



## Regular article

# A new Sponge-GAC-Sponge membrane module for submerged membrane bioreactor use in hospital wastewater treatment

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## ABSTRACT

A new Sponge-GAC-Sponge membrane module design for use in a membrane bioreactor (SGSMBR) is presented in this study. This work highlights an alternative MBR design in which a composite Sponge-Granular Activated Carbon-Sponge (SGS) layer is covered around the membrane module. The performance and membrane fouling of both the SGSMBR and a University of Cape Town with membrane (UCT-MBR) system are investigated for use in hospital wastewater treatment. It has been found that decreasing the hydraulic retention time (HRT) from 8 to 4 h resulted in higher COD, NH<sub>3</sub>, and P removal efficiency in the SGSMBR process when compared with the UCT-MBR process. Membrane fouling is controlled in the SGSMBR by decreasing the cake layer thickness on the membrane surface by about 96%. The flux recovery efficiency (FRE%) of the membranes was highly improved in the new SGSMBR design. The COD, NH<sub>3</sub>, and P removal efficiency was improved significantly from 73.6, 84.9, and 58% by using UCT-MBR to 85, 96, and 71%, respectively by using UCT-SGSMBR and SGSMBR. Finally, the SGSMBR showed biomass retention superior to that measured in the UCT-MBR. This work reveals, for the first time, that a composite layer covering the membrane module is a viable alternative to anoxic and anaerobic conditions in MBR systems.

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## 1. Introduction

In recent decades, membrane bioreactor (MBR) systems have emerged as a suitable alternative to traditional biological reclamation processes for carbon source as well as nutrient removal [1]. MBRs have several advantages, including high removal efficiency [1], low space requirements, perfect total solids removal, low sludge generation, and perfect retention of biomass inside the system [2,3].

**Abbreviations:** SGSMBR, sponge – granular activated carbon – sponge – membrane bioreactor; SGS, sponge – granular activated carbon – sponge; UCT-MBR, University of Cape Town with membrane; HRT, hydraulic retention time; SRT, solids retention time; COD, chemical oxygen demand; FRE, flux recovery efficiency; GAC, granular activated carbon; MBR, membrane bioreactor; GBF, green bioflocculant; WWTP, wastewater treatment plant; CIP, chemical cleaning-in-place; PAC, powder activated carbon; EPSs, extracellular polymeric substances; SMBR, sponge membrane bioreactor; PVC, polyvinyl chloride; DMAc, dimethylacetamide; PWP, pure water permeability; AS, activated sludge; MLSS, mixed liquor suspended solid; BAG, biomass attached growth; ZnO, zinc oxide; DO, dissolved oxygen.

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However, fouling, and bio-fouling in particular, acutely affects MBR processes. Generally, bio-fouling occurs via the accumulation of biomass at a membrane surface due to inorganic precipitation and adhesion of bacterial cells to the surface of the membrane [4,5]. One of the most serious operational problems encountered in MBR systems, bio-fouling causes rapid declines in the permeate flux, reduced membrane productivity, excess membrane substitution, and increased operational costs.

Various methods have been used in MBRs to decrease fouling of the membrane. Ngo and Guo [6] reported that the distributed injection of air through submerged MBR (SMBR) processes, along with the addition of low-dosage green bioflocculant (GBF), reduced layer fouling to nearly zero after 70 d of operation; this method also reduced backwash recurrence. Wei et al., [7] was explored a chemical cleaning-in-place (CIP) method for treatment of domestic wastewater in a long-term, pilot-scale operation using MBRs. The use of a biomass support medium such as powder activated carbon (PAC), plastic media, and sponges in MBRs is a powerful and promising strategy for membrane fouling control [8,9]. Combinations of a MBR and PAC, in which PAC is used as a pre-treatment before membrane technology, have proven promising in wastewater pre-treatment.

## Nomenclature

### Symbols

V	Volume (m <sup>3</sup> )
t	Time (h)
A	Area (m <sup>2</sup> )
P	Transmembrane pressure (bar)
R	Removal efficiency (%)
C <sub>p</sub>	Pollutant concentrations of the influent (mg/L)
C <sub>f</sub>	Pollutant concentrations of the effluent (mg/L)
J	Flux ((l/m <sup>2</sup> h)
M	Mass of the permeated water (l)
A	Effective membrane area (m <sup>2</sup> )

Actually, higher concentrations of PAC in the MBR resulted in better adsorption, deterioration, and biodegradation and reduced Mixed Liquor Suspended Solid (MLSS) fouling components such as Extracellular Polymeric Substances (EPSs) and fine colloids [10]. Sponges are considered to be ideal attached-growth material as they can be used as a transportation medium for active biomass, decrease cake layer accumulation on the membrane surface and retain biomass by encouraging a hybrid growth system (that combines suspended and attached growth) [10,11]. Sponges have performed well in biological treatments because of several advantages, for example; high interior porosity and specific surface area, high stability to hydrolyses, light weight and economy [10,12].

The impact on nitrogen removal of using a sponge cube as a biomass supported medium was studied by Deguchi and Kashiwaya [13]. They found that the rates of nitrification and denitrification in the sponge system were higher than those measured in a suspended growth reactor by 1.5 and 1.6 times, respectively. Guo et al., [14] studied the impacts on fouling and permeate flux of the membrane of suspending a cubic sponge in the tank of the SMBR. They reported that the suspended-sponge membrane process, in which the sponge filled 10% of the tank volume, decreased membrane fouling and enhanced the sustainable flux by 100% over that of the SMBR alone. Nguyen et al., [3] demonstrated that the suspended sponge membrane bioreactor (SSMBR) succeeded in decreasing membrane fouling and had high organic carbon and nutrient removal efficiencies.

Moreover, the influence of sponge size and type on the performance of a conventional biological system was reported by Nguyen et al., [15]. They used sponges of types S28-30/45R, S28-30/60R, S28-30/80R and S28-30/90R with dimensions of 1 cm<sup>3</sup>, 2 cm<sup>3</sup> and 3 cm<sup>3</sup>. The results indicated similar removal efficiencies for nutrients and organic substances among the various types of sponge.

The studies mentioned above explored the effects of introducing cubic sponges and granular activated carbon (GAC) to the MBR tank, finding that these additions improved treatment performance and decreased membrane fouling. Indeed, the direct addition of the cubic sponge to the bioreactor causes mixing with the activated sludge, making it impossible to separate the sponges and the sludge at the end of the process. Also while the addition of GAC causes a significant reduction in membrane fouling, it is not possible to reuse the GAC again. We therefore focus on, and solve, these problems in this study.

This study presents a new Sponge-GAC-Sponge membrane module in a membrane bioreactor (SGSMBR) design. This work highlights an alternative MBR design in which a composite layer, composed of three sub-layers made of Sponge-Granular Activated Carbon-Sponge (SGS), is covered around the membrane module instead of distributing the cubic sponges and granular activated carbon throughout the MBR tank. In this design, the composite

layer around the membrane module functions as an alternative to the aerobic, anoxic and anaerobic conditions in typical MBR systems; specifically, the first sponge sub-layer (at the outer surface of the composite layer) works as an alternative to aerobic conditioning, the second sub-layer (i.e., the internal porous surfaces of the sponge and granular activated carbon) works as an alternative to anoxic conditioning, and the third sponge sub-layer works as an alternative to anaerobic conditioning, as the previous two sub-layers prevent dissolved oxygen transport to this final sub-layer. Other benefits of this MBR design include low cost due to the possibility of reactivating sub-layers through periodic cleaning as well as reduced membrane fouling, enhanced permeation flux and improved phosphorus and nitrogen removal. Moreover, this new method facilitates long-term maintenance in SGSMBR processes.

The objectives of this study are investigating the effects of a new sponge-granular activated carbon composite layer covered the membrane on the performance of a SGSMBR for actual hospital wastewater treatment, examining the effects of the SGS composite layer on biomass growth on sponge surfaces and interior sub-layers as well as on the cake layer thickness on the membrane surface are evaluated, proving that the SGS composite layer covered the membrane module works as an alternative to the anoxic and anaerobic conditions in typical MBR systems; and studying effects of hydraulic retention time (HRT) on the COD, NH<sub>3</sub>, and P removal efficiency in the SGSMBR process when compared with the UCT-MBR process. In addition, a comparison was conducted in an effort to evaluate the performance of UCT-MBR, UCT-SGSMBR and SGSMBR systems.

## 2. Material and methods

### 2.1. Materials

PVC resins of 65 kg/mol were used as membrane materials and were obtained from the Georgia Gulf Company (Georgia, USA). N, N-dimethylacetamide (DMAc) solvents were supplied by Sigma-Aldrich. ZnO nanoparticles (99%; 10–30 nm in diameter; Product No. 8411DL) were purchased from SSNano, USA.

### 2.2. Membrane preparation

The PVC polymer material was dried at 60 °C in an oven for 4 h to remove moisture. The casting solution was prepared through the addition of dried 10 wt.% PVC to 90 wt.% N,N-dimethylacetamide (DMAc) solvent. The PVC was mixed with the DMAc using a magnetic stirrer for 2 d at 200 rpm and 40 °C until homogeneity was achieved, after which the inorganic ZnO nanoparticles were added. Then, the final casting solution with ZnO nanoparticles was placed in an Ultrasonic water bath for 15 min to prevent ZnO nanoparticle aggregation in the final casting solution.

The polymer solutions were cast with 200 μm thicknesses utilizing a motorized film applicator (CX4 mtvmesstechnik, Germany) under atmospheric conditions. The prepared membranes were submerged in a non-solvent coagulation bath (i.e., deionized water) at room temperature for deposition. The nascent membrane was kept in tap water for 48 h to remove the remaining DMAc. Finally, the membrane was moved and kept in a 30 wt% glycerol solution for 48 h to protect the membrane structure from collapse and cracking. Three identical membrane sheets were selected for membrane characterization and used in ultrafiltration UF tests to procure mean flux and pollutant removal values.

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