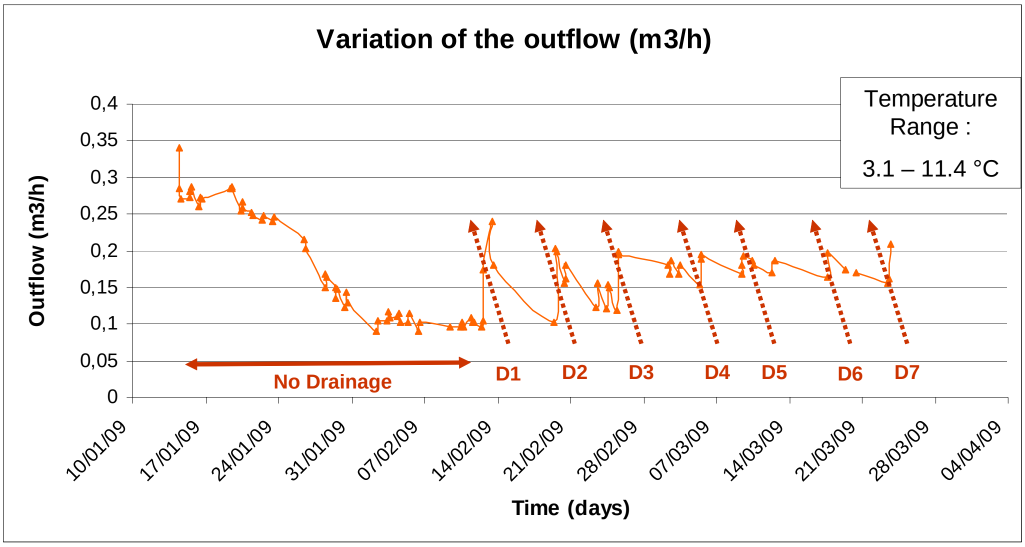


Figure 7 - Flux variation in regards to the drainage frequency

However, the following drainage events have progressively less impact on the flux enhancement. Indeed, Figure 8 illustrates a linear decrease of the flux enhancement for the 4 first drainage events (transition period of 1 month) and then a stabilization at around 20% is observed.

The flux stabilization is however not reached during the 1-week period of the drainage routine. Instead, a pattern seems to be created with flux values varying between 4 – 5 lmh after the 4th drainage event (D4), i.e. the flux could be doubled compared with the operation condition without drainage. With these operating conditions (continuous operation and weekly drainage), between 3.8 and 4.8 m^3/d of treated water is produced. That is consistent with the 5 m^3/d target that was established when scaling-up the Eawag lab investigations.

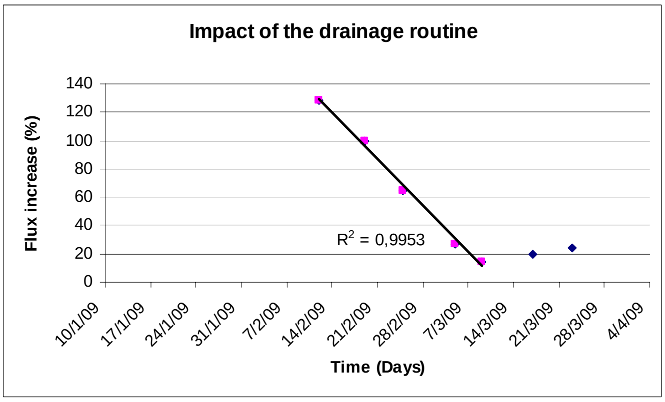


Figure 8 - Flux enhancement due to the drainage routine

3.3 Expectations for the South African conditions

As the unit will be also tested in South Africa, it is interesting to transpose the current results to South African-like conditions. Figure 9 simulates the flux variation which is corrected at 20°C based on water viscosity considerations [4] and it shows a flux stabilization between 5 and 6.5 lmh with similar operating conditions. In that virtual case, between 4.8 and 6.2 m^3/d of treated water would be produced, satisfying the design specification of the system. Besides, an increase of the temperature would also lead a better biological performance in the sand filter and the membrane reactor, and thereby better outputs.

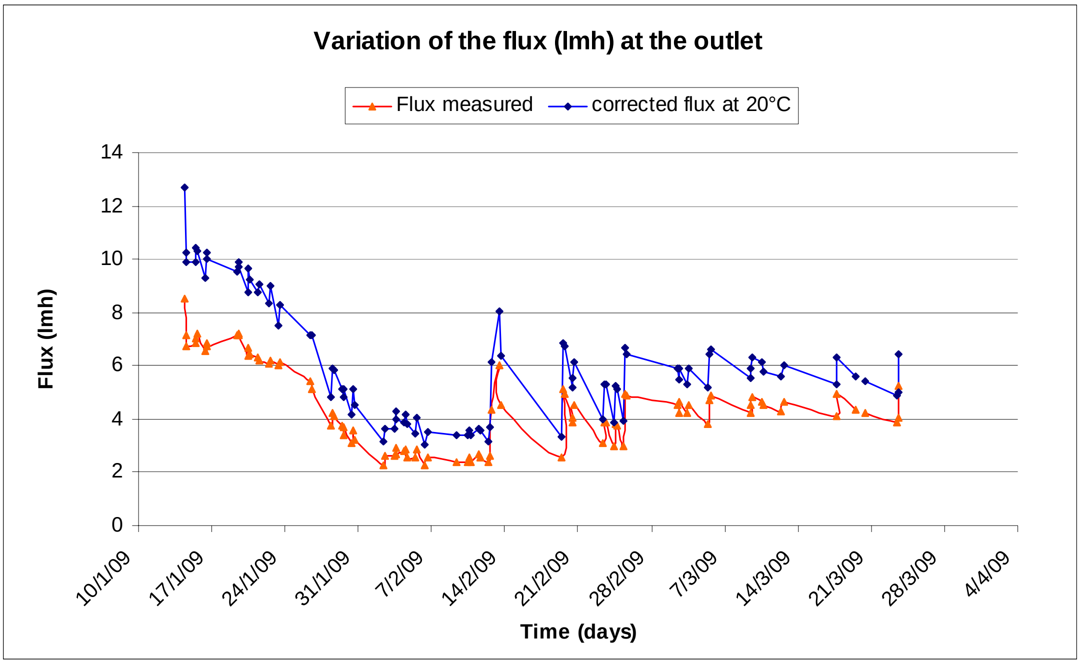


Figure 9 - Flux enhancement with a 20°C-correction

However, in South Africa, coping with high turbidity peaks (>300 NTU) could impact the present flux pattern. In that regard, more investigations on the pre-treatment options are therefore planned in the rest of the study.

3.4 Influence of the temperature and Relevance of the pretreatment

Even under European winter conditions - with the temperatures of the raw water varying from 3.1°C to 11.4°C, results in regards to flux values are promising. Yet, that range of temperatures is not well-adapted for the biological activity which is needed in the process unit : in the biosand filter and in the fouling layer of the membrane. From April 2009, a significant increase in temperature – along with the arrival of spring times – was observed. Figure 10 shows the variations of the oxygen contents in the raw water and the water from the sand filter and illustrates the activation of the biology in the sand filter through the consumption of the organic matter. It can be noticed that shortly after the temperature (in red) reaches the 15°C value (around Mid-April 2009), a significant drop in the oxygen content in the filtered water occurs beyond the decrease of oxygen content in the raw water due to lower saturation concentration with higher temperature. Besides, the oxygen concentration was never limiting for the biological process (this could be the case for higher temperature and/or higher initial DOC concentration) On Figure 11, which represents the flux variation on the whole trial period, this timing also corresponds to a significant drop in the flux value. It shows that the UF membrane step is not the limiting factor on the system water production but the biosand filter. From that event, the maintenance on the biosand filter, which consists in the removal of the upper layer was then necessary every 6 to 7 weeks. That frequency is quite high compared to what would be expected from standard slow sand filters (i.e. every 3-5 months) [5].

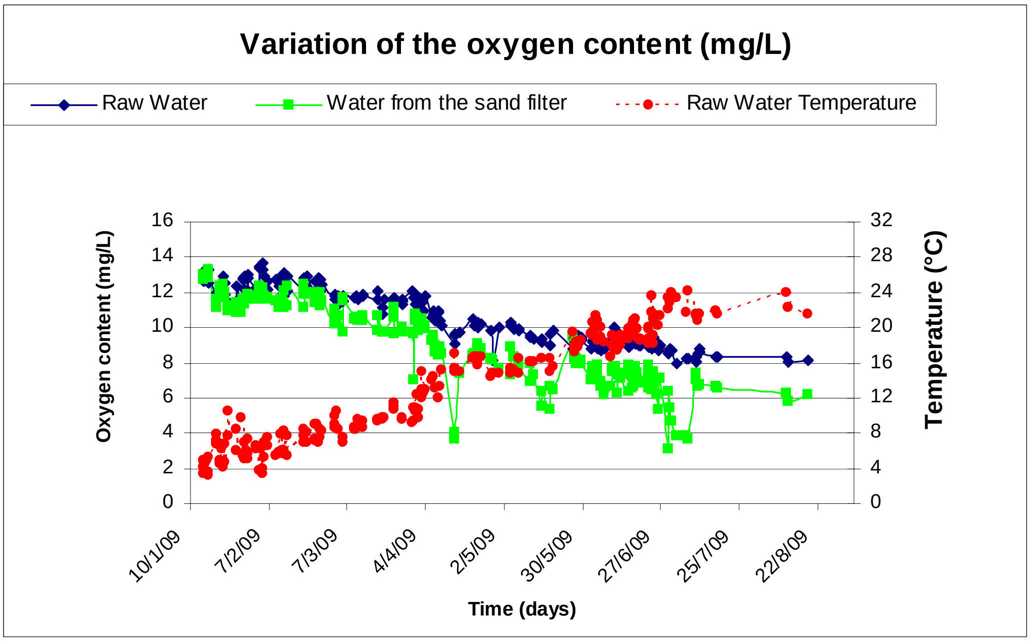


Figure 10 - Effect of temperature on the oxygen content

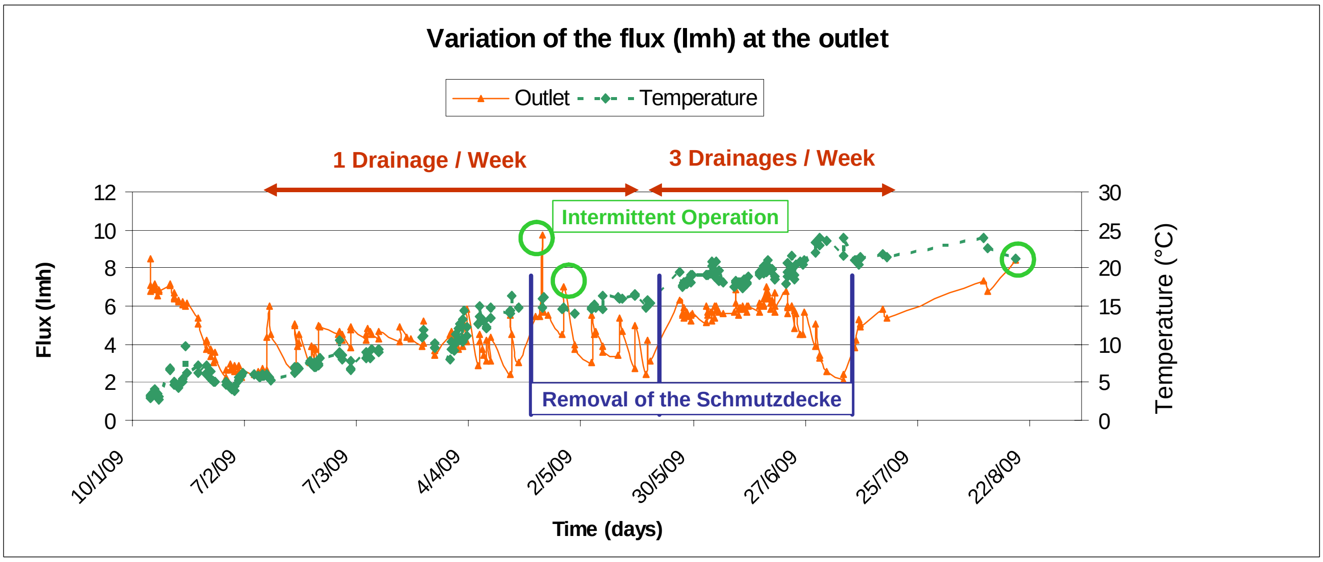


Figure 11 - Variation of the flux in function of the Operation and Maintenance conditions

Because of these maintenance requirements, the system stabilization process was disturbed. In order to enhance the flux values, it was decided to increase the drainage frequency to 3 times a week, leading to a stable flux ranging between 5 to 6 lmh, matching the target of about 5 m3/d. That is consistent with the values expected from paragraph 3.3 on South African conditions.

4 Conclusions

The gravity-driven UF compact unit that was developed by Opalium, Eawag and KWB has shown promising results in regards to flow capacity. Although first investigations occured in winter, a flux stabilization of 2.5 lmh was observed, which is below the results from Eawag lab tests (i.e. 7-10 lmh, at 20 ± 2°C). However, the “scaled-up” system can benefit from a weekly drainage which seems to enhance the flux to 4-5 lmh, and thereby, the unit is to produce more than 4 m^3/d, which is consistent with the design target of 5 m^3/d.

Moreover, along with warmer temperatures – leading to a better membrane permeability and an enhanced biological activity, the outputs would also increase to reach and exceed the design target. However, the clogging of the slow sand filter – which was faster than expected (i.e. every 6 to 7 weeks instead of every 3 to 5 months) – has strong impact on the flux values and represent the limiting factor of the overall system. Therefore, it was recommended with higher temperatures to increase the regeneration frequency of the sand filter and to increase the drainage frequency to 3 times/week in order to reach flux stabilization.

Thus, these early scaled-up tests enabled to better identify the operation conditions of the system and its limitations :

- A temperature below 5°C would prevent the biological activity in the sand filter and in the membrane reactor
- A temperature beyond 25°C would on this other hand bring out an excessive biological growth and oxygen depletion
- Flux enhancement can be reached with increasing the frequencies of the regeneration of the sand filter and the drainage of the membrane reactor.
- The biological sand filter seems to be the limiting treatment step (particularly for higher temperature), although it is the heaviest / largest piece of equipment. The system might then be more economical with a lower filtration flow (more membrane surface) but no or smaller pre-treatment

Water quality parameters were also monitored in order to ensure the bacterial removal and the membrane integrity. The efficiency of the slow biosand filter is however less satisfying and should be further investigated in the complementary trials in South Africa.

These results are particularly relevant for South Africa, where the unit is to be further tested from December 2009. The capacity of the system to cope with high turbidity peaks would then be particularly relevant. In that regards, capital and operational costs of the pre-treatment option will be further assessed.

5 References

[1] Hoa E. and Lesjean, B. (2008). *International Market Survey on Membrane-based Products for Decentralised Water supply (POU and SSS Units)*. EU Project TECHNEAU Report. D2.5.3. Berlin Centre of Competence for Water. Available at www.techneau.eu

[2] Varbanets M. and Pronk W. (2006). *Point-of-use Membrane Systems: Place in the World of Supply*, EU Project TECHNEAU Report D2.5.2. Eawag, CH.

[3] Peter-Verbanets M. and Pronk W. (2008). *Mechanisms of biofouling of UF membranes and evaluation of pre-treatment on fouling of UF membranes.* EU Project TECHNEAU report.D2.5.6/8/10. Eawag, CH.

[4] Trussell S., Adham S, and Trussell R (2005) *Process Limits of municipal wastewater Treatment with the submerged Membrane Bioreactor*. Journal of Environmental Engineering.

[5] Huisman, L. and Wood W.E. (1974), *Slow Sand Filtration*, Manual from the WHO – World Health Organisation.