Characterization of ultrafiltration of undiluted and diluted stored urine

J. Ouma, S. Septien, K. Velkushanova, J. Pocock and C. Buckley

ABSTRACT

Urine ultrafiltration (UF) was studied in terms of flux, permeability, resistance and fouling. Two types of samples were used: stored urine representing the feedstock obtained from urine diversion dry toilets; diluted stored urine representing the feedstock obtained from urinals. Three different filtration experiment sets were adopted in this study. For the first case, pressure was set in an ascending order, i.e. from 10 to 60 kPa during filtration of stored urine. For the second case, pressure was set in a descending order, i.e. from 60 to 10 kPa for the same feed stream. The third case involved filtration of diluted urine with pressure in ascending order, i.e. from 10 to 60 kPa. The results indicated that diluted urine had higher flux than undiluted urine with maximum values of 43 and 26 $L \cdot m^{-2} \cdot h^{-1}$ respectively. Cake formation was the dominating fouling mechanism during urine filtration with a contribution of about 90% to the total hydraulic resistance. The contribution of chemically irreversible fouling was low (−2%), unless operating from high to low high pressures. Indeed, irreversible fouling appeared to be greater during the experiments starting at higher pressure. Although undiluted urine had a higher fouling potential compared to diluted urine, the specific cake resistance was higher for diluted urine, probably due to a more dense cake caused by lower particle sizes in that sample. The permeate obtained after urine filtration had much lower suspended solids content compared to the feedstock, with rejections up to 99%. The concentration of the ionic species remained unchanged, and 75% of the organic compounds and dissolved solids remained in the permeate. Urine UF could then be used as pre-treatment to remove suspended solids.

Key words | flux, fouling, permeability, rejection, stored urine, ultrafiltration

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INTRODUCTION

Sanitation is a major challenge for developing countries. According to World Health Organization (WHO) and United Nations International Emergency Children's Fund (UNICEF), about 2.5 billion people in developing countries lack access to proper sanitation facilities WHO and UNICEF (2013). This has led to the spread of water borne diseases and reduction of the quality of life of the affected people. The 'Reinvent the Toilet Challenge', initiated by the Bill & Melinda Gates Foundation, aims at providing novel sanitation systems with hygienic and sustainable disposal of the human waste. Human excreta can be a source of nutrients such as phosphorous and nitrogen for agriculture (Larsen *et al.* 2009). According to Schouw *et al.* (2002), humans excrete 1.6 to 1.7 g of phosphorous per day, 60% of which come from urine. Urine consists of up to 95% water that could be recovered for reuse after proper treatment.

Human waste, i.e. urine and faeces, can be separated at the source using urine diverting dry toilets (UDDTs) and urinals. During storage, urine hydrolyses naturally over time such that urea is converted by bacteria enzymes to ammonia and carbon dioxide (Tilley *et al.* 2008). Stored urine has a high content of solids, organic molecules, nitrogen (mainly in the form of ammonia), and ionic compounds such as phosphates, potassium, sodium and chloride. In addition, a variety of microorganisms, which may include pathogens, can grow in source-separated urine during storage, as a result of high content of biodegradable organic compounds and cross-contamination with faeces (Udert *et al.* 2006). The degradation of organic compounds and ammonia evaporation cause odours and a negative effect in the environment (Troccaz *et al.* 2013). Additionally, urine can also contain micropollutants, such as residual

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pharmaceutical products and hormones. Treatment is then necessary to deal with the environmental and health hazards that urine can pose. In addition, it is possible to recover valuable resources such as fertilizer and reusable water. Urine treatment is an emergent area with growing interest with the recent development of decentralized sanitation. Several technologies have been developed, but most of them are still found in a laboratory stage and only a few have been tested at larger scale. Some promising technologies so far are: precipitation of struvite (Wilsenach *et al.* 2007) distillation of nitrified urine (Udert & Wächter 2012) microbial fuel cells (Ieropoulos *et al.* 2012) freeze-thaw and adsorption (Ganrot *et al.* 2007) stripping of the ammonium and recovery through absorption (Basakcilardan-Kabakci *et al.* 2007) nanofiltration (Pronk *et al.* 2006) osmotic membrane separation (Zhang *et al.* 2014).

Microfiltration and ultrafiltration (UF) are membrane separation technologies that have high potential to be incorporated into the urine treatment chain, as they can contribute with the removal of solid, particles, bacteria, parasite eggs and organic molecules with sizes larger than the pores of the membranes. It has been already demonstrated their suitability for the treatment of domestic wastewater (Udert *et al.* 2003; Fane *et al.* 2011; Adams 2012). However, their application for urine processing is very scarce in literature, with only one publication to date (Triger *et al.* (2012), maybe because this topic is less attractive than processes for resource recovery. Nonetheless, microfiltration and UF could be employed as pre-treatment to increase the efficiency of the upstream processes. The removal of solids from urine would lead to the reduction of fouling, clogging and hindering phenomena, and would limit possible sources of contamination for the end-product (e.g. struvite). Besides, the biological hazard related to the presence of pathogens would be diminished by the possible retention of bacteria and parasite eggs, as demonstrated by Lazarova (2000) during disinfection of waste water using UF membranes.

The present study aimed to evaluate the suitability of UF for urine treatment. The critical parameters to characterize filtration, such as flux, fouling and rejection, were determined at different conditions. The flux indicates the amount of permeate that can be obtained during urine filtration. The loss of flux due to fouling is one of the main inconveniences of using membranes and has to be limited during filtration (Judd 2006). Fouling also reduces the life span of membranes. It should therefore be minimized by understanding its mechanisms and subsequently determining the optimum operating conditions during filtration to limit it. Rejections were measured so as to determine the efficiencies of the membrane to remove given compounds and if the target of permeate quality is achieved. Two types of feedstock were investigated: a stored urine representing the feedstock obtained from UDDTs; a diluted stored urine representing the feedstock obtained from urinals. Although constant flux mode is preferred in the large-scale membranes systems, a dead-end configuration (batch mode) was used in this work for practical and material availability reasons. Despite this, the experimental rig will provide valuable indications on the behaviour of urine filtration with UF membranes, and applicability of the process.

MATERIALS AND METHODS

Feedstock

The feedstock in this study was stored urine collected from a storage tank located in Newlands KwaMashu Research Centre in Durban, South Africa. The urine from the storage tank is issued from UDDTs installed within Durban metropolis. For some of the experiments, the sample was diluted with distilled water by a factor of 5 to reproduce the feedstock obtained from a low water consumption urinal, using 1 L of water (Tilley *et al.* 2008) to flush 250 ml of urine. The latter assumption was based on the average volume of 1.4 L of urine excreted by an adult per day, produced in around 6 to 8 urinations (Tilley *et al.* 2008; Rose *et al.* 2015).

Experimental setup

Filtration experiments were carried out using an Amicon® cell in dead-end configuration (batch mode) and UF polyethersulphone (PES) disc membranes with 76 mm diameter (PBVK07610) from Millipore. The disc membranes had a molecular weight cut-off of 500 kDa and an effective area of 0.00418 m^2. PES was selected as the membrane material because of its hydrophilic characteristics, wide range of pH operations, suitability for aqueous solutions, acceptable mechanical strength and presumed low fouling propensity (Baker 2012; Ramaswamy *et al.* 2013). The pressure was controlled using two pressure regulators and a pressure gauge. The permeate was collected in a beaker placed on a digital balance (Adam HCB602H) which was connected to a PC for data acquisition using LabVIEW software. The experimental setup is depicted in Figure 1. During operation, the filtration cell was

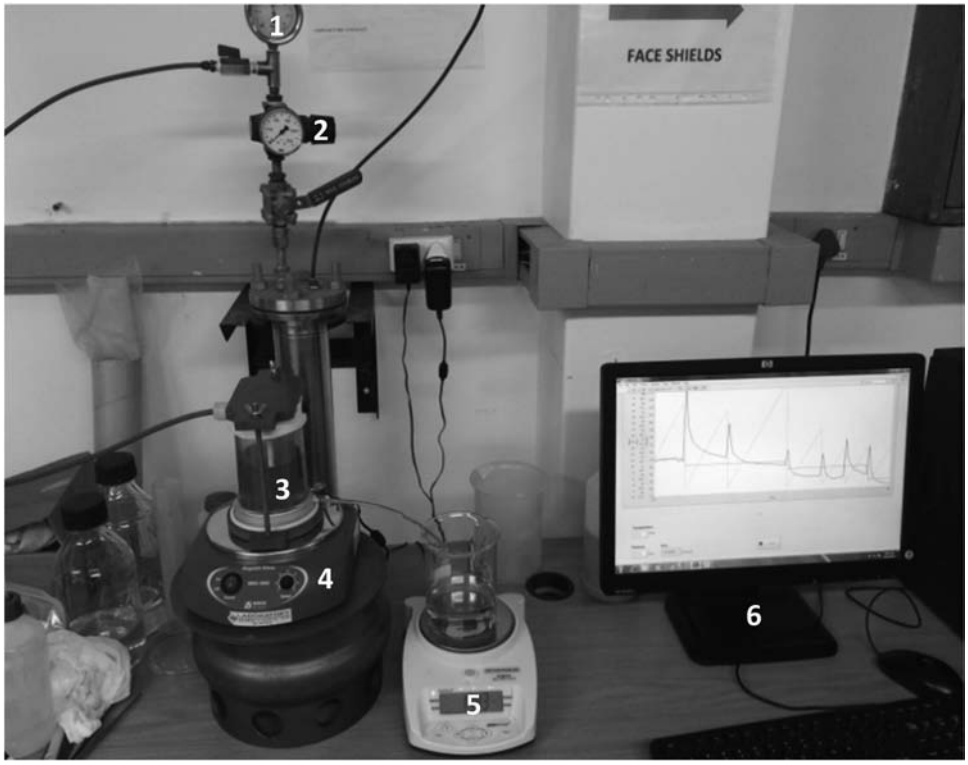


Figure 1 | Experimental setup (1: pressure gauge; 2: pressure regulator; 3: filtration cell; 4: magnetic stirrer; 5: weighing balance; 6: PC).

continuously mixed by a magnetic stirrer in order to maintain a homogenous solution and limit cake formation on the membrane.

Experimental methods during urine filtration

Filtration parameters such as flux, permeability, resistance, modified fouling index (MFI) and specific cake resistance were determined.

Flux determination

For each experiment, 350 ml of feedstock was added in the Amicon® cell. During filtration, the transmembrane pressure (TMP) was increased or decreased by 10 kPa after every 10 minutes. Three different filtration cases were studied. In case 1, filtration experiments were performed with stored urine by increasing the TMP in the range 10 to 60 kPa. In case 2, filtration was carried out by decreasing the TMP from 60 to 10 kPa. These experiments aimed to compare the behaviour of urine UF when the pressure is progressively incremented and when filtration starts straight at high pressure. In case 3, experiments were performed with diluted urine with TMP set from 10 to 60 kPa, in order to determine the effect of dilution.

During each TMP step, the flux declined until reaching a relatively constant value. The flux values at each TMP was presented as the average of the fluxes during the filtration time.

Permeability and resistances

Permeability and filtration hydraulic resistances of the membrane were measured through deionised water fluxes in the 3 following situations: using a virgin membrane; using this membrane after urine filtration; and after cleaning. Membrane cleaning was performed based on the manufacturer instructions and other methods from literature such as Waeger *et al.* (2010) and Legierse (2013). Membranes were cleaned by soaking them in a 0.1M NaOH solution for at least 30 minutes, followed by soaking in hydrochloric acid at pH 4 for 30 minutes and finally rinsing thoroughly with distilled water.

Clean water flux was measured using the same method as that used for urine permeate flux measurement. The graphs of clean water flux versus TMP were plotted as illustrated in Figure 2, so as to determine the permeability representing the slope of each graph. The membrane

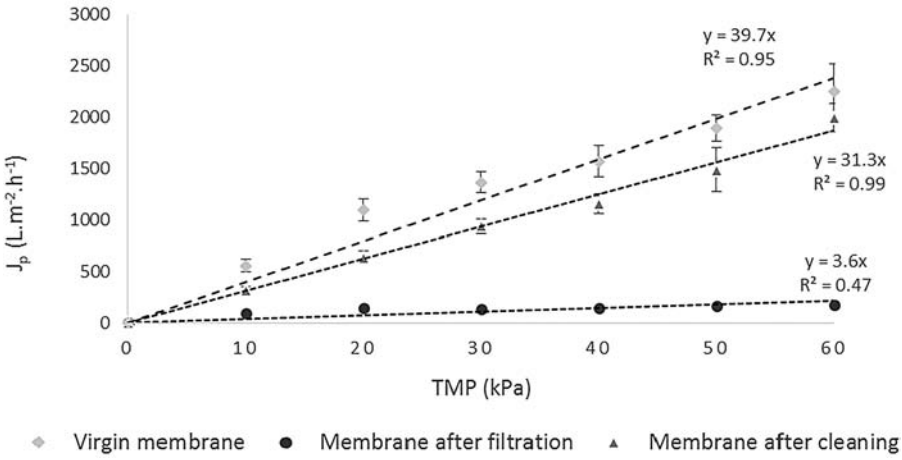


Figure 2 | Permeate flux as a function of the TMP for the virgin membrane, membrane after filtration and after cleaning, during the clean water flux tests for case 1.

resistances–intrinsic membrane resistance (R_m), resistance due to fouling (R_f) and the resistance due to cake layer (R_C)–were determined from the permeabilities using the general form of Darcy's law, shown in Equation (1).

$$J_P = \frac{\Delta p}{\mu(R_m + R_f + R_c)} \quad (1)$$

The parameters Jp, Δp and μ are the clean water flux [L·m^{-2}·h^{-1}], TMP [kPa] and viscosity water at 20 °C [Pa.s] respectively. The ratio $Jp/\Delta p$ represents the permeability [L·m^{-2}·h^{-1}·kPa^{-1}]. Flux can change as a function of temperature because of the viscosity dependence on temperature. Usually authors correct the flux to 20 °C, which is the reference value used in literature to normalize results (Judd 2010), as shown in Equation (2).

$$J_{P(20^\circ C)} = \frac{J_{PT}}{1.024^{(T-20)}} \quad (2)$$

The parameters $Jp_{20\,^\circ C}$, Jp_T and T are respectively the permeate flux corrected to 20 °C, the permeate flux at experimental temperature and the temperature during filtration.

R_m was obtained from the permeability of the virgin membrane, with R_f and R_c equal to zero. Knowing the value of R_m, R_f was calculated from the permeability of the membrane after use and cleaning, with R_c equal to zero. R_c was then deduced from the permeability of the membrane after filtration, with R_m and R_c already determined.

Typically, R_c is defined as membrane resistance removable by only physical means. In this work, R_c also includes the membrane resistance that can be cancelled by chemical means. Consequently, R_f refers to the chemically irreversible fouling that cannot be eliminated by any cleaning method, physical or chemical.

MFI and specific cake resistance

The MFI indicates the membrane fouling potential with a particulate feed stream (Le-Clech *et al.* 2003; Listiarini *et al.* 2009). This parameter was determined by measuring the permeate volume and the filtration time at 50 kPa. As illustrated in Figure 3(a), the filtration time divided by the permeate volume (t/V) was plotted against permeate

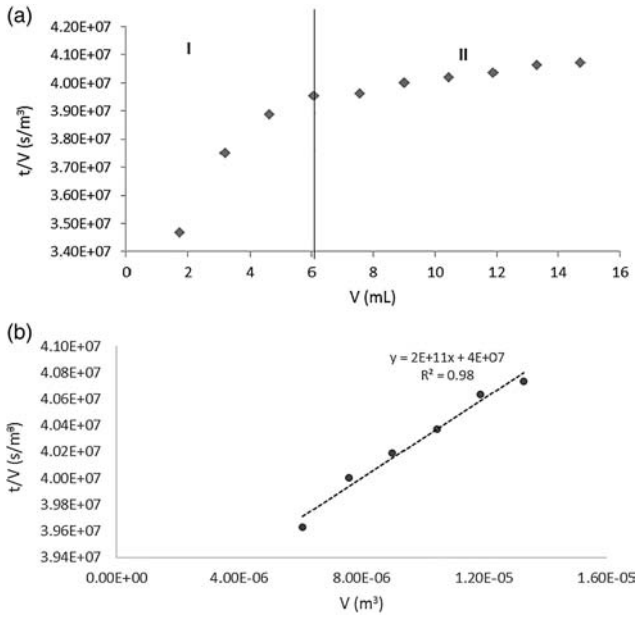


Figure 3 | Plots of t/V versus permeate volume at 50 kPa for case 1 – (a) entire curve; (b) linear section from the curve (section II).

volume (V). The slope of the linear section (section II) gives the MFI, as presented in Figure 3(b).

Specific cake resistance α is another fouling parameter. It is an indicator of the cake build-up mechanism and characteristics, such as porosity or particle size (Boerlage 2001; Chang and Kim 2005). A decrease in cake porosity or a decrease in particle diameter size leads to an increase in specific cake resistance (Madaeni 1999; Chang & Kim 2005).

The specific cake resistance can be deduced from Equation (3).

$$MFI = \frac{\alpha C_s \mu}{2S^2 * TMP} \tag{3}$$

The parameters C_s and S represent the mass of accumulated foulants in the cake per volume of permeate [mg·L^{-1}] and the membrane surface area [m^2] respectively. The mass of solids deposited on the membrane ($m_{foulants}$) can be approximated to the mass of the rejected compounds, according to Equation (4).

$$m_{foulants} = (C_{TS,\,feed} - C_{TS,\,permeate}) \times V \tag{4}$$

where $C_{TS,feed}$ and $C_{TS,permeate}$ correspond to the concentration of total solids (TS) in the feed stream and permeate [mg·L^{-1}], respectively. As Cs is defined as the ratio of $m_{foulants}$ to V, it was calculated using Equation (5).

$$Cs = C_{TS,\,feed} - C_{TS,\,permeate} \tag{5}$$

Physicochemical analysis of the streams

The concentrations of ionic species, organic matter, solids and particles were measured in the feed and permeate samples so as to monitor their rejection by the membrane. All the tests were done according to standard operating procedures based on those from for water and wastewater analysis (Federation and Association 2005). These are summarized in Table 1.

The rejections of chemical oxygen demand (COD), TS, total suspended solids (TSS), phosphates and chlorides were determined by Equation (6).

$$R = 1 - \frac{C_p}{C_f} \tag{6}$$

where R *is* the rejection, C_p is the permeate concentration and C_f is the feedstock concentration.

Statistical analysis

The uncertainty bars were determined using a t-student distribution at 95% confident interval. A total of 8 virgin membranes were used for the experiments: three membranes for case 1 and 3; two membranes for case 2. The experiments in each membrane were performed in duplicates. Each data point on the graphs represents the average of the replicate tests (6 replicates for cases 1 and 3; 4 replicates for case 2).

Table 1 | Parameters measured in this study

Parameter	Method of measurement	Purpose for measuring
COD	Closed reflux titrimetric method using potassium dichromate as oxidising agent	Determine the rejection of organic matter
TS	Weighing sample before and after oven drying	Determine the rejection of solids
TSS	Weighing of the residue from vacuum filtration before and after oven drying	Determine the rejection of suspended solids
Electrical conductivity	Conductivity meter (Hach MM150)	Indicator of changes in the ionic equilibrium of the solution after filtration
pH	pH meter (Hach MM150)	Indicator of changes in the chemical equilibrium of the solution and also to monitor the pH of solution so as not to damage the membranes
Phosphates	Spectroquant test kits and a spectrophotometer Merck KGaA 64293	Indicator of rejection of polyvalent ions
Chlorides	Sherwood chloride analyzer M926	Indicator of rejection of monovalent ions
Particle size analysis	Malvern Mastersizer 3000	Indicator of the particle sizes retained by the membrane

For the physico-chemical analyses, several replicates were performed for COD, TSS, TS, and Particle size, PO_4, Cl^-, EC and pH.

RESULTS AND DISCUSSION

Urine flux

Figure 4 presents the permeate flux of stored urine and diluted urine for the 3 case studies during urine UF.

In case 1, the flux increased up to 21 $L{\cdot}m^{2}{\cdot}h^{-1}$ from 0 to 40 kPa, then remained fairly constant at higher pressures. The stabilization of the flux was possibly due to the influence of fouling which was opposed to the increase of flux by increasing the pressure. A similar flux behaviour was observed by Defrance & Jaffrin (1999) during the filtration of wastewater at pressures between 0.4–1.4 bars in a membrane bio-reactor.

In case 2, the flux was the highest at the initial pressure, 60 kPa, with a value of 26 $L{\cdot}m^{-2}{\cdot}h^{-1}$. It then dropped to 21 $L{\cdot}m^{-2}{\cdot}h^{-1}$ at 50 kPa and remained relatively constant up to 20 kPa. At 10 kPa, the flux slightly decreased to 18 $L{\cdot}m^{-2}{\cdot}h^{-1}$. The highest flux at 60 kPa was due to the fact that the membrane was virgin at the beginning of the experiment. From 50 to 20 kPa, the flux was independent of pressure, possibly due to the fouling layer. The flux may have declined at 10 kPa because of the low TMP.

In case 3, the flux increased until reaching a maximum value (43 $L{\cdot}m^{-2}{\cdot}h^{-1}$). Then after, it declined from 20 to 60 kPa until around 34 $L{\cdot}m^{-2}{\cdot}h^{-1}$. From 20 to 60 kPa, flux decreased possibly because of the increasing influence of the fouling layer.

The significance of fouling can be clearly observed through the concentration volumetric ratio, i.e. the volume of permeate obtained during the filtration time divided by the initial feedstock volume (350 ml). During the clean water tests through a virgin membrane, the volumetric concentration ratio was equal to 1 as the entire feedstock permeated in less than 10 minutes for each TMP. In contrast, the permeate volume obtained after one hour of urine UF was about 120 ml for case 1 and 2, and 150 ml for case 3, leading to volumetric concentration ratio lower than 0.5. Indeed, the permeate fluxes for the three cases were very low if compared to the flux of pure water across the membrane (Figure 2), which highlights the strong influence of fouling during urine UF. Even for urine diluted by a factor of 5, the permeate flux was almost as low as that from an undiluted sample.

Operating at high pressure did not lead to higher fluxes during urine filtration, as no considerable gain in flux was observed after 10 kPa probably due to the fouling. Similar fluxes were obtained for case 1 and 2, while for case 3, the flux was slightly higher. These results could be corroborated to the calculated MFI values, indicator of fouling propensity. The MFI was the same for the both cases of undiluted urine filtration (-2×10^{11}), and lower for diluted urine (-8×10^{10}).

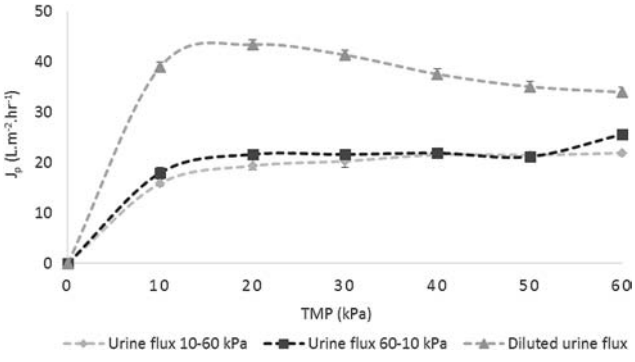


Figure 4 | Permeate flux versus TMP for case 1 (urine flux 10–60 kPa), case 2 (urine flux 60–10 kPa) and case 3 (diluted urine flux).

Permeability

Figure 5 presents the membranes permeabilities from the three cases studies. It can be seen that the permeability of the virgin membrane was relatively similar at an approximate value of 40 $L{\cdot}m^{-2}{\cdot}h^{-1}{\cdot}kPa^{-1}$ for the different cases. This result was expected as the same type of membrane was used. After urine filtration, the permeability of the membrane was drastically diminished to values lower than 4 $L{\cdot}m^{-2}{\cdot}h^{-1}{\cdot}kPa^{-1}$, due to high fouling. After membrane cleaning, a major part of the initial permeability was recovered for case 1 and case 3 (80%). Permeability recovery was lower for case 2 (40%).

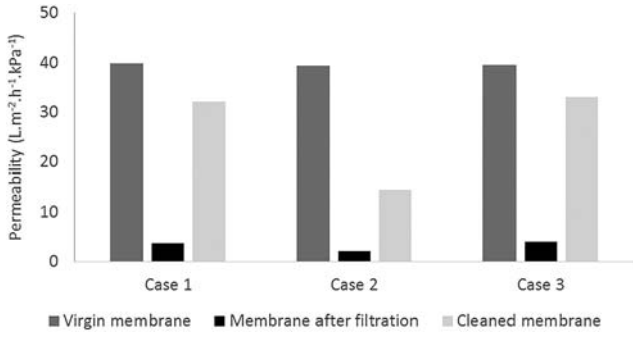


Figure 5 | Permeabilities of the virgin membrane, after urine filtration and after cleaning.

In summary, urine UF led to considerable fouling. Nevertheless, most of the fouling on the membrane could be cancelled with the cleaning method employed in this work, except for part of the fouling from case 2. The latter would probably require a more severe cleaning for its removal (for example by employing stronger chemical reagents and/or increasing the contact time; employing alternative mechanical methods such as backwashing). The reversibility of fouling seemed to depend on how the filtration had proceeded, particularly on the applied pressures experienced by the virgin membrane.

Hydraulic membrane resistances

Figure 6 displays the different hydraulic resistances and their contribution to the total resistance. The intrinsic membrane resistance was the same for all the cases as expected. Resistances due to irreversible fouling and cake were the same for case 1 and case 3, and higher for case 2, particularly with respect to irreversible fouling.

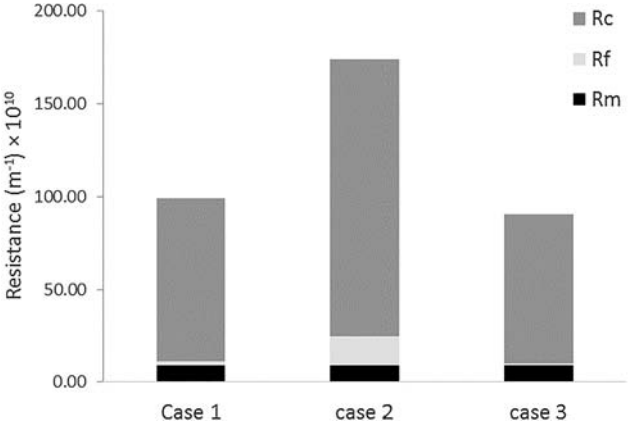
For each case, the cake resistance was the most influencing with a contribution to total resistance of over 85–90%, while the contribution of intrinsic membrane resistance remained below 10%. Irreversible fouling had the minimum contribution to the total resistance with a value lower than 2% for case 1 and case 3. Nonetheless, its contribution was higher for case 2 with approximately 10%. Therefore, irreversible fouling was low if formed at low pressure, but can increase if built at high pressures.

Fouling was considerably influenced by pressure during its formation. Fouling resistances, particularly irreversible fouling, was much higher when fouling build-up started at high pressures. Cake formation was by far the major fouling mechanism during urine UF.

Specific cake resistance

As seen in Figure 7, the specific cake resistance from diluted urine filtration (case 3) was higher than that of undiluted urine filtration (case 1 and 2). There was no difference of the specific cake resistance when operating from low to high pressure or vice versa. As known, the specific cake resistance depends on cake porosity and particle size. If the particle size of the foulants is lower, the formed cake is denser, hence a lower porosity. In fact, the space between the particles is reduced in the cake as particles have a smaller size. The higher specific cake resistance of diluted urine could be due to the smaller particle sizes in this sample, as indicated by the particle size distribution analysis in Figure 9. Undiluted urine showed particles with sizes ranging from 0.4 to 280 μm, with 85% in the range of 100 to 280 μm, while diluted urine contained particles with sizes in the range of 0.2 to 150 μm, with 92% in the range of 0.2 to 100 μm. Dilution should enhance the solubility of solids, leading to the decrease of particle size. Based on the particle size analysis, the flux decline observed during the incremental increase of the TMP (from 20 kPa), during diluted urine filtration (Figure 4), and could be then due to the densification of the cake.

From observation, after one hour of filtration at varying pressures from 10 to 60 kPa, the residue formed on the membrane was thicker and darker for undiluted urine as feedstock compared to the diluted sample (Figure 8). Nevertheless, the cake from diluted urine filtration was denser (higher specific cake resistance) and presented also a high hydraulic resistance (Figure 6).



Q4 **Figure 6** | Hydraulic membrane resistances during the filtration of stored urine and diluted stored urine.

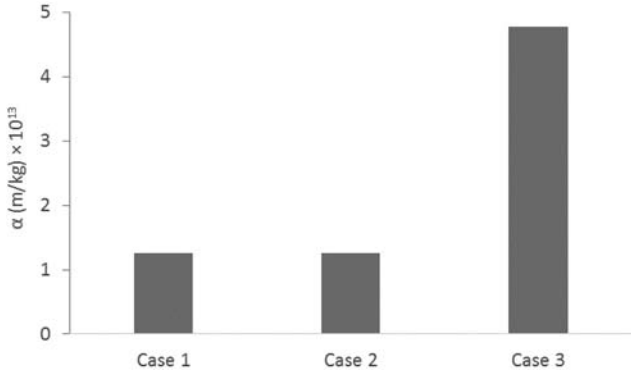


Figure 7 | Specific cake resistance estimated for the different experimental cases. Q5

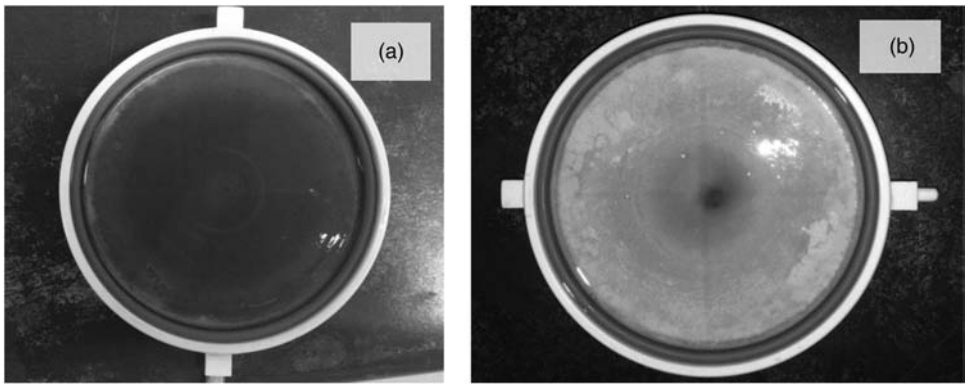


Figure 8 | Photographs of the membrane after urine filtration – (a) undiluted urine filtration; (b) diluted urine filtration.

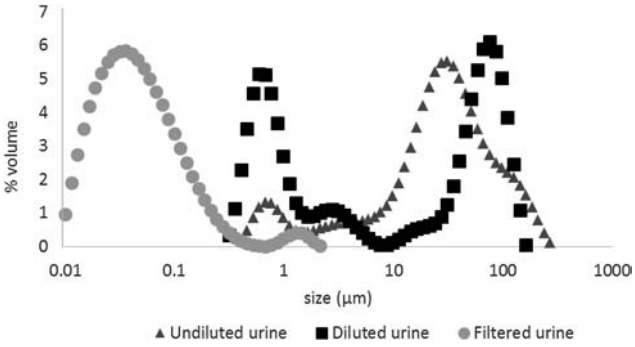


Figure 9 | Particle size distribution in the stored undiluted, diluted urine and permeate (filtered urine).

Rejections

Table 2 summarizes the physico-chemical properties of stored urine before and after filtration, and the rejections. The values measured for stored urine coincided with those reported in literature by authors such as Elisabeth (2009), Udert *et al.* (2003) and Pronk *et al.* (2007). Note that the suspended solids concentration represents only 2% of the TS. This means that most of the solids are found as dissolved in the urine.

Urine UF presented higher rejections than 99% for the TSS. These rejections can be related to the drastic decrease of particle size distribution after filtration: while in urine most of the particles were comprised in the range 10–100 μm, the particle sizes in the permeate were lower than 1 μm (Figure 9). About 25% of the COD and TS were rejected. A rejection about 23% was then estimated for dissolved solids. There was no rejection of the ions PO_4^- and Cl^-. Indicators of the ionic distribution, such as pH and electrical conductivity, demonstrated identical values for the raw urine and the permeate: pH was approximately 9 and the EC was approximately 25 $mS \cdot cm^{-1}$. These results suggest that no ions were rejected by the membrane.

In summary, the rejections achieved are those expected for an UF system, with permeate virtually free of solids larger than 0.1 μm and without alteration of the ionic composition. The membrane was able to reject a part of

Table 2 | Physico-chemical analysis on the undiluted urine and the permeate after filtration (case 1)

	Feedstock					Permeate				
Parameter	**Unit**	**Min**	**Max**	**Average**	**±**	**Min**	**Max**	**Average**	**±**	**Rejection (%)**
COD	$mg \cdot L^{-1}$	1,591	2,776	2,176	501	1,206	1,982	1,599	322	26.5
TSS	$mg \cdot L^{-1}$	240	270	258	10	0	5	1	2	99.6
TS	$mg \cdot L^{-1}$	10,013	12,620	11,369	533	8,013	9,613	8,635	681	24
PO_4	$mg \cdot L^{-1}$	242	256	245	4	216	252	240	13	2
Cl^-	$mg \cdot L^{-1}$	3,980	4,020	4,000	16	3,960	4,000	3,980	16	0.5
Particle size	μm	41.2	45.3	43.1	2.1	0.01	0.1	0.1	0.03	
EC	$mS \cdot cm^{-1}$	20.1	32.9	26.5	4.0	20.8	32.6	26.5	3.7	
pH	–	8.7	8.9			8.7	8.9			

dissolved solids and organic compounds, but the major part was still present in the permeate.

CONCLUSIONS

UF of stored urine led to relative low permeate fluxes due to high fouling. Under low pressure experimental conditions, urine filtration was more convenient as it resulted in no gain in permeate flux if pressure was increased over 10 kPa, and limited fouling.

Filtration of diluted urine led to slightly higher permeate flux compared to undiluted samples. In fact, dilution decreased the fouling potential of the membranes and resulted in the formation of a thinner cake layer. However, fouling was still considerable in this case and the resulting cake was denser compared to that formed from undiluted urine.

The membrane cleaning method employed in this work, mixing chemical and mechanical processes, was effective to remove most of the fouling. However, the efficiency of this method was reduced if the fouling was built-up at the higher pressures. Indeed, operating at high pressures decrease fouling reversibility.

The permeate obtained after urine UF was much lower in solids compared to the feedstock. Particularly, the entire suspended solids in the urine were filtered. However, the concentration of the ions remained unchanged and the concentrations of organic matter and dissolved solids were still relatively high.

UF is suitable for urine pre-treatment because of its capability of removing suspended solids and particles larger than 0.1 μm that can negatively affect up-stream processes. However, fouling can be a major problem which will drastically limit the performance of the UF unit. The process could be significantly improved by methods limiting cake formation, for example through high turbulence and stirring near the membrane surface. In addition, irreversible fouling have to be minimized during urine UF, as it will lead to a perdurable deterioration of the membrane performance. For instance, operating at too high TMP should be probably to be avoided. The development of performing cleaning methods would also be critical to limit fouling irreversibility.

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