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Ultrafiltration: A solution to recycle the breeding waters in shellfish production

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Abstract :

Shellfish profession is jeopardized by water quality problem that concerns inlet, with the need to protect the animals from pathogens contaminations, and effluents potentially harmful for the environment with the presence of pathogens, nutrients or organic matter. In this study, ultrafiltration was tested to answer these issues. The objective of the work was two-fold: (i) treat a real effluent from an oyster breeding, the pilot had to continuously face a water containing organic matter and pathogens and (ii) use ultrafiltered water to feed an oyster spat. The process was proved to be efficient in terms of total suspended solids (TSS) and bacterial retention, and especially for *Vibrio bacteria,* some of whom are potentially harmful for shells. The sustainability of the process facing this pollution was demonstrated and thus for different filtration conditions. Indeed, backwashes and air-backwashes performed were efficient enough to control the fouling generated, so a chemical cleaning was necessary about every 12 h. Water quality parameters, physico-chemical and bacterial, of ultrafiltered effluents were similar to the one obtained with a classical seawater used to feed oyster spats. Ultrafiltration was efficient to treat an effluent from oyster farm and produce water allowing the grown of juveniles. This process could be a solution to reuse effluents in shellfish farms.

Highlights

► Ultrafiltration process was efficient to treat shellfish effluents. ► The sustainability of the process facing this pollution was demonstrated. ► An oyster spat was successfully bred with ultrafiltered effluents. ► A protection of the juveniles from pathogens was obtained.

Keywords : Ultrafiltration, aquaculture, shellfish effluent, spat protection.

Abbreviations: AB, air-backwash ; CB, classic backwash ; CEB, chemical cleaning ; Lp, permeability ; MWCO, molecular weight cut-off ; RR_0 and RR_{end}, retention rates at the beginning and end of filtration cycle ; TMP, transmembrane pressure ; TSS, total suspended solids ; UF, ultrafiltration ; VCF, volumetric concentration factor.

I. Introduction

In aquaculture, water quality management is essential to ensure a sustainable and environmentally responsible production. Water issues concern both inlet waters to protect animals from biological or chemical pollution, and outlet to eliminate discharges that could potentially impact the environment.

In the case of inlet waters, disease is one of the most important factors suppressing the full growth potential of marine aquaculture (Sindermann, 1990). In particular for shellfish aquaculture, since 2008, the industry is regularly struck by mortality crisis affecting both adult oysters *Crassostrea gigas* and juveniles. Two pathogens have been identified as partly responsible to these deleterious phenomena for the shellfish industry: herpes virus OsHV-1 and bacteria *Vibrio aestuarianus* (Renault, 2011). It's not the first time that this type of bacteria is linked to larval mortalities in hatcheries. Indeed, for examples can be cited *Vibrio anguillarum Vibrio tubiashii* in North American west coast, (Disalvo, 1978; Elston *et al.*, 2008) *Vibrio splendidus* in north Brittany (Lacoste *et al.*, 2001) or *Vibrio neptunius* in Spain (Prado *et al.*, 2005). To protect juveniles bred in hatcheries or nurseries from those microorganisms, inlet waters must then be treated. Moreover, water treatment technologies, in addition to eliminating pollution, must produce water with a quality adapted to farmed

animals. It's especially in the case of hatcheries and nursery in which fishes or molluscs are very sensitive.

Pathogens are a problem concerning inlet water but also outlets. Indeed, aquaculture outlet effluents are responsible of introduction and spread of shellfish diseases (Bower, S.M. *et al.*, 1994). This dissemination can impact natural fish populations (Bomo *et al.*, 2003; Ford *et al.*, 2001). More of pathogens, the three main types of pollutants that can be produced by aquaculture facilities are: chemicals for maintaining facility cleanliness, drugs used for disease control, and metabolic products such as faeces, ammonia and uneaten food (Mugg *et al.*, 2000). The principal risk with this last pollution is the eutrophication (R. C. Summerfelt, 2003). Finally, emergent pollutions must be considered. In the case of shellfish aquaculture, the release of biological material, for example in the case the production of exotic oysters, could impact the marine biodiversity. Water treatment technologies must be able, beside eliminating pathogens and remove those several sources of pollution, to handle those loaded effluents.

Sand filtration, sedimentation and screening are common technologies used in aquaculture to remove particles from inlet water and effluent. The elimination of suspended solids is necessary to protect animals or environment, but also to guarantee the efficiency of downstream processes of disinfection (Cripps and Bergheim, 2000; Lekang, 2013). To remove pathogens the main processes used to treat inlet water and effluents are disinfection using chemical oxidation such as chlorine or ozone and UV treatment (Bomo *et al.*, 2003; Kasai *et al.*, 2002). In the case of shellfish culture, these three technologies were proved to be efficient against pathogens such as *Vibrio aestuarianus* (Stavrakakis *et al.*, 2017). Ozone is widely used in aquaculture applications for achieving disinfection, water quality improvement by oxidizing organic wastes and nitrite, or supplement the effectiveness of other water treatment units (Gonçalves and Gagnon, 2011; S. T. Summerfelt, 2003). However, for inlet

waters, residual oxidants from ozonation can be harmful to larvae (Ozawa *et al.*, 1991). An additional treatment is then necessary to protect the animals, such as PAC (powder activated carbon) adsorption (Kasai *et al.*, 2002; Ozawa *et al.*, 1991). In the case of chlorine disinfection, thiosulfate should be used (World Organization for Animal Health (OIE), 2009). Moreover, oxidation using chlorine or ozone to treat aquaculture effluents presents the huge disadvantage of creating subspecies potentially harmful for the aquatic environment (Delacroix *et al.*, 2013; Lazarova *et al.*, 1999; Reiser *et al.*, 2011).

UV seems an alternative to chemical oxidation because it doesn't require chemical reagents and there is no formation of hazardous disinfection by-products after treatment (Cobcroft and Battaglene, 2013; S. T. Summerfelt, 2003). Nonetheless, the treatment efficiency is linked to the turbidity of water (Gullian *et al.*, 2012; Qualls and Johnson, 1983). Furthermore, some pathogens show resistance to ozone or UV treatment (Liltved *et al.*, 2006). Means of treatment which take account of the quality of the water to be treated and constraints encountered by the profession (costs, flows, effluent standard) must be developed.

Membrane processes are widely used in water and waste water treatment for their disinfection efficiency (Madaeni S. S., 1999). In aquaculture, they were principally tested in recirculating aquaculture systems (RAS) applications. Indeed, reverse osmosis, nanofiltration, microfiltration or ultrafiltration were tested in terms of retention and production to remove contaminants such as BOD (biological oxygen demand), total phosphorous and total iron to required limits (Ali *et al.*, 2011; Gemende *et al.*, 2008; Harvianto, 2013; Qin *et al.*, 2005). It was shown that membrane bioreactor were effective to reduce turbidity and lowering the total number of bacteria in the backwater (Sharrer *et al.*, 2007; Wold *et al.*, 2014). In the case of inlet waters, immersed microfiltration membranes present a good potential to remove toxic micro-algae (Castaing *et al.*, 2011) but membranes processes are still an emergent technology in aquaculture field, few studies exist on this subject. Several disadvantages limit the

development of this promising process in aquaculture such as high fouling rate, or implementation and replacement costs (Ng *et al.*, 2018). In the case of specific pollutions, Cordier *et al.* demonstrated the ultrafiltration efficiency in gametes removal (spermatozoa and oocytes from oysters *Crassostrea gigas*), 3 to 5 log, from shellfish farms (Cordier *et al.*, 2018a).

In the present study, ultrafiltration was tested for the reuse of real effluents coming from an adult oyster breeding to supply an oyster spat. This treatment was evaluated at a semi industrial scale. To evaluate the treating efficiency of the process, total suspended solids and bacteriological measurement were realized on the time of the study and the resistance of this semi-industrial unit of treatment facing this pollution was validated by the continuous following of hydraulic performances. The rearing efficiency of ultrafiltered effluent for the spat breeding was validated by the control of water quality parameters, bacteriological and physico-chemical, and confirmed by the comparison of growth evolution of those oysters with the one obtained using a classical seawater.

II. Materials and Methods

II.1 Pilot plant

In this paper, the naming “inlet” and “outlet” is relative to the farm and not the UF process. As presented Figure 1, seawater effluents coming from six breeding tanks of adult oysters *Crassostrea gigas* were used to feed the UF pilot plant as shellfish effluents (outlet). This discharge contained faeces, pseudo faeces and micro algae not consumed by the shells. Each tank was continuously fed with pre-treated seawater (sand filtration 25-30 µm and UV disinfection) drained by overflow and once a day they were emptied and rinsed with fresh water to clean them. Waters recovered by overflow and from the cleaning were regrouped in a tank and pumped to the feeding tank of the UF pilot plant.

To be noted that in this case of experimental breeding, the microalgae concentration given to the animals, between 1.5 10^9 to 2.5 10^9 cells.oyster^{-1}.d^{-1}, was superior to the ones applicated in a classical breeding, 1.0 10^9 cells.oyster^{-1}.d^{-1} (Spencer, 2008). The pollution generated in our working conditions were then overestimated compared to normal outlet conditions.

The ultrafiltration pilot had then to face two water qualities: the continue overflow, with a turbidity measured in the feeding tank of the pilot around 1 NTU, and the spick in turbidity generated by the cleaning of breeding tanks once a day. This pollution could reach a turbidity of 30 NTU. The pilot plant treated the effluent continuously at constant flux, without recycling the retentate.

Two spats of oysters *Crassostrea gigas* of about 2500 oysters were placed in tanks (V = 150 L) fed with different water qualities: the control one with classical seawater filtered at 25-30 µm are treated with UV and the other one with ultrafiltered effluents coming from the oyster breeding, with the aim to use a more challenging water. Prefiltration was realised with a sand filter with a filtering surface of 3 m² and a grain size between 0.7 and 1.3 mm. UV treatment was carried out with a Bio UV device able to deliver 35 mJ.cm^{-2} (for 6 m^3.h^{-1} and a sea water transmittance at 10 mm of 0.85). Both control water and UF permeate were continuously fed with the same concentration of microalgae (2.5 L.h^{-1}) and bred in the same conditions of temperature (between 12 and 22 °C), and flow (100 L.h^{-1}) during a two months period.

II.2 Membrane and pilot

Membrane used for the tests were Aquasource hollow fibres in polyethersulfone with 7 channels of a 0.9 mm inside diameter. Their MWCO was 0.02 µm and initial permeability 1000 L.h^{-1}.m^{-2}.bar^{-1}. The membrane module of a total area of 8 m² has been integrated into a semi industrial pilot Figure 1 (Moll *et al.*, 2007), able to treat 20 m^3.d^{-1} (Cordier *et al.*, 2018b). The tests were all performed in dead end and inside-out filtration at constant flux of 60 L.h^{-}

^{1}.m^{-2} and the permeate was recovered in a buffer tank in order to perform backwashing. To eliminate fouling, three membrane cleanings were automatically carried out by the pilot: classical backwashes (CB), air backwashes (AB), which consists in a previous air injection in the membrane before backwashing, and chemical cleaning (CEB). CEB was a two steps procedure: first a basic solution with an addition of chlorine (pH = 9.5) in order to reach a chlorine concentration between 100 and 200 ppm in membranes depending on the treatment needed, was injected in the membranes. Then, after 30 min, the module was rinsed with permeate at 2 m^{3}.h^{-1} and filled with an acid solution (pH = 2). After 30 min the module was finally rinsed with permeate at 2 m^{3}.h^{-1}.

To follow hydraulic performances, Lp and TMP, respectively membrane permeability and transmembrane pressure were calculated and recorded continuously every minute. All the results are expressed taking into account the variation of temperature. Indeed, flux is affected by the water temperature and must be normalized to a standard temperature to account viscosity fluctuations with this parameter. Filtration conditions, permeate flux (L.h^{-1}.m^{-2}) and filtration time (min), were pre-selected according to the literature (Guilbaud *et al.*, 2019, 2018) and previous studies (Cordier *et al.*, 2018a, 2018b).

II.3 Analyses

II.3.1 Total suspended solids

Total suspended solids (TSS) were measured by filtering a sample on a glass fibre membrane (Whatman) in order to retain particles superior to 0.7 µm. The membrane was rinsed with distilled water and dried during minimum 2 h at 105 °C and 70 °C before and after filtration of the sample, respectively. The TSS concentrations were then obtained by calculating the difference of weight before and after filtration. To control quality and the retention rate of the

process, TSS measures were realised twice a week on feeding water (effluents from adult oyster breeding), permeate, backwash and air-backwash waters.

To evaluate the retention of the process toward TSS, retention rate (*RR)*, of the membrane were calculated: RR_0, at the beginning of filtration and RR_{end} at the end of the filtration cycle to take account of the accumulation of particles inside the membrane. This accumulation results in a concentration inside the membrane higher after 30 min of filtration than initially and consequently, a higher retention rate. The Volumetric Concentration Factor (VCF) is calculated with the volume filtered during a filtration cycle and membrane volume (1.8 L).

These parameters were calculated using the measured TSS at membrane inlet and in permeate water with the following formulae:

$$RR_0 = \left(1 - \frac{C_p}{C_0}\right) \times 100$$

$$RR_{end} = \left(1 - \frac{C_p}{C_0 \times VCF}\right) \times 100$$

with,

$$VCF = \frac{V_{feed}}{V_{membrane}}$$

C_p = TSS concentration in permeate

C_0 = TSS concentration in the feed

$C_0 \times VCF$ = TSS concentration in membranes at the end of filtration cycle

TSS concentration in the permeate versus time was not recorded and it was impossible to estimate the concentration in the membrane versus time. Thus, the RR were calculated at the beginning and at the end of the filtration step. For the last value, the permeate concentration was considered equal to zero to estimate the inlet concentration and the RR_{end} was calculated with the equation above. The consequence is an estimation by excess of retention rates. Due to the high VCF, this excess on the final estimated value remains very low (see TSS measurements).

II.3.2 Turbidity

Turbidity was measured and recorded every minute in the feeding tank of the pilot using a prob VisoTurb 700 IQ (WTW).

II.3.3 Microbiologic analyses

In shellfish culture, some species of *Vibrio* bacteria are toxic for oysters. Their presence in the water feeding spats must then be controlled. Although, total bacterial load and *Vibrio* were analysed in these waters. To measure bacteria concentrations, counting method on plate culture was used. 20 µL of sample was spread on heterotrophic or TCBS agar for total load bacteria and *Vibrio* counting, respectively. Microbiologic analyses were realised twice a week in effluents feeding the pilot and waters in the two breeding tanks containing spats. The aim of these analyses was to validate the absence of *Vibrio* but also control the bacteriological quality of waters feeding spats with the addition of microalgae. To evaluate the efficiency of ultrafiltration to eliminate bacteria from the seawater, two sets of measures of total bacteria and *Vibrio* were realized in effluent feeding the pilot, permeate and control water before their injection in breeding tanks.

II.3.4 Physico-chemical parameters of waters

Physico-chemical parameters of waters feeding the spats were measured to validate that conditions adapted for oyster development. Thus, salinity, temperature and dissolved oxygen were controlled daily in the two breeding tanks of spats using probes (WTW measuring instrument).

II.3.5 Development of spats

The development of spats was followed in order to compare their growth in classic water and ultrafiltered water. Once a week, the weight of 100 individuals and the height of 10 were measured.

III. Results and discussion

III.1 Treatment of effluents

The aim of this part was to prove the efficiency of the process to treat the effluent. Ultrafiltration must handle the effluent and remove the pollution.

III.1.1 Hydraulic performances

Impact of the pollution on membrane fouling

The ultrafiltration process was first tested for the treatment of the effluent with conditions of flux of 60 $L.h^{-1}.m^{-2}$ with a backwash every 30 min and an air-backwash (AB) every 5 classical backwash (CB). To confront the pilot to the same pollution but with harder conditions and with a lower permeate consumption, the filtration time was then raised up to 60 min but with one AB every 3 CB (instead of one AB every 5 CB). The evolutions of permeability and turbidity in the feed tank of the pilot on a period of 8 days and 9 days, for filtration time of 30 min and 60 min respectively, are presented Figure 2 (a and b).

Spicks in turbidity generated by the cleaning of breeding tanks every day are noticeable. If values around 50 NTU are presented, these ones are caused by the deposit of particles on the probe and not representative of the average quality of the water which the turbidity was around 30 NTU.

To evaluate the fouling generated by the pollution, evolutions of permeability obtained for the effluent filtration for the two conditions are compared with the ones obtained for seawater filtration in the same conditions (Figure 3). As expected, the drop of permeability is superior

in the case of the filtration of effluent: the presence of faeces, pseudo faeces and microalgae lead to a significative fouling of the membranes and it increases with the filtration time. In the case of filtration of pre-treated seawater, the limit of permeability before chemical cleaning, 300 $L.h^{-1}.m^{-2}.bar^{-1}$ was reached after three days of filtration whereas in the case of treatment of effluents, this limit was reached after an average of 12 hours of filtration during the two months, depending on the efficiency of chemical cleaning and the quality of the water.

Despite the significative fouling generated by the pollution, the pilot was able to face the effluent. Indeed, a CEB carried out about every 12 h is considered industrially viable in terms of permeate and chemical consumption as sustainable conditions (Field and Pearce, 2011).

Chemical cleanings of the membranes

Figure 2 shows that the cleaning efficiency is not equal after each CEB. During the first four days, a permeability under 500 $L.h^{-1}.m^{-2}.bar^{-1}$ is recovered whereas it's around 600 $L.h^{-1}.m^{-2}.bar^{-1}$ after every other CEB of the period. This difference was explained by the concentration of chemicals, especially chlorine (130 ppm), injected inside the membranes during CEB. After a few days this concentration was raised up to 150 ppm and the membrane regeneration was effective. This result highlights the importance of adapting the quantity of chemicals, especially chlorine to the pollution and controlling this parameter. Figure 2a. underlines the importance of control of another parameter: pH of the chemical solution injected during CEB. Indeed, the two lasts CEB (pH < 9) results in a gain of permeability inferior than the previous ones with a same concentration of chlorine but for a pH between 9.5 and 10. These results are in agreement with the chlorine forms versus pH so to ensure an efficient fouling removal this pH must be between 9,5 and 10.

Influence of air-backwashes on membrane fouling

Figure 4 a. and b. represent the impact of air-backwash on the control of membrane fouling in the case of a filtration time of 30 min. In effect, in Figure 4 a. the air backwashes are clearly identifiable and the measure of TMP gain obtained after AB compared to the average gain obtained after the 5 previous CB confirms this observation (Figure 4 b). The TMP gain (mbar) is the difference of TMP before and after the backwash.

This cleaning procedure has a significative impact on the stability of the process facing this pollution. These results justify the choice of increasing the AB frequency in the case of harder filtration conditions and confirm the conclusion obtained in a previous study on the efficiency of air backwash to eliminate fouling generated by the filtration of seawater and an effluent containing biological material from oysters (Cordier *et al.*, 2018b).

The process is stable and able to face the fouling generated by the effluent with a flux of 60 $L.h^{-1}.m^{-2}$ and filtration times of 30 and 60 min.

III.1.2 Treatment efficiency

In the previous part, the pilot was proved to be able to face the pollution. In this part, the objective is to validate the efficiency of ultrafiltration to remove TSS and bacterial pollution.

TSS measurements

On Figure 5 are represented the daily TSS measurements in pilot feed (effluent), permeate, backwash and air-backwash waters. TSS concentrations in effluents feeding the pilot were between 3.4 and 38.8 $mg.L^{-1}$ with an average of 13.4 $mg.L^{-1}$. In permeate water, TSS concentration is around 2.0 $mg.L^{-1}$, whatever the TSS concentration in feeding waters. This value was due to a high VCF in the membrane and a high retention factor. The ultrafiltration process must face a variable quality of inlet water but produced a ultrafiltered water with a

constant quality on the period of the study. The retention rates obtained were between 40 and 92 % at the beginning of the filtration cycle, and superior to 99% taking account of VCF at the end of the filtration step. These RR_{end} were calculated taking account a zero concentration in the permeate. For an inlet concentration of 3.4-5.8-6.2 $mg.L^{-1}$, the calculated RR_{end} is 99.8-99.6-99.8 % respectively. If we take into account the average concentration in the permeate during the filtration step in the mass balance, the RR_{end} values become 99.0-99.0-99.7 % respectively. Thus, as mentioned above the value of RR_{end} overestimates the retention but allows to correctly estimate the final retention without the need to measure the permeate concentration over time. In the case of backwash waters, there is a huge difference between the concentrations in air-backwash waters and classical backwash waters. Indeed, the average is 17,9 $mg.L^{-1}$ (10.1 $mg.L^{-1}$ – 24.3 $mg.L^{-1}$) in the case of CB and an average of 56.1 $mg.L^{-1}$ (23.5 $mg.L^{-1}$ – 146.8 $mg.L^{-1}$) in the case of AB. These results highlight the enhancement cleaning of the membranes generated by a previous injection of air and confirm the result obtained about TMP gains measured.

Bacteriological measurements

Total flora and vibrio analyses were realised on the effluent feeding the pilot, in buffer tank of permeate, and in control water feeding one of the spats. Results presented Table 1 underscore a removal of 4 log of total bacterial from effluents and a total retention of vibrio. By comparison, Kasai *et al.* (Kasai *et al.*, 2002) obtained the same results with UV and ozonation with treatments of respectively, 1,0. 10^5 $\mu W.sec.cm^{-2}$ and TRO (total residual oxidants) concentration 0.5 $mg.L^{-1}$ for 1 min. With sand filtration, the removal of *Cryptosporidium* and *Gardia* obtained is between 0.5 and 1 log (AFSSA, 2002).

The measurements in control water, which is seawater filtered on sand filter (25-30 µm) and UV treated, are also represented. This seawater present higher bacterial concentrations than

ultrafiltered effluent. The ultrafiltration process seems to offer a better bacterial control than the classical treatment used to feed oyster spat although it was fed with effluents. To be noted that bacteria measured in treated waters may be due to a development in tanks or pipes.

Table 1: Vibrio and total bacterial load measurement [J = 60 L.h^{-1}.m^{-2} and $t_{filtration}$ = 60 min]

	Total Bacterial Load (UFC.mL^{-1})			***Vibrio* (UFC.mL^{-1})**		
Date	*Effluent*	*Permeate*	*Control*	*Effluent*	*Permeate*	*Control*
06/01/2018	7740	12	58	38	0	0
06/05/2018	1660	0	14	50	0	0

Considering these results, ultrafiltration process is efficient to treat effluents from adult oyster breedings both in terms of pollution removal (TSS and bacterial contamination) but also in terms of hydraulic efficiency regarding its sustainability facing the pollution. This conclusion is validated for two different filtration conditions during a long time and for semi industrial conditions.

III.2 Use of ultrafiltered effluent to feed an oyster spat

The process is able to remove the pollution. The objective is now to validate the use of ultrafiltered effluent to feed an oyster spat.

III.2.1 Evolution of spat growth

The spat characteristics were followed every day for 4 months to compare the impact of the water quality on the development of oysters, as shown Figure 6. Growth is similar for both spats on samples characterized. To be noted that height is measured only on 10 animals and the shape of oysters can be different from an individual to another. This parameter is then less representative than weight to describe spat growth. Ultrafiltered offers growth performances identical to classical seawater.

III.2.2 Evolution of water quality

Physico-chemical parameters

Water quality parameters were followed during the study. Results presented Figure 7 explain the outcome of spat growth on the two different waters. Indeed, the parameters measured on the 4 months period show no significant difference between the two breedings. It's important to underline that the pilot, contrary to the blank spat, was not fed with seawater but effluents from an adult oyster breeding. The salinity remains similar around 32 $g.L^{-1}$. The use of fresh water to clean breeding tanks hasn't a significative impact on the salinity. This may be explained by a sufficient dilution with seawater. On the first three days of the study, a drop of dissolved oxygen is observed in both waters. Bubbling is then added in breeding tanks the third day to maintain this parameter to a value superior to 70 %, acceptable limit for the proper development of oysters. Then, the dissolved oxygen is between 70 % and 100 % until the end of the test.Ultrafiltered water temperature is constant with an average of 16 °C. Seawater feeding the breeding of adult oysters is regulated to 14.5 °C justifying this constant value in the pilot plant. On the contrary, seawater temperature in the control spat varies from 12 to 22 °C. Because temperature has an impact on oyster growth, a heat pump was installed the 05/24 in order to control the temperature in control water.

Total bacteria and vibrio concentrations

The bacterial quality of the waters was also followed on the period of the study twice a week. Figures 8 and 9 represent, respectively, the evolution of total bacteria load and *Vibrio* concentrations in effluents feeding the pilot and in the two breeding tanks. These two analyses, in UF and control waters used for spats, were realized after the adjunction of microalgae in order to compare the bacterial quality in the two waters.

In the case of total bacterial load, Figure 8, no major difference between the two waters is observed. Ultrafiltered water contains less bacteria than the effluent, despite the addition of microalgae confirming the efficiency of the process on bacteria removal.

In the case of *Vibri*o concentrations (Figure 9), a presence of these bacteria in the first week of the study is observed. However, no vibrio is then detected in waters from breeding tanks, both ultrafiltered and control water. Besides, *Vibrio* bacteria are detected in every samples from effluent feeding the pilot. These analyses confirm the efficiency of the process to remove this pathogen, potentially dangerous for oysters.

These results confirm that ultrafiltration process is able to produce water with a quality equivalent to classical seawater used to feed spat.

IV. Conclusion

Ultrafiltration appears efficient to treat effluent from a real oyster breeding. The process showed its capacity to remove TSS and bacterial pollution with a better removal than for classical treatment (sand filtration and UV treatment for this study). In terms of hydraulic performances, the process remains stable. A chemical cleaning every 12 hours was necessary to control fouling for the two filtration conditions tested. These conditions are sustainable in terms of treated water and energy consumption, justifying the use of this process for this application. However, to ensure a sustainable membrane cleaning and maintain the resistance of this process, chemicals concentrations must be regularly controlled. Regarding the TMP gain obtained air-backwash, the impact of this cleaning procedure on membrane fouling is a significative information for the stability of the process. Moreover, this might be an answer to fouling rate, one of the problems restricting the implementation of membrane technology.

These results are in agreement with a previous study on the treatment of shellfish discharges. Oocytes and spermatozoa effluents were treated by ultrafiltration under different conditions to simulate pollutions that could be generated by shellfish farms in the case of non-endemic

oyster productions. Whatever the concentrations of gametes and the conditions of filtration, the process was efficient to treat these pollutions with removal rates between 3 and 5 log. With these results, ultrafiltration demonstrates its treatment capacity to protect the environment from aquaculture effluent containing biological material, metabolic products and bacteriological contamination. For CEB a control of pH and chloride is necessary to optimise the membrane recovery.

Secondly, the use of the ultrafiltered effluent shows rearing capacity identical to classical water. Indeed, the physico-chemical and bacterial parameters were comparable in the two waters, leading to a similar development of oysters in the two conditions. Ultrafiltration process is able to protect the animals from bacterial contamination, especially *Vibrio* species, but doesn't remove elements indispensable for the development of animals.

Ultrafiltration is then efficient to treat effluent from oyster farms but also produce a water with a quality adapted to feed juveniles. Considering these results, the possibility of reuse effluents from breedings to feed others seems a feasible solution.

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Figure 1: Process configuration of treatment of effluents and use of permeate to feed a spat

Figure 1: Evolution of permeability versus time for the treatment of effluent a. [J = 60 $L.h^{-1}.m^{-2}$ et $t_{filtration}$ = 30 min] and b. [J = 60 $L.h^{-1}.m^{-2}$ et $t_{filtration}$ = 60 min]

Figure 2: Comparison of evolution of permeability versus time for treatment of effluents and seawater filtration a. [J = 60 $L.h^{-1}.m^{-2}$ and $t_{filtration}$ = 30 min] and b. [J = 60 $L.h^{-1}.m^{-2}$ and $t_{filtration}$ = 60 min]

Figure 3: Impact of air-backwash on membrane cleaning [J = 60 $L.h^{-1}.m^{-2}$ and $t_{filtration}$ = 30 min] a. Evolution of permeability versus time and b. comparison of TMP gain after CB and AB

Figure 4 : Evolution of TSS versus time in feed, classical backwash waters (CB), Air-Backwash waters (AB) and UF permeate

Figure 5: Evolution of spats growth versus time for different spat feed waters: control water and UF permeate

Figure 6: Evolution of physical-chemical parameters of the inlet spat feed waters: UF permeate and control seawater

Figure 7: Evolution of total bacterial load versus time in the feed of UF process and the inlet waters of spat of oysters *Crassostrea gigas* (control water and UF permeate)

Figure 8: Evolution of *Vibrio* concentrations versus time in the feed of UF process and the inlet waters of spat of oysters *Crassostrea gigas* (control water and UF permeate)

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Highlights

- Ultrafiltration process was efficient to treat shellfish effluents.
- The sustainability of the process facing this pollution was demonstrated.
- An oyster spat was successfully bred with ultrafiltered effluents.
- A protection of the juveniles from pathogens was obtained.

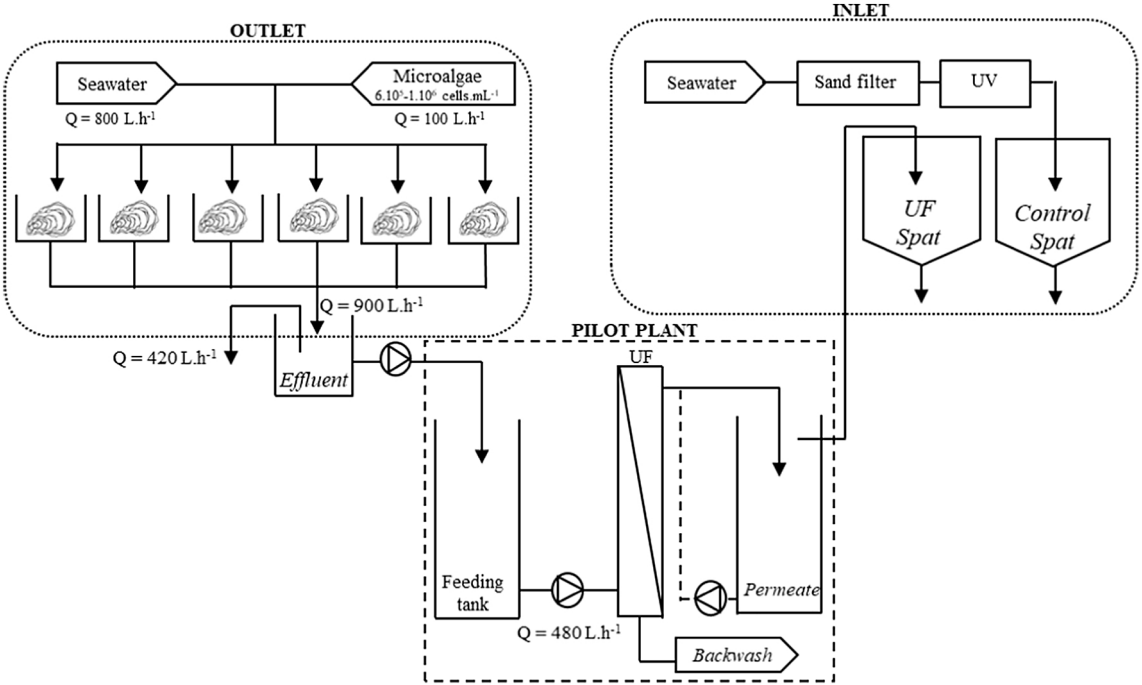
OUTLET
Seawater
Q = 800 L.h-1
Microalgae
6.10⁵-1.10⁶ cells.mL-1
Q = 100 L.h-1
Q = 900 L.h-1
Q = 420 L.h-1
Effluent
INLET
Seawater
Sand filter
UV
UF Spat
Control Spat
PILOT PLANT
UF
Feeding tank
Q = 480 L.h-1
Permeate
Backwash

Figure 1

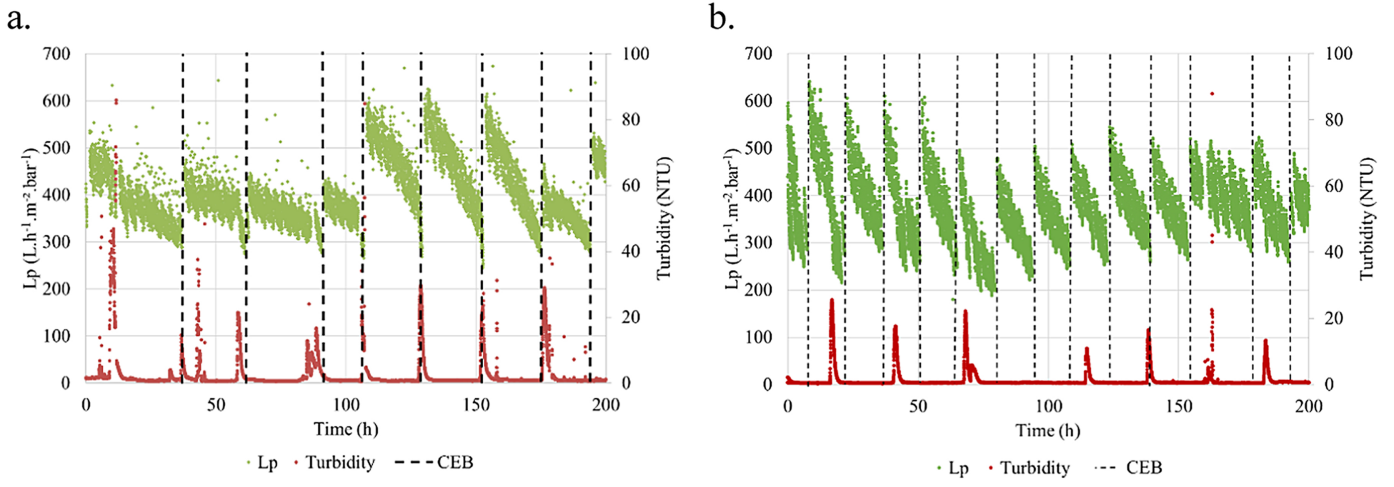

Figure 2

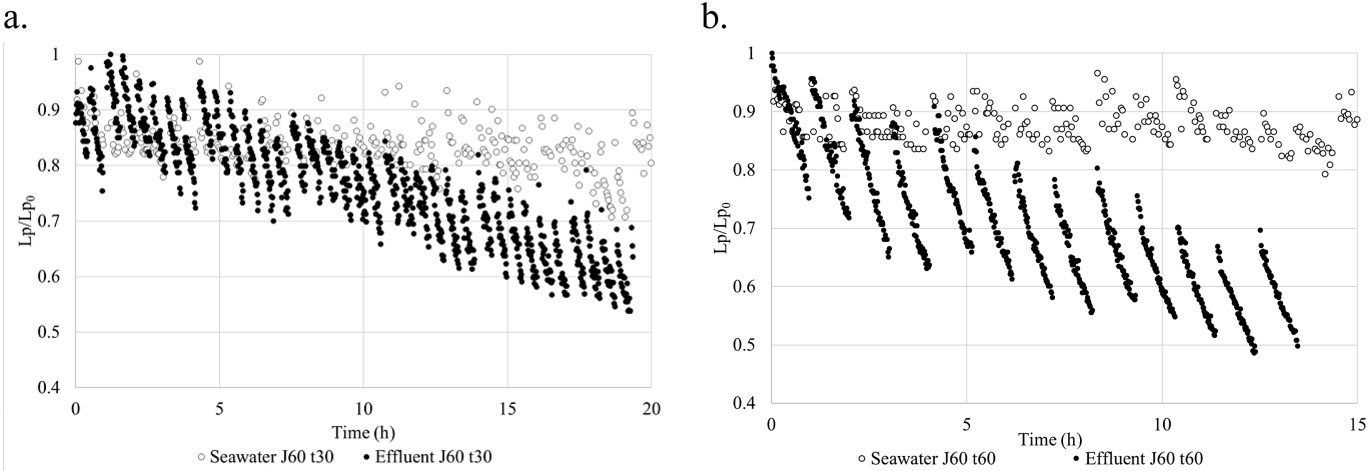
a.
b.
Lp/Lp0
Time (h)
Seawater J60 t30
Effluent J60 t30
Seawater J60 t60
Effluent J60 t60

Figure 3

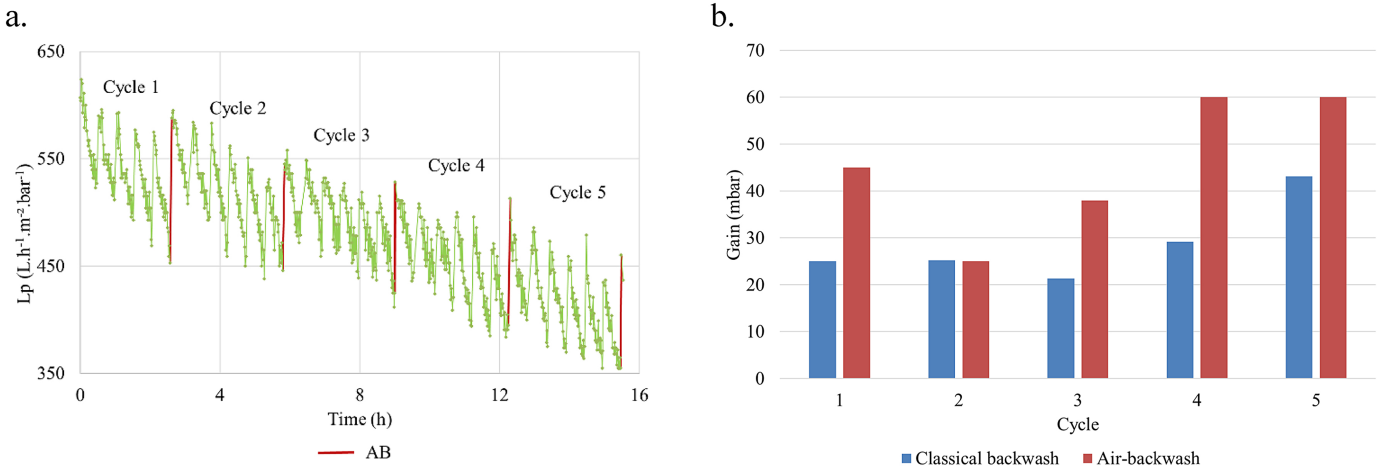
a.
650
550
450
350
Lp (L.h-1.m-2.bar-1)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Cycle 5
0
4
8
12
16
Time (h)
AB
b.
70
60
50
40
30
20
10
0
Gain (mbar)
1
2
3
4
5
Cycle
Classical backwash
Air-backwash

Figure 4

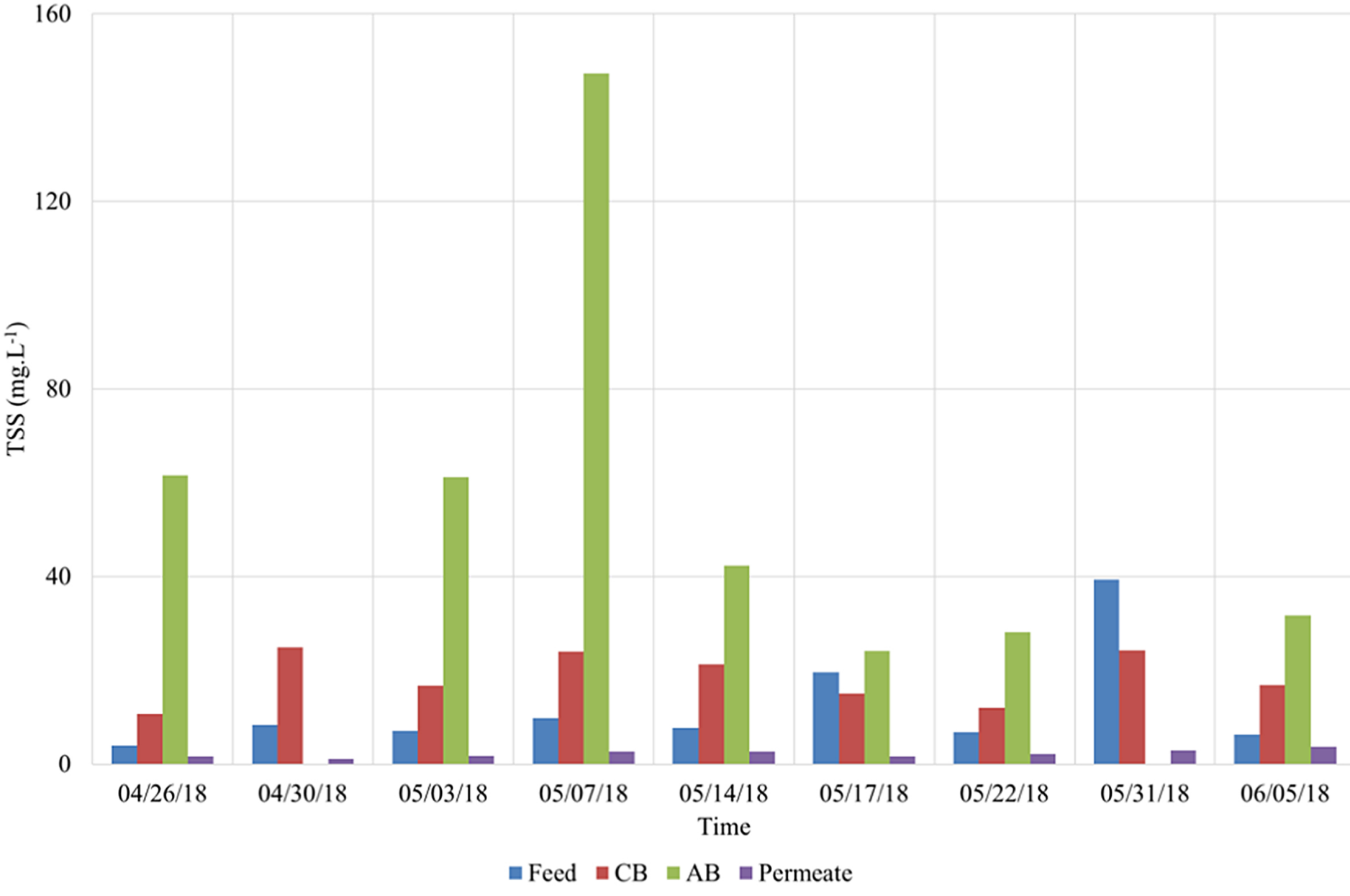
160
120
80
40
0
TSS (mg.L-1)
04/26/18
04/30/18
05/03/18
05/07/18
05/14/18
05/17/18
05/22/18
05/31/18
06/05/18
Time
Feed
CB
AB
Permeate

Figure 5