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Development of a Submerged Membrane Bioreactor simulator: a useful tool for teaching its functioning

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ABSTRACT

Among the technologies used to treat wastewater, the Submerged Membrane Bioreactor (SMBR) has excellent prospects because of the possibility it provides for water reuse. In this work, an SMBR computer simulator is developed. A mathematical model was implemented, which integrated the biological degradation process using activated sludges with the physical separation process using membranes. The simulator functioning was validated with experimental results and its use in teaching was evaluated through the development of a simulated laboratory running for three and a half hours. This gave access to trends and orders of magnitude that would take more than fifteen months to obtain with real experiments. It was successfully used and accepted by the students.

Keywords: Improving classroom teaching; Interactive learning environments; Simulations; Submerged Membrane Bioreactor

1. Introduction

Fresh water is becoming known as the “blue gold” of the 21st century. It is a natural resource already in short supply and it will become even scarcer with increased urbanization and population, climate change, and industrial pollution, making it humanity’s most precious resource and one of the major environmental issues of this century (Buzatu and Lavric, 2011). For this reason, many governments today are devoting considerable resources and efforts to the development of new technologies for wastewater treatment and the decontamination of contaminated sources. An example of these technologies is the Submerged Membrane Bioreactor (SMBR).

The SMBR can be defined as a system that combines biological degradation of wastewater effluents with membrane filtration (Cicek et al., 1999). For many years, these systems have shown their effectiveness in the treatment of municipal and industrial wastewater (Jimenez et al., 2010; Santos et al., 2011). In the last two decades, SMBR technology has grown exponentially due to its advantages over conventional wastewater treatment processes, such as reduced environmental impact, improved effluent quality and better process control (Buer and Cumin, 2010; Drews, 2010). The major potential advantage of this technology is found in the field of water reuse. This is because the SMBR can use ultrafiltration membranes and thus retain bacteria, some viruses and many organic and inorganic components that are often found in the effluent from conventional biological treatments (Lobos et al., 2007; De Luca et al., 2013).

Therefore, the effluent of an SMBR may be suitable for direct reuse or water supply for a reverse osmosis process. That is one of the reasons why research in the SMBR field is increasing continuously at present, due the commercial and scientific interest that it has aroused (Stephenson et al., 2000; Van Nieuwenhuijzen et al., 2008). Nevertheless, the effective application of membrane bioreactors (MBRs) is limited by

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Nomenclature

A	membrane area (m^2)
C	sludge concentration (kg/m^3)
C_d	coefficient of drag and lifting forces
d_p	particle size (m)
F_l	lifting force
F_a	suction force
G	apparent shear intensity of the fluid turbulence (s^{-1})
g	gravitational constant (m/s^2)
G_i	apparent shear intensity of the fluid turbulence on the ith section of the membrane surface (s^{-1})
J	overall flux (m^3/m^2 s)
J_i	local filtration flux through the ith membrane section ($m^3/(m^2$ day))
M_{td}	mass of sludge in the dynamic sludge film cake adhering to the membrane surface (kg/m^2)
$M_{tf(i)}$	mass of sludge in the stable sludge cake attached to the ith membrane section (kg/m^2)
$M_{td(i)}$	mass of sludge in the dynamic sludge film cake in the ith membrane section (kg/m^2)
n	total number of sections in the membrane surface area
q_a	aeration intensity ($L\,m^{-2}\,s^{-1}$)
Q_{BG}	coarse bubble flow (L/s)
R_m	intrinsic resistance of the membrane (m^{-1})
R_p	pore fouling resistance (m^{-1})
r_p	specific pore fouling resistance in terms of filtrate volume (m^{-2})
R_T	overall filtration resistance (m^{-1})
r_{td}	specific filtration resistance of dynamic sludge film (m/kg)
R_{td}	resistance of dynamic sludge film (m^{-1})
R_{tf}	resistance of stable sludge cake layer (m^{-1})
r_{tf}	specific filtration resistance of sludge cake layer (m/kg)
$R_{TS(i)}$	filtration resistance for the ith membrane section (m^{-1})
S_i	a section of the membrane surface area
S_I	concentration of soluble undegradable organics ($gCOD/m^3$)
SMBR	Submerged Membrane Bioreactor
SMP	soluble microbial products
S_{O_2}	concentration of dissolved oxygen (g/m^3)
SRT	sludge retention time (days)
S_S	concentration of easily biodegradable substrates ($gCOD/m^3$)
S_{SMP}	concentration of soluble microbial products ($gCOD/m^3$)
t	time (s)
t_{aBG}	time of coarse bubble aeration (min)
t_f	filtration time (min)
TMP	trans-membrane pressure (Pa)
t_{paBG}	time without coarse bubble aeration (min)
t_{pf}	relaxation time (min)
t_{STOP}	time to simulate (days)
V	bioreactor volume (m^3)
V_f	water production within a filtration period of an operation cycle (m^3/m^2)
X_H	concentration of ordinary heterotrophic organisms ($gCOD/m^3$)
X_I	concentration of particulate undegradable organics ($gCOD/m^3$)
X_S	concentration of slowly biodegradable substrates ($gCOD/m^3$)
X_{TSS}	concentration of total suspended solids ($gTSS/m^3$)
α	stickiness of the biomass particles
β	erosion rate coefficient of the dynamic sludge film
Δt	time step (s)
γ	compression coefficient for the dynamic sludge film ($kg\,m^{-3}\,s^{-1}$)
ε_a	fraction of the membrane surface area (or distance ratio to the bottom of the membrane module) where the shear intensity is increasing
ε	fraction of the membrane surface area (or distance ratio to the bottom of the membrane module)
θ_f	filtration time in an operation cycle (min)
ρ_s	density of sludge suspension (kg/m^3)
ψ	reduction index of cake compression coefficient
μ_s	viscosity of sludge suspension (Pa s)

membrane fouling and the associated cost and energy burdens (Menniti and Morgenroth, 2010). At the same time, experimentation in these types of installations is very expensive and time consuming.

On the other hand, it is necessary to take all the elements mentioned above into account in the training of engineers and of the staff that will operate the SMBR. It is essential to develop tools that can help in the learning process, both at universities and at operator training centres. The development of simulators is a necessity since they constitute a platform to enhance virtual laboratories (Corter et al., 2011). Virtual laboratories can provide a dynamic Problem-Based Learning experience where students engage in an authentic, industrially situated task. They simulate what expert engineers do in practice, and are very different in character from the physical laboratory at university (Koretsky et al., 2011). Another advantage of a simulator is its value in the training process from the research point of view: to help to solve problems that are as yet unsolved. Simulators are also an important support for the study of process optimization.

The use of simulated experiments can considerably reduce the cost of a laboratory course, increase the number of experiments in the learning process and enable experiments to be carried out that would otherwise involve working with dangerous materials and/or in dangerous conditions (Skorzinski et al., 2009). For all these reasons, the mathematical modelling of an SMBR and the development of a simulator of this process provides an alternative that can solve many problems. The objective of this work is to develop a computer simulator of an SMBR and to show its potential in teaching how such processes work.

2. Materials and methods

A computer simulator consists of three main parts: the mathematical model, the numerical solution method and the graphical interface. The integrated model proposed by