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E. N. Peleka[a]; K. A. Matis[a]
[a] Department of Chemistry, Aristotle University, Section of Chemical Technology & Industrial Chemistry, Thessaloniki, Greece

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Bioremoval of Metal Ion and Water Treatment in a Hybrid Unit

E. N. Peleka and K. A. Matis
Section of Chemical Technology & Industrial Chemistry, Department of Chemistry, Aristotle University, Thessaloniki, Greece

Abstract: Several biomass types, such as yeast (in the present *Saccharomyces*, a brewery waste), have been reported to remove heavy metals (i.e., zinc) from aqueous solution. The separation of metal-loaded biomass and hence, the production of a clean water stream using a hybrid flotation-microfiltration unit were investigated. The hybrid cell consisted of a microfiltration module submerged directly into a flotation cell. Air bubbling, constituting the transport medium during flotation, meanwhile has been used in order to limit the membranes fouling. The effects of air sparging, the solid particle content, and the type and concentration of flotation reagents on the performance of the hybrid process were the main examined parameters.

Keywords: Biosorptive flotation, biomass, hybrid system, membrane, microfiltration, saccharomyces

INTRODUCTION

Remediation of contaminated groundwater remains one of the most intractable problems of environmental restoration (1). Contaminants typically enter groundwater at concentrations that are thousands times above risk-based action levels and then disperse as they are carried through aquifers in flowing groundwater. Chemical phenomena, such

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Address correspondence to E. N. Peleka, Section of Chemical Technology & Industrial Chemistry, School of Chemistry, Aristotle University, PO Box 116, GR-54124, Thessaloniki, Greece. Tel.: +30-2310997836; Fax: +30-2310997759. E-mail: peleka@chem.auth.gr

as slow dissolution of contaminant sources or slow desorption from the aquifer matrix, further limit the success of remedial efforts. Having in mind the adverse effects of heavy metals environmental agencies set permissible limits for their levels in drinking water and other types of water. The maximum allowable limit for zinc (for example) in discharged water was set by the Environmental Protection Agency to be 5 mg L^{-1}.

Treatment processes employed for toxic metal removal from wastewater may involve precipitation with disposal of the resultant sludge or recovery, membrane processes, ion exchange resins, although these are often expensive and ineffective at low metal concentrations. Therefore, there is a need for a cost-effective treatment method that is capable of removing low concentrations of metal from solution. Biosorption is not anymore a property of certain types of inactive, non-living microbial biomass to bind and concentrate heavy metals from even very dilute aqueous solution. Biomass exhibits this property, acting just as a chemical substance, as an adsorbent or ion exchanger of biological origin. The advantages of biosorption in contrast to bioaccumulation are as follows (2–3):

- Growth-independent biomass is not subject to toxicity limitation of cells. No requirement of costly nutrients required for the growth of cells in feed solutions. Therefore, the problems of disposal of surplus nutrients or metabolic products are not present.
- Biomass can be procured from the existing fermentation industries, which is essentially a waste after fermentation.
- The process is not governed by the physiological constraint of living microbial cells.
- As non-living biomass behave as an adsorbent, the process is very rapid and takes place between a few minutes to a few hours. Metal loading on biomass is often high, leading to efficient metal uptake.
- Because cells are non-living, the processing conditions are not restricted to those conducive for the growth of cells. In other words, a wider range of operating conditions such as pH, temperature, and metal concentration is possible. No aseptic conditions are required for this process.

Centrifugation, being a conventional separation method in microbiology and biochemistry, is relatively expensive, considering the power demand per unit of microorganism cells recovered. Therefore, alternative biomass separation methods, such as flotation, are worthy of being examined (4). That microorganisms, both living and dead, and products derived from the organisms, can function as flotation and flocculation agents is abundantly clear (5). Yeast has been used by humans for over

6,000 years for a variety of applications and it is presently one of the most important commercial microorganisms.

Gaudin, back in 1962, examined the flotation of *Escherichia coli, Bacillus cereus, B. subtilis, B. megaterium*, and *Serrata marcescens* (6). In a survey, the application of the flotation process to microbiology was studied based particularly with *B. cereus* (7). Flotation of bacteria and materials causing color in water was elsewhere reported (8), while Grieves dealt also with six species of bacteria (9). In an excellent work, (dissolved-air) flotation of algae and activated sludge, among other materials, was analysed (10); mention was also made to electrolytic flotation. Another efficient separation method is membrane filtration that is increasingly employed for the removal of bacteria and other microorganisms, particulate material, and natural organic material, which can impart color, tastes, and odors to water, and react with disinfectants to form disinfection byproducts (11–12). A hybrid process consisting of coagulation and ultrafiltration was published (13).

The principal limitation of membrane processes lies in membrane fouling, which is mainly associated with the deposition of a biosolids cake layer onto the membrane surface, thus limiting the permeate flux. Membrane fouling leads to frequent cleaning and/or replacement of membranes, which then increases operating costs. Gas sparging has been used for fouling prevention or treatment (14–15).

The scope of the current paper is to investigate the separation of zinc-loaded biomass and the production of a clean water stream using a hybrid flotation-microfiltration unit. As the cost of biomass production for biosorption applications would be possibly economically prohibitive on an industrial scale, the use of waste microbial biomass has been considered as an alternative option (16). The hybrid cell consisting of a micro-filtration module submerged directly into a flotation cell. Air bubbling, constituting the transport medium during flotation, meanwhile has been used in order to limit the membranes fouling. The application upstream of biosorption, as the metal ions removal technique and the study of the behaviour of this new innovative hybrid unit constitute the original part of the work.

EXPERIMENTAL

In this study, use was made of waste slurry (65% humidity) of brewery yeast *Saccharomyces* kindly supplied by a local brewery (Amstel). The yeasts were kept at a temperature of 4°C in pure tissues rinsed with deionized water. The source of zinc was $Zn(NO_3)_2 \cdot 6\ H_2O$ solution prepared on filtered tap water. The sample

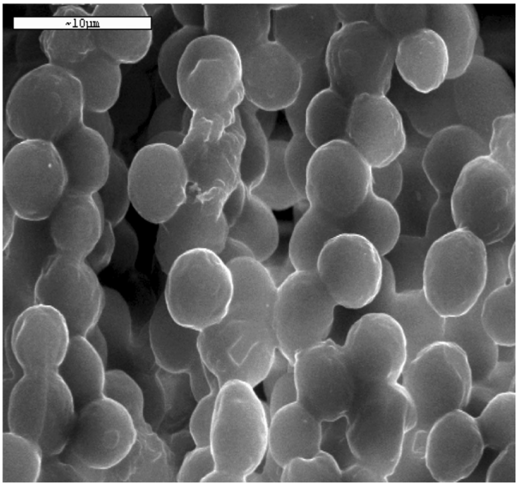


Figure 1. SEM images of the brewery waste yeast.

was analyzed using a scanning electron microscope (SEM) and its micrographs are presented in Fig. 1.

Batch dispersed-air flotation experiments were carried out at ambient temperature using a microcell, consisting from a Plexiglas column (3.4 cm diameter and 500 mL volume), which was connected through a rotameter, a washing trap and a 3-way valve to the main air pressure supply system of the laboratory. The necessary requirements for the flotation process gas bubbles were created by an appropriate porous diaphragm (Schott G4), located at the bottom of the flotation column. The dispersed-air flotation technique was preferred than the dissolved-air flotation (17). A disadvantage of flotation lies in the fact that the removal efficiency may be reduced, if some of the undesired substances are not sufficiently hydrophobic, thus remaining in the bulk dispersion (or solution).

The hybrid flotation-microfiltration cell consisted of a cylindrical flotation column made of plexiglas (i.d. $D_C = 100$ mm) equipped with a ceramic gas sparger with an average porosity $D_{por} = 40$–$100\,\mu m$, placed 20 mm from the flat bottom of the column. The air supply in all investigations was determined by that which was required for the flotation process. Hence, certain limitations were imposed from the decision to work in a hybrid cell. Further, to achieve stable membrane performance with higher fluxes, backflushing proved to be necessary (12).

A membrane module comprising a twin set of parallel, double-sided ceramic (97.1% Al_2O_3 and 2.9% SiO_2) membranes was positioned at a distance of 60 mm above the gas sparger. The membranes were hydrophilic, had a mean pore size of 0.3 μm and a total surface area of 0.021 m^2. Many of the present membrane processes employ polymer membranes; however, ceramic membranes have some significant advantages in various respects (11).

A small amount (2 g L^{-1}) of yeast, was dispersed in a mixing tank containing a zinc solution with an initial Zn^{2+} concentration of 50 mg L^{-1}, and was then fed at a constant flow rate into the hybrid cell using a peristaltic pump. Clean water permeate was drawn at a constant flow rate from the membrane module using another peristaltic pump.

In this compact hybrid unit apparently no energy was added for fouling control of the membraness, further to that required for flotation, leading to low operation costs of the process compared to conventional membrane filtration (18). For the flotation phase of the process, cetyl-trimethylammonium bromide (CTMA–Br) was used as collector (in most cases), to render the yeast or the zinc-loaded yeast particles hydrophobic, at a concentration of 20 mg L^{-1}. Moreover, a cationic synthetic flocculant Zetag 63 (of ex-Allied Colloids) was used in order to promote flocculation by causing colloids and other suspended particles in liquids to aggregate. As a target for the flotation process was set an (at least) 90% solid particles recovery, i.e., only the rest ~10% would be treated by the membranes themselves.

RESULTS AND DISCUSSION

Biosorption applied for the effective removal or recovery of dissolved metals from aqueous waste streams is based upon several mechanisms, the most important of them being physical adsorption (electrostatic forces), ion exchange, surface complexation, and surface precipitation (19–20). On biomass surfaces several chemical groups may be present, which could attract and subsequently sequester metal ions from the surrounding aqueous environment, such as acetamido groups of chitin, amino and phosphate groups of nucleic acids, amino, amido, imino, sulphydryl, and carboxyl groups of proteins. Attention should be paid to the possible influence of pH on these chemical species. Nevertheless, the presence of particular functional groups does not necessarily guarantee their accessibility as sorption sites due to the possible co-existence of steric, conformational or other types of barriers.

Sorption of zinc ions was strongly affected by the pH value of the metal solution. Maximum sorption of Zn(II) from the tested concentration (50 mg L^{-1}) occurred at pH 7.0–7.5. It is known, as can be calculated from thermodynamics (i.e., the Mineql programme), that for the above conditions, zinc precipitates out as hydroxide around the pH value of 8.3 reaching almost 100% recoveries and this percentage decreases at higher zinc concentrations. Nevertheless, zinc redissolves at a pH of about 11. It should be also noted that between a hydrolyzed metal ion and its undissolved hydroxide, an intermediate stage exists where the cation starts to polymerize and gradually as this proceeds, the corresponding hydroxide appears, the oxygen atom playing the role of a bridge.

Sorption of Zn(II) increased with a rise in pH, may be due to the fact that the functional groups of biomass are protonated at low pH and thus unavailable for binding the metal ions. As pH increases, the concentration of protons in the solution decreases, and hence these functional groups efficiently release their protons in the solution and become available for the binding of positively charged metal ions. The other possible explanation for enhanced metal sorption with increase in pH is the lowering of concentration of protons in the solution that are known to compete with metal ions for the binding sites. Sorption of Zn(II) by the brewery yeast was very rapid attaining the equilibrium within 30 min. Preliminary attempts of biomass regeneration and reuse for metal removal purposes were carried out in five subsequent treatment cycles, using 0.1 M sodium hydroxide (Fig. 2). The zinc desorption was almost 100%, while during the subsequent treatment cycles the brewery yeast can remove Zn(II) with about the same high effectiveness.

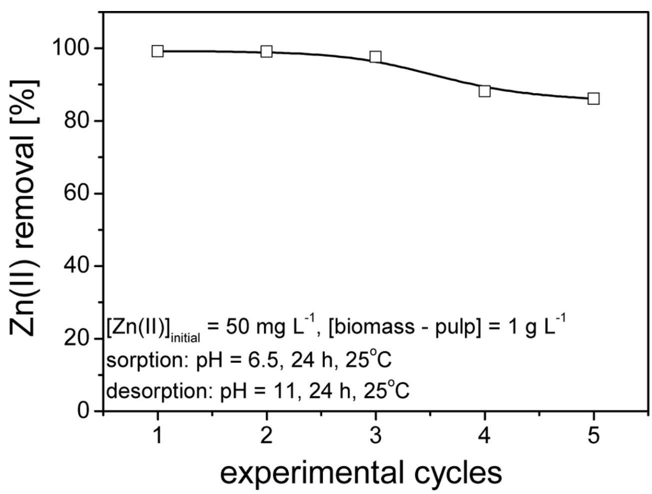


Figure 2. Sorption capacity of brewery yeast following multicycles operation treatment.

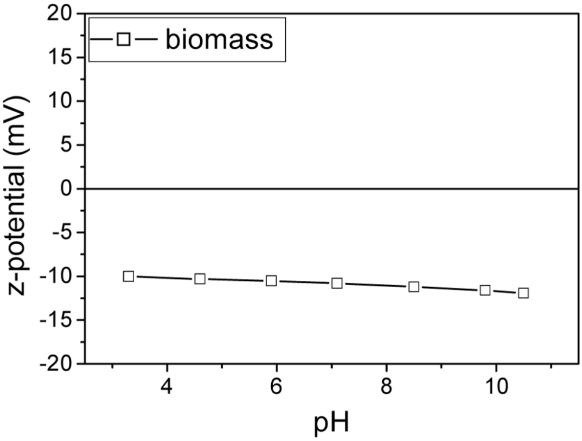
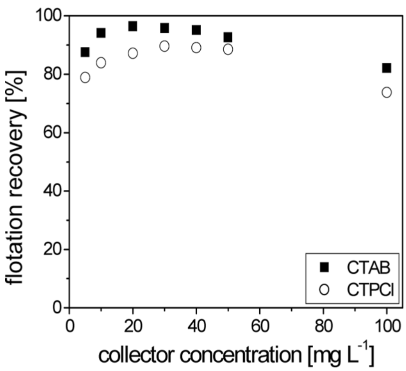


Figure 3. Electrokinetic measurements of brewery yeast as a function of solution pH.

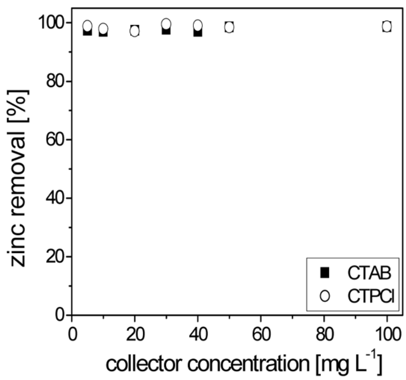
The preliminary electrokinetic study, presented as Fig. 3 for the case of yeast, provided certain preliminary information, regarding the type of necessary addition of surfactant for the induced separation of fine particles by flotation. The observed negative surface charge throughout the examined pH range (3–11) proved the application of a cationic surfactant to render hydrophobic, and hence floatable, the yeast.

Typical batch flotation experiments were conducted in order to certify the process. Representative results, concerning the flotation recovery and zinc removal efficiency are presented in Fig. 4. The separation of biomass by flotation was examined at natural pH value (6.0–6.5), by applying different concentrations of cetyl-trimethyl-ammonium bromide as collector and Zetag 63 as flocculant. It was observed that the obtained recoveries of solids were higher in case of CTAB and using $20\,mg\,L^{-1}$ the flotation recovery was in the order of 95%. The use of cetyl-pyridinium chloride (denoted as CTPCl), another cationic surfactant, was also tested, although it produced lower recoveries and therefore, further experiments with this collector were not performed.

In a solid/liquid/gas system, as the present, hydrophobicity plays a significant role; being, however, a complex phenomenon and the result of different interactions. The hydrophobicity of bacteria cells is mainly due to the properties of the cell wall, i.e., the biosorption sites, which strongly depend upon the presence of various polysaccharides, proteins and lipids that form a biopolymer layer (1). Related work on hydrophobicity, with surface tension, contact angle, and zeta-potential measurements, correlated well with the flotation results.



(a)



(b)

Figure 4. Batch flotation experiments using the brewery waste yeast: (a) effect of type and concentration of collector on flotation recovery, and (b) removal of zinc ions with 2 g L^{-1} yeast; $[Zn^{2+}] = 50$ mg L^{-1}, [Zetag 63] = 2 mg L^{-1}, sorption time = 10 min, conditioning time = 10 min, flotation time = 3 min, air flow rate = 160 cm^3 min^{-1}, pH = 6 – 6.5.

As far as the zinc ions are concerned, their removal was almost always total (Fig. 4b) for the tested experimental conditions. The removal of zinc is obviously affected by various physicochemical parameters, e.g., pH, zinc initial concentration, biomass concentration, among others; however, all these parameters were kept constant. In previous work, it was shown that the problem of effective metal removal was merely a matter of the adsorbent (zeolite) quantity (11). It is also noted that the applied pH value is lower, by around one unit, of that where zinc is expected to precipitate out as hydroxide (1). This innovative system was successfully examined *in situ* with a real industrial wastewater at an open pit copper mine of Assarel-Medet (Bulgaria); the precipitate flotation and the adsorbing colloid flotation techniques were also tried.

Fouling describes the gradual deterioration of membrane performance in terms of permeation flux (and selectivity) due to the accumulation of solids on its surface and/or inside its pores. The flow rate of the clean water and the pressure drop through the membrane (termed trans-membrane pressure, *TMP*) were continuously monitored; the pressure gauge reading being corrected by the difference of the height of the water level in the column. The decline of permeate flux and/or the increase in transmembrane pressure are direct results of membrane fouling. The permeate flux is calculated from the corresponding flow rate and the membrane surface, while TMP allows the calculation of the membrane permeability. The total resistance of the fouling layer is typically related to the permeate flow rate using Darcy's law (12). From the suspension and gas flow rates it is possible to calculate the corresponding superficial velocities, which may be more useful for comparing results obtained in different-scale equipment.

The major obstacle in the extensive use of a microfiltration (MF) unit in water and wastewater treatment is membrane fouling (21), which is a generic term; much of the information that we have in the area is coming from the membrane bioreactors. The mechanisms of membrane fouling include those of pore blocking, concentration polarization and cake formation. The next step was the separation of zinc loaded yeast from the clean water applying membrane microfiltration or membrane microfiltration combined with the flotation process. Figure 5 presents the effect of air superficial velocity on trans-membrane pressure, permeability, and total resistance, for the simple microfiltration process. As the air flowrate

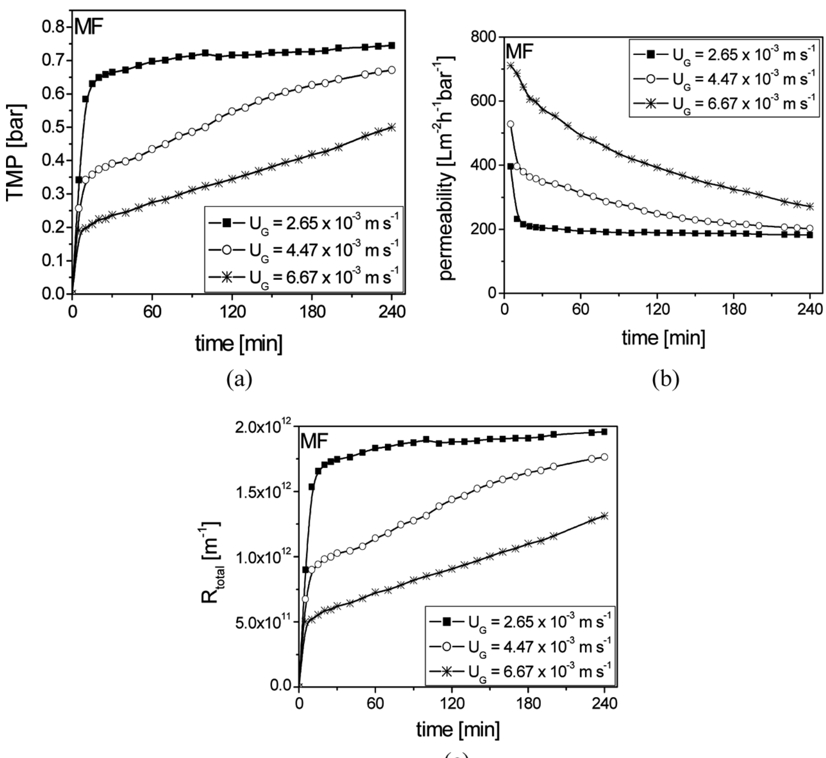


Figure 5. Effect of air superficial velocity (U_G) on (a) trans-membrane pressure, (b) permeability and (c) total resistance for the simple MF process; [yeast] = $2\,g\,L^{-1}$, [Zetag 63] = $2\,mg\,L^{-1}$, $U_L = 1.01 \times 10^{-4}\,m\,s^{-1}$.

(expressed here as superficial velocity) was increased, the TMP and total membrane resistance in simple microfiltration systems was decreased. Injecting gas into the feed stream to create a gas–liquid two-phase cross flow can effectively control cake formation in microfiltration, thus enhancing the permeate flowrate.

The influence of bubbling in membrane applications depends on the relative dimensions of the flow path and the bubbles. In the majority of cases bubbles behave as slugs in close proximity to the membrane surface; these slugs create very high shear stresses on the membrane wall and improve the performance of membranes (14,22). A notable increase of TMP due to malfunction of collector dosing was noticed during a 3-days operation of a similar system in UPT Institute of Saarbrücken (18).

The effect of gas flow rate on the hybrid process (see Fig. 6) is more complex, since air bubbles are involved not only in membrane surface cleaning but also in the removal of solid particles by flotation. The increase of air velocity affected positively the hybrid cell performance, but up to a critical value ($u_G = 0.447\,cm\ s^{-1}$), beyond which any additional increase resulted in the same results.

A comparison is possible with the aforementioned case of no flotation. So, after 4 hours of operation with the medium air flowrate ($0.447\,cm\ s^{-1}$), the trans-membrane pressure was 0.428 bar for the hybrid system, compared with 0.671 bar for microfiltration alone (Fig. 7). Thus, it is evident that the removal of the solid particles by flotation is

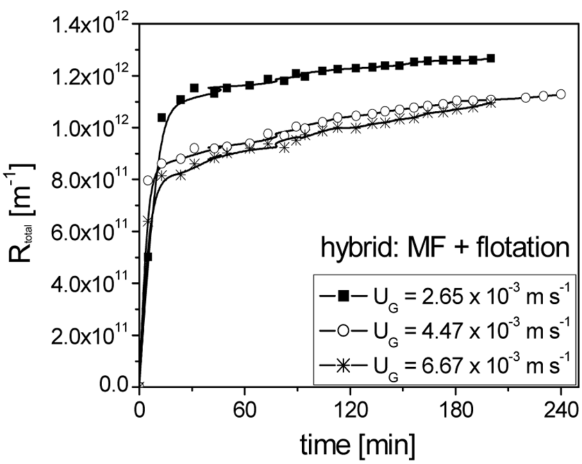


Figure 6. Effect of air superficial velocity (U_G) on total resistance for the hybrid flotation – MF process; [yeast] = $2\,g\,L^{-1}$, [CTAB] = $20\,mg\,L^{-1}$, [Zetag 63] = $2\,mg\,L^{-1}$, $U_L = 1.01 \times 10^{-4}\,m\,s^{-1}$.

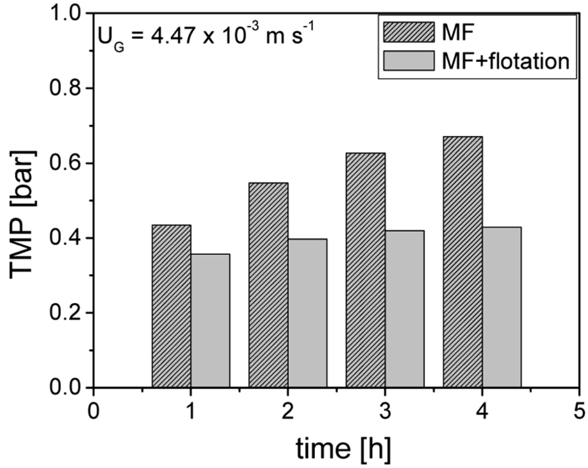


Figure 7. Improvement of hybrid flotation – MF system operation as compared with simple MF system with air sparging.

beneficial to the overall process since it considerably reduces membrane fouling. At higher air flowrates problems were observed with flotation due to turbulence.

It is interesting to note, from earlier work, a comparison on the influence of zeolites (of 3 μm particle size) between the simple microfiltration and the hybrid process, with ten times different particles load. Membranes fouling and hence, efficient operation is expected to be a function of their loading with solid particles. As it was shown, the effect of increasing the input concentration had only little influence in the case of the hybrid cell.

In order to determine the effect of solids concentration on membrane performance, three different wastewater feeds were tested in the experiments 0.2, 1.0, and 2.0 g L^{-1} and the results are illustrated in Fig. 8. The higher solids concentration corresponds to a higher membrane resistance. For example, after 3 h of operation with initial 0.2 g L^{-1} yeast, the total resistance was $5.2 \times 10^{11}\,m^{-1}$ and with 2 g L^{-1} membrane resistance was $1.0 \times 10^{12}\,m^{-1}$. Therefore, during a typical filtration period the TMP was increased and the permeability was decreased as solids accumulated on the membrane surface.

Backflushing is an *in situ* method, in which the permeate is periodically forced back through the membrane in the reverse direction to normal permeate flow, in order to flush out the accumulated fouling material from the membrane pores and the membrane surface (18). The cake layer would normally be re-suspended in the cell. Periodic backwashing

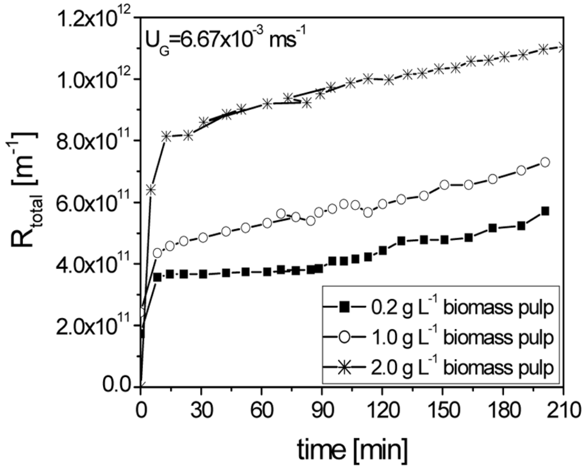


Figure 8. Effect of solids concentration on total resistance for the hybrid flotation – MF process; [CTAB] = 20 mg L^{-1}, [Zetag 63] = 2 mg L^{-1}, $U_G = 6.67 \times 10^{-3}$ m s^{-1}, $U_L = 1.01 \times 10^{-4}$ m s^{-1}.

improves membrane permeability and reduces fouling, thus leading to optimal, stable hydraulic operating conditions. Conventionally, backflushing has been applied with a typical regime of reverse flow for 5 or 10 s at intervals of 5 or 10 min, or with longer time periods (23). Experimental results have shown that the average permeate flux was higher for backflushed systems, compared to standard, non-backflushed systems (24). An undesirable consequence of backflushing is a slight reduction of the membrane cell operating time.

The interesting, in the present case, was the parallel operation of flotation with the backflushing. Figure 9 presents selected results for membrane backflushing frequencies every 5 min or 15 min, lasting each time either 5 s or 10 s. A backflush duration of 5 s at frequency of backflushing, $f_{BF} = 12\,h^{-1}$ was found to be satisfactory, giving low TMP drops and resistances and high permeability values. When the backflush duration was doubled, the TMP evolution deteriorated.

In the microfiltration of bacterial suspensions, the cake layer is often the largest hydraulic resistance, because of the highly compressible nature of the cell cake. The effect of particle size was related to the specific cake resistance using the Carman-Kozeny equation, showing that the particle size has an integral role in determining the flux, with larger particle size leading to higher flux (25). Adding flocculation-coagulation agents limits membrane fouling by aggregation of the colloidal fraction, thus reducing internal clogging of the membranes (26).

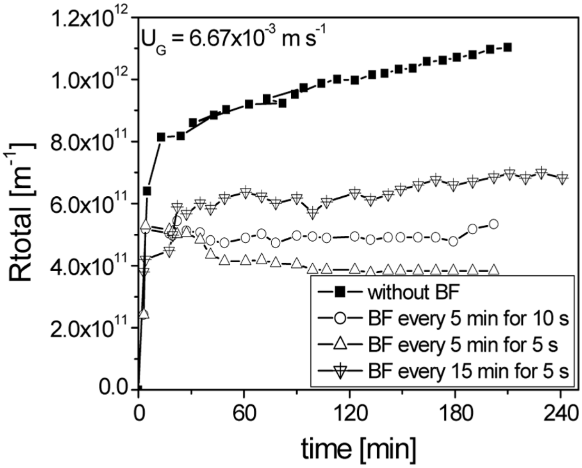


Figure 9. Effect of frequency and duration on total resistance for the hybrid flotation – MF process; [CTAB] = 20 mg L^{-1}, [Zetag 63] = 2 mg L^{-1}, $U_G = 6.67 \times 10^{-3}$ m s^{-1}, $U_L = 1.01 \times 10^{-4}$ m s^{-1}.

This suggests flocculation could be an effective treatment for the complex systems. Figure 10 presents the effect of the commercial flocculant (quaternary acrylate salt and acrylamide) concentration on total membrane resistance for the hybrid system. The proper flocculation of biomass, which will in part depend on the surface zeta-potential, will

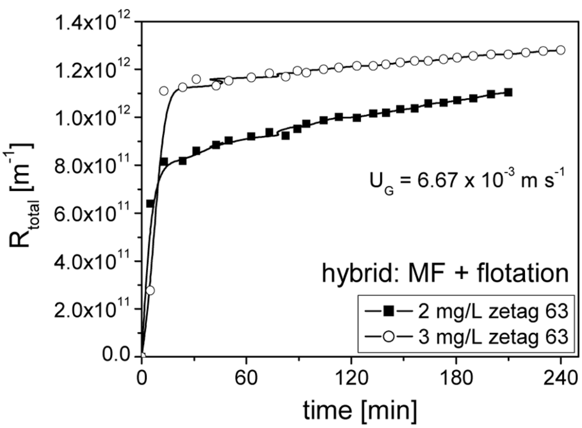


Figure 10. Effect of flocculant concentration on total resistance for the hybrid flotation – MF process; [yeast] = 2 g L^{-1}, [CTAB] = 20 mg L^{-1}, $U_G = 6.67 \times 10^{-3}$ m s^{-1}, $U_L = 1.01 \times 10^{-4}$ m s^{-1}.

assist its subsequent separation. The amount of polyelectrolyte that must be added to the suspension to obtain the desired degree of flocculation depends strongly on the characteristics of the suspension and the polyelectrolyte.

Table 1 gives the main outcome of the current work (hybrid biosorptive flotation-microfiltration system) comparison with the previous published cases of zinc removal using

1. zeolite for metal bonding and the hybrid sorptive flotation-microfiltration system for the solid/liquid separation (11,12), and
2. metal precipitation as hydroxide (with pH adjustment) and the hybrid precipitate flotation-microfiltration for the S/L separation (27).

The lower permeabilities were observed in biomass systems (both simple microfiltration and hybrid flotation-microfiltration system) may be due to the nature of the particles and the filtration mechanism. Generally yeast cells are larger than bacteria, vary considerably in size. A typical yeast cell is about 2.5 to 10 μm wide by 4.5 to 21 μm long (28). Yeast cells morphology is commonly spherical to oval shaped and varies, depending on the yeast species, nutrition levels, and cultural condition. As far as the filtration mechanism is concerned, the biomass filtration mechanism differs from that of zeolite and zinc hydroxide and according to Mahesh Kumar (29) followed three stages—initially pore blocking

Table 1. Comparison (in terms of permeability) between simple microfiltration and hybrid flotation-microfiltration process for three different zinc removal systems after 3h of operation ("MF 1" & "Hybrid 1" is the simple microfiltration and hybrid biosorptive flotation – microfiltration system using brewery yeast, "MF 2" and "Hybrid 2" is the simple microfiltration and hybrid sorptive flotation – microfiltration system using zeolite and "MF 3" and "Hybrid 3" is the simple microfiltration and hybrid precipitate flotation – microfiltration system); $[Zn(II)]_{initial} = 50\,mg\ L^{-1}$, pH = 6.5 for "Hybrid 1," pH = 10.5 for "Hybrid 2" and pH = 9.0 for "Hybrid 3," $[HDTMA\text{-}Br] = 10\,mg\ L^{-1}$, $[zeolite] = 5g\ L^{-1}$, $[yeast] = 2g\ L^{-1}$, $U_L = 0.0101$ for "Hybrid 1" and $0.0168\,cm\ s^{-1}$ for "Hybrid 2 & 3"

	$U_G = 0.265\,cm\ s^{-1}$	$U_G = 0.447\,cm\ s^{-1}$	$U_G = 0.647\,cm\ s^{-1}$
MF 1	187	216	324
MF 2	667		
MF 3	3.434	4.293	6.868
Hybrid 1	283	323	330
Hybrid 2	1.588	1.263	876
Hybrid 3	6.992	14.856	11.795

occurred (cake layer formation), which was followed by cake filtration and subsequently followed by cake filtration with compression of the cake layer. The smallest membrane pores were blocked by all particles arriving to the membrane. The inner surfaces of bigger pores were covered. Some particles arriving to the membrane covered other previously arrived particles, while others directly blocked some of the pores. Finally a cake started to build and consequently grew with time.

Several techniques have been implemented to prevent the particles from reaching the membrane surface, which include modifying the surface of the membrane so as to reduce the attractive forces or increase the repulsive ones between the solute and the membranes (23,26). Other techniques were used also for preventing fouling or treating fouled membranes (like feed pretreatment, ultrasonic or electric fields, low temperature plasma activation, and gas sparging); many of the recent developments have been focused on improving the mass transfer at the membrane surface. Depending on the membrane process the function of air can be differents—to un-stick and carry away a particle deposit by a gas backflush, to prevent or to limit the formation of a particle or concentration polarization, and even to transfer a compound from the gas to the liquid phase. A technico-economic study was also accomplished for the hybrid unit, showing lower capital and operating costs for it (24).

CONCLUSION

Considering the harmful effects of heavy metals (zinc was the example in the present), it is necessary to remove them from liquid wastes, at least to a limit accepted by national and international regulatory agencies before their discharge to the environment. The interactions between metal ions and microorganisms present potential applications for the remediation of metal-contaminated waters generated in various industries. Yeast biomass represents an important source of biosorbents because it is not an expensive material, it can be easily recovered at the end of fermentation processes, and it is produced as waste by-product in large quantities. Furthermore, the separation of metals from waste solutions would be beneficial, as the removed metal may be subsequently desorbed from biomass; the latter recovered for reuse, while the cleaned water recycled (30). Recently, biosorptive flotation has been studied applying flotation for downstream processing of metal-loaded biomass from the suspension. In today's world of economical and environmental constraints for the chemical and related industries, may be process intensification is a path for the future of chemical and process technology (31).

In conclusion, membrane filtration technologies are increasingly used for S/L separation purposes in water and wastewater treatment plants. One of the major problems encountered during their operation is fouling by solid particles, causing a gradual degradation in process efficiency. In this work, it has been demonstrated that it is possible to reduce substantially the fouling process by combining membrane microfiltration with flotation, with the membrane module submerged inside the flotation cell. In such a process, having upstream biosorption by a yeast biomass, flotation removed effectively a major part of the solid (biomass) particles responsible for membrane fouling. The addition of surfactants has been to improve substantially the system performance. This results in a longer membrane operation time with less frequent membrane cleaning.

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