Desalination 288 (2012) 135–144

Contents lists available at SciVerse ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Evaluation of cake filtration biological reactors (CFBR) vs. membrane biological reactors (MBR) in a pilot scale plant

B. Ozdemir [a,*], A. Saatci [b], O. Yenigun [a]

[a] Institute of Environmental Sciences, Bogazici University, Bebek, Istanbul, Turkey
[b] Environmental Engineering, Marmara University, Goztepe, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 9 August 2011
Received in revised form 22 December 2011
Accepted 24 December 2011
Available online 24 January 2012

Keywords:
Cake filtration
Membrane bioreactor
Membrane filtration
Cloth filter
Filtration models

ABSTRACT

In this study, cake filtration biological reactors (CFBR) and membrane biological reactors (MBR) were operated in the same environment. The initial flux of CFBR was 1,517.5 L/h/m^2 and the start-up cake resistance was around 6 kPa. The flux dropped sharply during the first run, and at the end of first run flux was 110 L/h/m^2. During the second run, the flux declined further from 60 L/h/m^2 to 48 L/h/m^2 and during the last 4,000 hours period flux was considered to be stable. However, the pressure difference (Δp) increased steadily for about 2,300 hours until it reached a stable Δp value at the termination of the run. On the other hand, the design operation flux of the membranes was 17.5 L/h/m^2. The system was operated around design flux values; however, more stable operation was achieved when the flux was around 9 L/h/m^2. Both the cloth filter and the membrane produced effluents with suspended solid concentrations of less than 10 mg/L, but the effluent quality of the cloth filter was inferior to the membrane with respect to coliform removal. Activated sludge cake, which formed on cloth media during filtration, was evaluated according to conventional cake filtration theory using the plots of V vs. t and t/V vs. V. The plot of V vs. time t for filtration of different MLSS concentrations in laboratory cell was best fitted to second order polynomial regression ($R^2 > 0.98$); a linear relationship between t/V against V was not observed. Separately, an evaluation of V vs. t showed that CFBR was best fitted to second order polynomial regression ($R^2 = 0.995$ for first run and $R^2 = 0.989$ for second run); however, a linear relationship between the reciprocal of filtration rate (t/V) and the cumulative volume was observed individually. A transition between two linear plots was considered to be a change in the filtration characteristics. Standard blocking model plots of CFBR were fitted better ($R^2 > 0.95$) than complete blocking and intermediate blocking models with the measured data for the initial period of filtration; the latter period of filtration was best fitted to the cake filtration model ($R^2 > 0.99$).

1. Introduction

Membrane bioreactor (MBR) technology is advancing rapidly around the world for both research and commercial applications. A membrane system can be defined as two essentially uniform and homogeneous fluid phases between which matter and energy can be exchanged at rates governed by the properties of a third phase or group of phases that separates them [1]. The third phase is called the membrane and is simply a perm-selective material that resists transport [1,2]. MBRs offer several advantages, including high biodegradation efficiency, excellent effluent quality, low sludge production and compactness [3]. As a result, MBR is an attractive option for the treatment and reuse of industrial and municipal wastewaters.

When the treated wastewater and biomass are separated by filtration, very large quantities of mixed liquor contact with the filter material. Ideally the filter material allows the passage of the fluid through its pores while retaining all suspended solid particles originally present in the fluid. Microorganism cells tend to adhere to surfaces; this is considered to be a survival strategy. Regardless of the surface material and hydrophobicity or hydrophilicity in a membrane system, adhesion to a membrane surface is facilitated by the water flow through the membrane. So, some organisms will settle on the surface of the membrane material, and they will multiply and form a sludge cake that is considered to be membrane biofouling during operation [4]. Biofouling is an operational term applied when the effects of biofilms exceed a certain threshold or tolerance level, and filtration always leads to increase in flow resistance, which consequently decreases flux.

Cake layer formation is the key factor limiting the flux when operating a membrane bioreactor. The formed cake layer on the media can act as a secondary membrane that determines filtration properties of the

* Corresponding author. Tel.: +90 212 227 7133; fax: +90 212 227 7153.
E-mail address: burcudozdemir@gmail.com (B. Ozdemir).

0011-9164/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.desal.2011.12.024

system, so the membrane material itself may no longer be necessary. Thus, the membrane material may be replaced by a low cost material, which does not provide excessive media resistance; coarse filters act as a support over which a cake layer can be formed. Such systems, which solids rejection will be provided by a cake layer defined in literature as self-forming dynamic membrane [5]. Moghaddam et al.2006 [6] operated a non-woven coarse pore filtration activated sludge process under high mixed liquor suspended solids (MLSS) concentration in aerobic and anoxic/aerobic conditions. Jeison et al.2008 [7] studied with two types of materials to act as a support for dynamic membrane formation in an anaerobic system; a non-woven material which is used as a spacer material to cast membranes and polyester mesh fabrics of different pore sizes in the range 1–150 µm. Kiso et al.2000 [8] operated an aerobic bioreactor equipped with a 100 µm mesh, at fluxes over 20 L/m^{2}h. However, many other researchers have recently researched on self-forming dynamic membrane formation over coarse filters and showed that such membranes can be operated successfully under aerobic and anaerobic conditions [9–16].

The membrane filtration theory and conventional cake filtration theory is based on the local properties in the filter cake, and assumes a one-dimensional Darcian flow in the filter cake. Cake filtration is considered to be an important method for solid and liquid separation and is widely used in the chemical and process industry. Indeed, investigations of cake filtration have received considerable attention in the past. According to conventional cake filtration theory, the total resistance in filtration comprises a series of the resistances of a medium and those of a cake. The development of conventional theory consists of two steps: 1. Combining the mass balance equation and the momentum balance equation (Darcy's law) for the liquid phase in the cake to form the governing equation with both porosity and liquid pressure as the dependent variables and 2. Assuming that only point contacts exist between particles [17,18]:

$$q_l = \frac{dV}{dt} = \frac{p_0}{\mu\left\{[\alpha_{av}]_{\Delta p_c}\frac{V\rho s}{1-\overline{m}s} + R_m\right\}} \quad (1)$$

The above expression states that instantaneous filtration rate (q_l) is directly proportional to the applied pressure p_o and inversely proportional to the flow resistance [19]. For constant applied pressure filtration, Eq. (1) may be written as:

$$\mu s\rho(1-\overline{m}s)^{-1}[\alpha_{av}]_{\Delta p_c} V\frac{dV}{dt} + \mu R_m\frac{dV}{dt} = p_0 \quad (2)$$

Integrating with initial condition V = 0, t = 0 and R_m assumed to be constant:

$$\overline{\mu s\rho(1-\overline{m}s)^{-1}[\alpha_{av}]_{p_{s_m}}}\frac{V^2}{2} + \mu R_m V = p_0 t \quad (3)$$

q_l	Superficial liquid velocity (m/s)
q_{l_m}	Value of q_l for cake/medium interface (m/s)
V	Cumulative filtrate volume per unit medium surface area (m)
t	Time (s)
p_o	Operating pressure (Pa)
μ	Fluid viscosity (Pa.s)
α_{av}	Average specific cake resistance (m/kg)
Δp_c	Pressure drop across cake (Pa)
ρ	Filtrate density (kg/m^3)
s	Particle mass fraction of suspension (-)
$\overline{m}$	Wet to dry cake mass ratio (-)
R_m	Medium resistance (m^{-2})
β	Fraction of cake removal or fraction of particle flux being deposited (-)

For cross-flow filtration, by modifying the conventional filtration theory to account for the presence of particle depolarisation in cake formation, instantaneous filtration velocity is [19]:

$$q_{l_m} = q_l = \frac{p_0}{\mu s\rho(\alpha_{av})_{p_{s_m}}\int_0^t \frac{\beta q_{l_m}dt}{1-s[(\overline{m}-1)\beta+1]} + \mu R_m} \quad (4)$$

For $\beta = 1$, the above expression reduces to Eq. (1). In an ideal case, the surface shear resulting from the cross-flow prevents the accumulation of particles on the membrane surface. However, there is always cake formation on the membrane surface, and as this cake grows its hydraulic resistance increases, and the filtration flux at a constant applied pressure declines. Consequently, accumulation of particles on the membrane surface for unit volume of filtrate decreases. This causes the decline of filtration flux to slow and, in some cases, causes a steady or pseudo-steady flux [20].

From the conventional constant pressure filtration equation, a plot of t/V vs. V is expected to yield a linear relationship for the entire filtration data. The linearity of t/V vs. V plot is observed only when the value of V (or time) or the cake thickness is sufficiently large. The initial part of the data contributes to the non-parabolic behavior of the entire range of filtration data [21]. Flux decline in cross-flow filtration is considered to be due to two distinct independent mechanisms: pore plugging and cake deposition. The initial rapid flux decline is mainly due to pore plugging by particle adsorption on the membrane wall or pore constriction, and the latter slow flux decline is due to cake deposition on the membrane surface [22]. In usual cases, when filtering suspensions containing more than a few percent of solids, blocking of particles inside or on the top of the membrane occurs, leading to a reduction in filtration flux [23].

There are four filtration models that are generally used to describe the fouling mechanisms during a filtration run [24,25]:

- Complete blocking is a mechanism of plugging of pore entrances and the prevention of any flow through pores as a result of the reduced open flow area.
- Standard blocking is a mechanism by which particles accumulate inside the membrane on the pore walls. Since the pores are constricted, the membrane permeability is reduced.
- Intermediate blocking is a mechanism of plugging of pore entrances by a fraction of particles and a deposition of the rest on top of them.
- Cake filtration is a mechanism by which particles accumulate at the surface in a permeable cake of increasing thickness that adds a hydraulic resistance to filtration.

These expressions were derived by the assumption of separate mechanisms (Table 1) and for a constant pressure filtration they

Table 1
Filtration models and fouling mechanisms.

Filtration model	n	Derived form [27]	Fouling mechanism
Complete blocking	2	$Q = Q_0 - k_b \cdot V_f$	Pore blocking
Standard blocking	1.5	$t/V_f = k_s/2 \cdot t + 1/Q_0$	Pore constriction
Intermediate blocking	1	$1/Q = k_i \cdot t + 1/Q_0$	Pore blocking and surface deposit formation
Cake filtration	0	$t/V_f = k_c/2 \cdot V_f + 1/Q_0$	Surface deposit formation